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FROM LABORATORY TO FIELD: QUESTIONING ISOTACH VALIDITY IN PEAT COMPRESSION

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ABSTRACT

Multiple long-term constant rate of strain (CRS) tests were performed on Zegveld peat from the Netherlands. The aim of performing these tests is to check the validity of the classical isotach framework in describing the compression behaviour of peat. Based on parallel equidistant isotachs, the classical isotach framework forms the basis of common settlement prediction models.

The strain rates of different projects built in peat areas are analysed to compare field strain rates with the strain rates applied during conventional CRS laboratory testing. This showed that field strain rates are substantially lower than those applied in conventional CRS testing.

Different isotachs are visualized by changing the applied displacement rate during CRS testing. The trajectories of these isotachs are determined to conclude on both the level of parallelism as well as the mutual distance between different isotachs. From the performed tests it is concluded that the classical isotach framework is inadequate in capturing the compression behaviour of the tested Zegveld peat at low strain rates. This is important since it is concluded that low strain rates best approach field conditions.

Keywords: isotach, strain rate, CRS, peat.

INTRODUCTION

Building infrastructure on soft soils such as peat presents unique geotechnical challenges due to their high compressibility and high heterogeneity. Rijkswaterstaat, part of the Dutch Ministry of Infrastructure and Water management, is responsible for the design, construction and management of main infrastructure in the Netherlands. Rijkswaterstaat faces challenges in managing and maintaining an even road surface in infrastructure such as highways built on peatlands. Accurate settlement predictions are a crucial aspect in guaranteeing a smooth road surface.

OBJECTIVE

The classical isotach framework forms the backbone of commonly used settlement prediction models aimed to describe the compression behaviour of soft soils such as peat. Validation of the classical isotach framework in describing the compression behaviour of peat is therefore pivotal in order to make accurate settlement predictions.

Long-term CRS laboratory tests aimed to evaluate the compression behaviour of peat are therefore performed on Zegveld peat. The constitutive behaviour of the tested material after a change in strain rate is of primary interest to validate the concepts of the classical isotach framework.

In addition, quantifying the difference in estimated peat strain rates of field projects and strain rates used in CRS laboratory testing on peat is of great interest. This proves to be important since it has been shown how determination of settlement parameters such as the pre-consolidation pressure are strain rate dependent (Leroueil, 1985).

The performed study concludes on the practical consequences of the observed constitutive behaviour in step-changed CRS testing and the identified difference between strain rates used in laboratory testing and those estimated in field conditions. This is ultimately used to conclude on the validity of the classical isotach framework.

The results described in this paper are part of a larger study aimed to evaluate the validity of the classical isotach framework in describing the compression behaviour of other soft soils such as clay.

THE CLASSICAL ISOTACH FRAMEWORK

Leroueil et al. (1983, 1985) performed eighteen CRS tests on Batiscan clay and visualized the compression curves in a void ratio versus effective stress plot. From these results it was concluded that the compression curves are dependent on the selected rate of displacement. Consequently, the constitutive behaviour of the tests could be described by a unique combination of effective stress (σ'), strain (ε) and strain rate ($\dot{\varepsilon}$).

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Šuklje (1957) performed oedometer tests on Lacustrine chalk samples and drew the relationship between void ratio and effective stress. In here, Šuklje identified lines of equal strain rate and conveniently named them 'isotachs'. In Greek 'iso' translates to 'equal' and 'tachy' to 'velocity'. Postulated by Šuklje (1957) and later advanced by Bjerrum, Leroueil and Den Haan, the isotach framework forms the backbone of widely used settlement models aimed to describe the compression behaviour of soft soils. Examples of these models are the NEN-Bjerrum isotach model or the abc-isotach model. The classical isotach framework, as implemented in engineering practice in The Netherlands, is built on three fundamental concepts;

1. A unique relationship exists between strain (ε), effective stress (σ'), and strain rate (ε') called isotachs.
2. Lines of equal strain rate are parallel when plotted on strain vs. the logarithm of effective stress.
3. The mutual distance between different isotachs remains constant when plotted on strain vs. the logarithm of effective stress.

The classical isotach framework renders parallel equidistant isotachs. As a result, the total accumulated (creep) strain is stress-independent as shown in Figure 1.

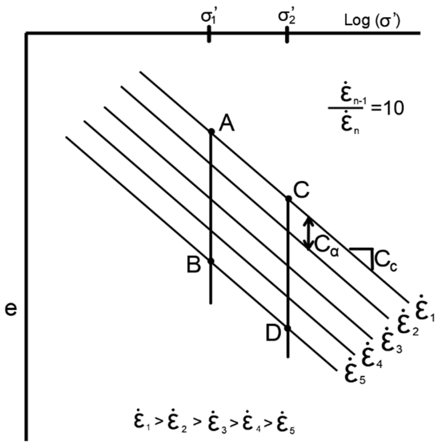

Figure 1 *The classical isotach framework*

Stress path A-B and C-D both result in the same amount of (creep)strain. The virgin compression index (C_c) and the secular compression index (C_α) are assumed to be strain rate-independent, as shown in Figure 1. The constant rate of strain (CRS) test, as introduced by Crawford (1959), provides a controlled method for examining soil deformation under axial strain, making it a valuable method for studying the constitutive compression behaviour of soft soils such as peat. This method aligns with the work of Šuklje (1957) and Leroueil et al. (1983, 1985), who demonstrated that compression curves are strain rate dependent, thereby reinforcing the relationship between effective stress, strain, and strain rate observed in both CRS and creep oedometer tests. As shown in Figure 2, changing the displacement rate during a CRS tests allows for the visualisation of (parts of) different isotachs.

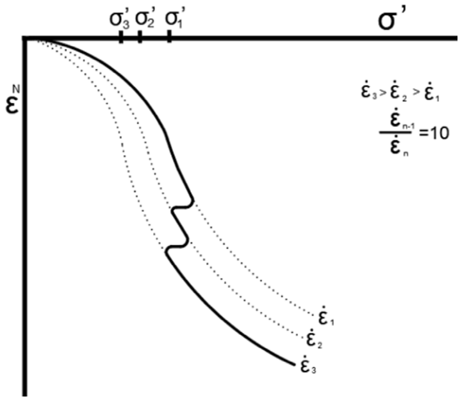

Figure 2 *A change in rate of displacement in a CRS test initiates movement to a different isotach*

LABORATORY CRS TESTS

To evaluate the constitutive behaviour of peat around changes in strain rate, a series of five identical CRS tests has been conducted at the Deltares Geotechnical Laboratory in Delft, The Netherlands. The lower bound of strain rate of the Deltares CRS apparatus is fixed at = 10-8 s-1. Table 1 depicts the strain rate selection of the executed strain rate controlled CRS tests. The characteristics of the used material show a high degree of uniformity despite the visually observed heterogeneity of the peat. The calculated initial void ratios ranged from 8.1 - 8.3. Each sample had an initial height of 30.0 mm.

Table 1 Strain rate configuration of peformed CRS tests.

Step	Strain rate [s^{-1}]	Displacement [mm]	Time [days]
1	10^{-6}	4.0	1.54
2	$5 \cdot 10^{-7}$	2.0	1.54
3	10^{-7}	1.5	5.79
4	10^{-8}	1.0	38.58
5	10^{-7}	1.5	5.79
6	$5 \cdot 10^{-7}$	2.0	1.54
7	10^{-6}	2.0	0.77
Total		14	55.56

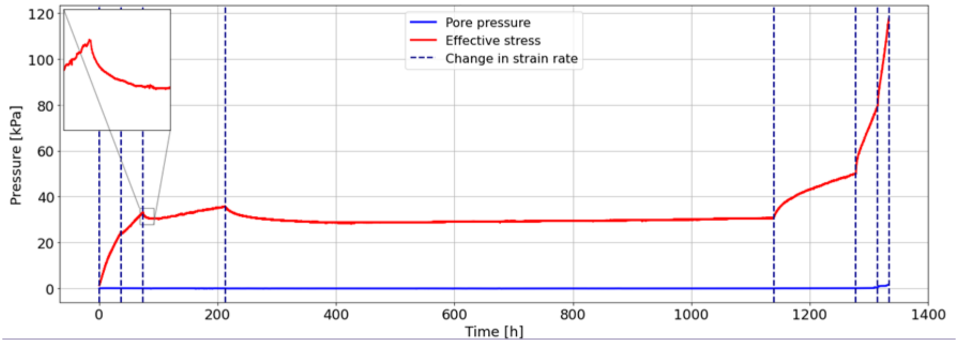

Figure 3 *Stress development of strain rate controlled CRS test as shown in Table 1*

The stress development of one of the CRS tests is shown in Figure 3. The selected strain rates of Table 1 are relatively low. Consequently, there is sufficient time for excess generated pore pressure to dissipate throughout the test. Changes in applied rate of displacement as shown in Table 1 are indicated by the dashed purple lines in Figure 3. Figure 3 clearly shows transient behaviour around a change in strain rate. Only when the soil's state has fully moved to the isotach corresponding to the new strain rate does the effective stress start to increase again.

Figure 4 shows the effective stress against natural strain of one of the same CRS test. Changes in applied rate of displacement result in movement to a different isotach and thus visualisation of a unique compression curve. Parts of different isotachs can clearly be identified. Subsequently, the constitutive behaviour of the tested peat samples is strain rate dependent. The first concept of the classical isotach framework is thus met.

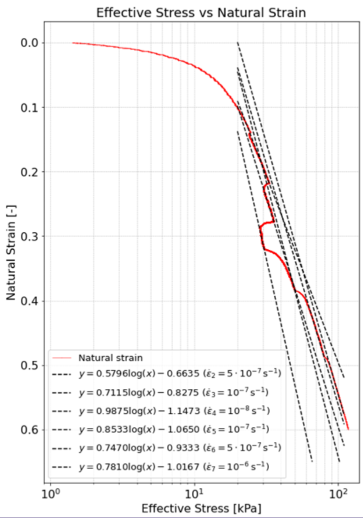

Figure 4 *Tangent lines through parts of the different visualised isotachs show increased divergence with a decrease in strain rate*

Only in the strain rate regime of $\dot{\varepsilon} = 10^{-7}$ - 10^{-6} s^{-1} do the trajectories of parts of different isotachs show a high degree of parallelism. The degree of parallelism is shown to decrease with a decrease in strain rate. For the tested Zegveld peat the second fundamental concept of the classical isotach framework of parallel isotachs is therefore not met below a strain rate of $\dot{\varepsilon} = 10^{-7}$ s^{-1}. This observation is made in all five long-term CRS tests.

In practice this divergent behaviour would result in stress-dependency of the secular compression index (C_α). As a result, the net amount of creep strain accumulated over a certain period of time would be dependent on the current stress level. This is against the current understanding of creep development and not implemented in common settlement prediction software such as the NEN-Bjerrum isotach model or the abc-isotach model.

The mutual distance between different isotachs is shown to increase with decreasing strain rate. The third concept of the classical isotach is therefore not met below a strain rate of < 10-7 s-1. This observation is made in all five long-term tests. In practice this increased spacing results in a non-linear creep rate with the logarithm of time. This can possibly be explained by tertiary compression which is known to occur in peat (Den Haan and Edil, 1994).

FIELD STRAIN RATES

To investigate the practical consequences of the observed diverging isotachs with a decrease in strain rate, it is important to evaluate the order of magnitude of strain rates in field conditions. Data from three different locations in the Netherlands is evaluated.

Zegveld: Subsidence plates in the Zegveld polder were monitored for over 50 consecutive years. Since the subsidence plates are placed below the groundwater table, the majority of the observed deformation rate is attributed to creep (Massop et al., 2024). The resulting estimated strain rates

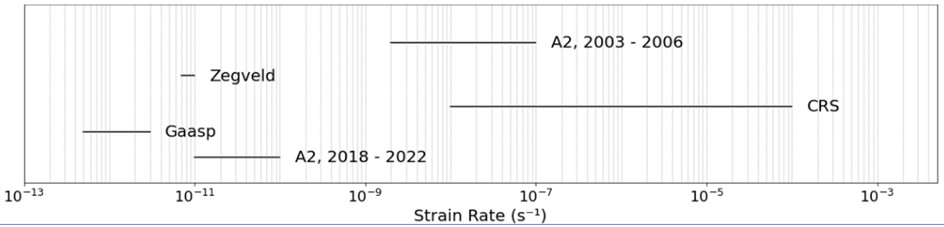

Figure 5 *Comparison of strain rates in peat projects and conventional CRS laboratory testing*

are in the range of $\dot{\varepsilon}$ = 7 · 10^{-12} - 10^{-11} s^{-1}. A corner reflector placed in the Gaasp peat meadow yields an even lower strain rate as shown in Figure 5.

A2 Vinkeveen: The A2 highway between Amsterdam and Utrecht is located in a predominantly peat area. A new embankment was created near Vinkeveen in the period 2003-2006. The resulting settlement and vertical deformation rates were monitored during construction using subsidence plates placed in the embankment. The resulting estimated strain rates during construction were in the range of $\dot{\varepsilon}$ = 2 · 10^{-9} - 10^{-7} s^{-1}. The estimated strain rate of the same embankment, approximately 20 years after construction is finished, is evaluated using Interferometric Synthetic Aperture Radar (InSAR). The subsequent strain rates estimated from this deformation time series is in the range of $\dot{\varepsilon}$ = 10^{-11} - 10^{-10} s^{-1} for the period 2018 - 2022.

Combined: The estimated strain rates of projects situated in peat areas are orders of magnitude lower than those in conventional CRS laboratory testing, Figure 5. From this it is concluded that the strain rates of field projects in peat areas and conventional CRS laboratory testing only have a similar order of magnitude during the first months of construction. As time progresses, and the strain rate naturally reduces, the difference in strain rate between laboratory testing and field conditions in peat can differ by a factor of 10^4 - 10^6.

CONCLUSIONS

The classical isotach framework assumes parallel equidistant isotachs resulting in a linear creep rate on logarithmic timescale. From the performed strain rate controlled CRS tests it is concluded that the trajectories of different isotachs start to diverge at a strain rate of $\dot{\varepsilon} < 10^{-7}$ s^{-1}.

The validity of the classical isotach framework in describing the compression behaviour of peat is therefore questionable regarding field conditions for which it is demonstrated that strain rates aregenerally lower than $\dot{\varepsilon} < 10^{-7}$ s^{-1}.

The increased mutual distance between different isotachs results in a non-linear creep rate with the logarithm of time. Tertiary creep can help explain this observation. Existing settlement models such as the NEN-Bjerrum isotach model or the abc-isotach model are built on the assumed validity of the classical isotach framework and do not automatically simulate a non-linear creep rate on logarithmic timescale. Consequently, it is concluded that this can result in the under estimation of long-term settlement in peat.

It is of future interest to further investigate the physical reasons for the observed diverging isotachs. This ultimately helps in a better understanding of long-term compression behaviour in soft soils such as peat.

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