

North Sea Chalk characterisation through laboratory testing in comparison with ALPACA findings

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ABSTRACT: A great deal of work has recently been performed to increase the understanding of Chalk as a geomaterial in relation to driven piled foundations with a particular emphasis on larger diameter piles used in offshore renewables developments. The majority of this work has been performed as part of the Axial-Lateral Pile Analysis for Chalk Applying Multi-Scale Field and Laboratory Testing Joint Industry Project (ALPACA JIP). This has involved field scale axial and lateral pile load testing at an onshore test site complimented by comprehensive *in-situ* and laboratory investigation of the behaviour of intact low to medium density chalk, and this same chalk, when de-structured into chalk putty, mimicking the material which develops in proximity to the walls of driven piles. In this paper, the authors examine the results of a high-quality laboratory testing programme performed on chalk recovered from the North Sea and compare these findings to the chalk behaviour published from the ALPACA test site. One Dimensional consolidation testing to establish yield stresses, followed by monotonic and cyclic direct simple shear (DSS and CDSS) were performed, along with drained triaxial compression tests at effective confining pressures of up to 7MPa, undrained monotonic triaxial, undrained cyclic triaxial and multistage undrained cyclic triaxial. The authors illustrate the similarities between both chalk types in some conditions, and in others, highlight behaviour of the North Sea Chalk which diverges from the ALPACA findings, demonstrating the value of site-specific chalk testing to validate ALPACA assumptions. Important observations are made relating to the relevance of trying to truly replicate the site specific *in-situ* and loading conditions during stress controlled cyclic testing and commentary is provided on the challenges for replicating the ALPACA research testing techniques during commercial testing programmes.

KEYWORDS: Chalk, ALPACA, Offshore, Piles, Laboratory.

1 INTRODUCTION

Chalk is a complex biogenic carbonate material with highly variable mechanical properties and poses ongoing challenges to offshore geotechnical engineering, particularly in relation to pile foundation design. In Europe, chalk may be encountered within pile founding depth across large areas of the North and Baltic seas. Chalk's response to static and cyclic loading is sensitive to initial structure, degree of cementation, saturation conditions, and loading history (Vinck 2021). While chalk can present as a moderately strong rock capable of maintaining vertical faces in excavation and natural cliff faces, its behaviour under engineering loads, especially after pile installation can vary drastically, transitioning from brittle, bonded material to a destructured, soft putty with low strength and stiffness.

Recent large-scale efforts, including the ALPACA and ALPACA Plus Joint Industry Projects (JIP) have significantly advanced our understanding of chalk behaviour through the integration of high quality field, laboratory, and modelling programmes based on low to medium density chalk from Saint Nicholas at Wade (SNW) in Kent, UK, the behaviour of which was characterised by Vinck et al (2022). These initiatives have yielded new design methodologies for driven piles in chalk, under both axial and lateral loading conditions.

Academic laboratory studies have addressed the monotonic and cyclic behaviour of both intact and destructured chalk under varying confining pressures, effective stress conditions, and loading regimes (Ahmadi-Naghadeh et al 2022, Alvarez-Borges et al 2020, Liu et al 2022, Liu et al 2023, Vinck 2021, Vinck et al 2022). Together, these studies have proposed baseline understanding of the yield surfaces, failure envelopes, critical states, and rate effects relevant to SNW chalk.

High-pressure drained triaxial testing of the intact chalk revealed a strong pressure dependency in its mechanical behaviour, with a clear transition from brittle, bonded response at low confining pressures to ductile behaviour under elevated pressures (Liu et al. 2023). At *in-situ* conditions, failure occurred through early bifurcation at small strains due to

bonding and micro-fissuring, while higher pressures led to compressive volumetric strains, delayed peak resistance, and critical state behaviour characterised by $M = 1.25$ ($\phi' \approx 31^\circ$). Behaviour beyond initial yield was elastic-plastic and time-dependent, with progressive destructure of the chalk's bonded microstructure.

Undrained cyclic triaxial testing of intact chalk at *in-situ* conditions, such as that performed by Ahmadi-Naghadeh et al. (2022), demonstrated stable and nearly linear visco-elastic response under one way cyclic loading at low strain amplitudes. Intact chalk was shown to withstand thousands of cycles without measurable strength degradation, and in some cases, stiffness increased modestly, presumed due to micro-fissure closure. However, failure when it occurred, was abrupt without prior warning signs, indicative of brittle collapse mechanisms driven by stress concentrations along microstructural imperfections. The fatigue response of intact chalk in this regime resembled that of bonded rocks, concrete, or even metals, markedly different from that of conventional unbonded soils.

In contrast, research into destructured chalk reveals behaviour far more akin to saturated silts or silty sands. As illustrated by Liu et al. (2022), triaxial cyclic loading of reconsolidated chalk putty generated both contractant and dilative stages, leftward effective stress path drift, and progressive stiffness degradation making it vulnerable to early cyclic failure. Nevertheless, long-duration cyclic loading could lead to re-consolidation effects and post-cyclic stiffness recovery, indicating a capacity for partial healing in aged putty zones.

This paper builds upon these findings by comparing new experimental data with those reported in the above studies. The authors examine the differences between the SNW chalk and that encountered at a North Sea site, and explain some of the challenges associated with replicating academic research testing practices within a commercial testing programme.

2 CHALK CLASSIFICATION

2.1 Classification of the North Sea Chalk

The chalk obtained from the North Sea site contrasts from that present at SNW. Table 1 provides a summary of the range of bulk/dry density (ρ_b/ρ_d), particle density (P_d), water content (W), liquid limit (LL), plasticity index (PI) and intact voids ratio (e_0) for two investigated North Sea locations (Loc 1 and Loc 2) along with the same data for SNW as presented by Vinck et al (2022). The majority of the testing programme in this research was performed on medium density specimens from Loc 1. The ρ_d and e_0 of the North Sea Chalk is compared to SNW chalk in Figure 1 and Figure 2 respectively illustrating some immediately significant differences between the materials present at the different sites.

Table 1. Chalk classification [min/max]

Parameter	SNW*	Loc 01	Loc 02
W: (%)	28 / 33	21 / 26	8 / 23
LL: (%)	30 / 32	27	-
PI: (%)	6.5 / 9.5	8	-
ρ_d : (Mg/m ³)	1.43 / 1.53	1.55 / 1.68	1.67 / 2.20
ρ_b : (Mg/m ³)	1.85 / 1.98	1.95 / 2.06	2.05 / 2.38
P_d : (Mg/m ³)	2.71	2.69	-
e_0 : (-)	0.761 / 0.893	0.630 / 0.770	0.480 / 0.640

*Vinck et al (2022)

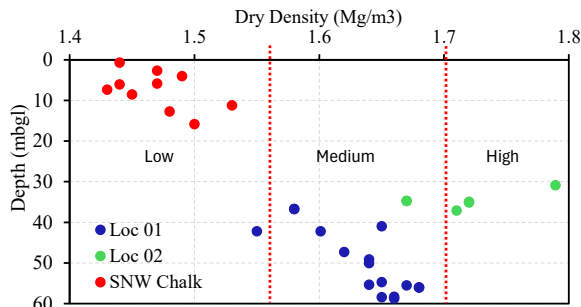


Figure 1. North Sea Site dry density compared to SNW after Vinck et al (2022).

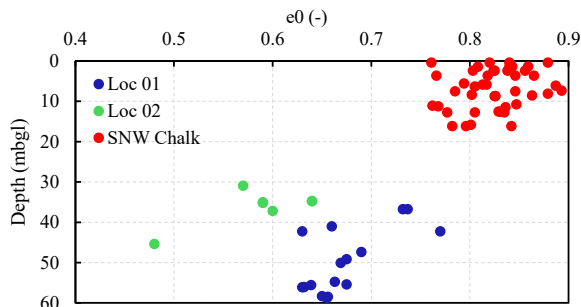


Figure 2. North Sea Site intact e_0 compared to SNW after Vinck et al (2022).

2.2 Characteristics of North Sea Chalk Putty

The North Sea putty chalk samples were prepared as batches relating to defined depth ranges and fully homogenised. Particle size analysis of the Loc 1 putty was performed using sieving and hydrometer methods. D50 was $3\mu\text{m}$ with particle size proportions Sand: 6%, Silt: 57% and Clay: 37%. The grading curve for the putty is presented in Figure 3 overlaid upon the grading curve of the SNW putty chalk developed by Vinck (2021) for the ALPACA laboratory testing. Note however that the SNW curve was determined using a Laser Diffraction Mastersizer, and the y axis depicts % passing by volume, whereas the PSD performed as part of this study is % passing by mass.

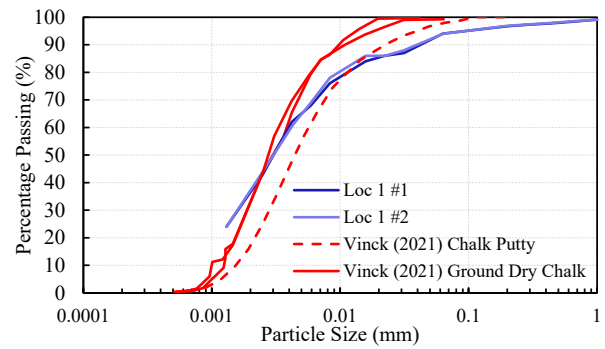


Figure 3. North Sea Site Putty Grading compared to SNW Putty approximated from Vinck (2021).

3 TESTING PROGRAMME OUTLINE

The laboratory testing programme carried out at Russell Geotechnical Innovations Ltd (RGI) on intact and putty chalk was designed to evaluate:

- The classification of the materials in terms of moisture content, density, particle density, voids ratio and grading.
- The compressional and creep behaviour using high-capacity constant rate of strain oedometer methods.
- The behaviour in monotonic and cyclic simple shear.
- The behaviour in monotonic and cyclic triaxial shear of isotropically consolidated specimens.

And for intact chalk alone.

- The compressional and subsequent triaxial shear behaviour of separate specimens subjected to a range of isotropic confining pressures between *in-situ* and up to 0.7 times the estimated yield stress (σ'_{vy}) of the chalk (estimated using the results of the CRS tests)

4 COMPRESSIBILITY BEHAVIOUR

4.1 One-Dimensional Consolidation Testing

The primary purpose of these tests within the testing campaign was to benchmark the yield stress (σ'_{vy}) of the chalk so that a suite of effective stresses could be developed for the high-pressure CID testing. The secondary purpose was to evaluate the compressional characteristics of the post-yield chalk, both in compression and unloading and to compare the intact behaviour to the putty chalk behaviour.

The utilised rates of strain ranged from 0.02 to 0.1mm/min for intact chalk and between 0.02 and 0.03mm/min for putty chalk. Although ASTM D4186-20 requires for rates of strain to be selected so that excess pore water pressures can be developed to be of the order 3% to 15%, due to the inherent porosity of the intact chalk specimens, this was not possible even at 0.1mm/min. Much higher rates of strain would be needed to develop the suggested pore pressure. After discussion, it was deemed that the primary purpose of the testing was to establish σ'_{vy} and that the porous microcrystalline fossiliferous nature of the chalk prevented generation of excess pore pressure, this stipulation of the testing standard was therefore relaxed. It was instead important that during the loading that the material volume was reduced by yielding the bonds between the mineral grains, closing the pores through one-dimensional compression alone and that the selected rates of strain would reduce the chance of the voids ratio (e) vs log vertical effective stress (σ'_v) curve being influenced by creep.

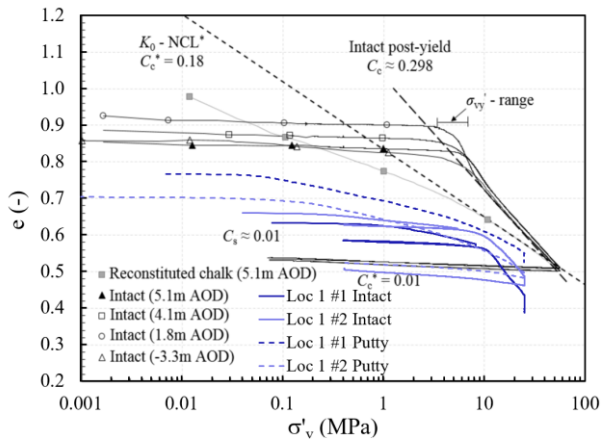


Figure 4. Location 1 Medium Density intact and putty CRS overlaid on ALPACA tests presented by Vinck (2021).

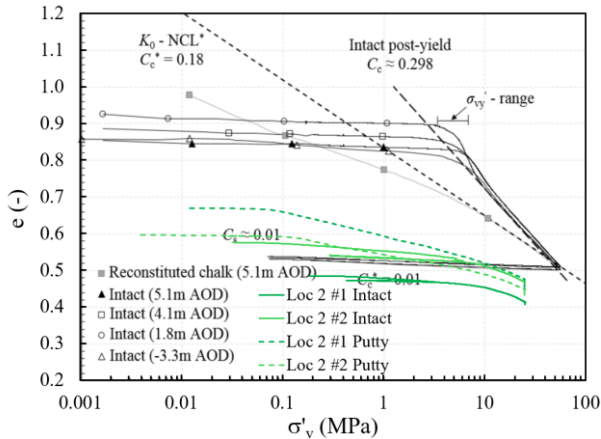


Figure 5. Location 2. High Density intact and putty CRS overlaid on ALPACA tests presented by Vinck (2021).

Table 2. Chalk compressional behaviour

Test	σ'_{vy} [kPa]	C_c [-]	C_s [-]
Loc 1 #1 Intact	9720	0.330	0.012*
Loc 1 #2 Intact	8450	0.344	0.01* / 0.013**
Loc 2 #1 Intact	7000	0.135	0.013*
Loc 2 #2 Intact	10030	0.133	0.006*
Loc 1 #1 Putty	-	0.158	0.012**
Loc 1 #2 Putty	-	0.150	-
Loc 2 #1 Putty	-	0.131	-
Loc 2 #2 Putty	-	0.138	-
SNW Intact***	3300 < 6900	0.298	0.01

* C_s from unload reload loop. ** C_s from final unload stage. *** after Vinck et al (2022)

All tests on intact chalk included an unload reload loop at a stress close to yield and for Loc 1 #1, a full unload from 25MPa was performed (See Figure 4), returning the normal stress to an estimate of *in-situ* vertical effective stress (σ'_{v0}). For putty specimens, no unload reload loops were performed, but a final unload stage was performed on Loc 1 #1.

The Swelling index (C_s) of the Loc 1 chalk, determined from the final unload on the #1 tests in both intact and putty state are 0.013 and 0.012 respectively, which is essentially identical behaviour and almost identical to SNW chalk reported by Vinck (2022) at 0.01. Interestingly, the C_s determined from unload reload loops performed before or around σ'_{vy} provide the same values (except for Loc2 #2). This suggests that for the specimens tested, the chalk's tendency to expand in response to changes in pressure is similar whether it is intact or destructured and that changes in pressure appear not to have a significant

impact on C_s . Furthermore, the similar behaviour of both intact and putty chalk under high pressures (25MPa in this testing programme and 50MPa by Vinck 2021) implies that the material will likely continue to exhibit a consistent behaviour over time, even after the application of high pressures due to the calcitic haptophyte algae coccolith microstructure.

4.2 Chalk Creep behaviour under one-dimensional consolidation

All intact and Putty Chalk specimens were evaluated for secondary consolidation (creep) at maximum vertical effective stress applied of 25MPa.

Hold periods at 25MPa varied from 4 to 223 hours for the intact chalk and between 4 and 145 hours for the putty chalk. Higher Secondary consolidation indices (C_α) were observed for medium density Loc 1 chalk (0.0034 to 0.005) compared to the higher density Loc 2 chalk (0.001 to 0.002).

To examine the effect of the different creep hold periods and to compare between creep in the different intact chalks, then evaluate against the putty chalk, plots of log strain and log strain rate vs log time were constructed and presented in Figure 6 and Figure 7.

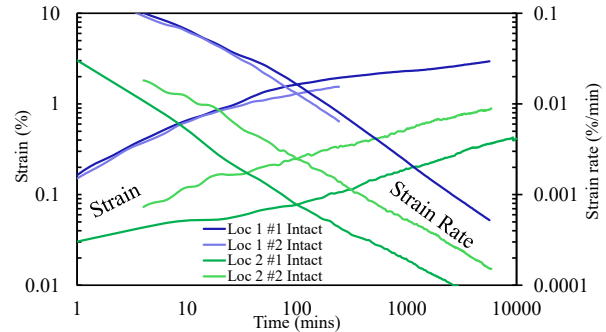


Figure 6. Creep Characteristics Intact Specimens

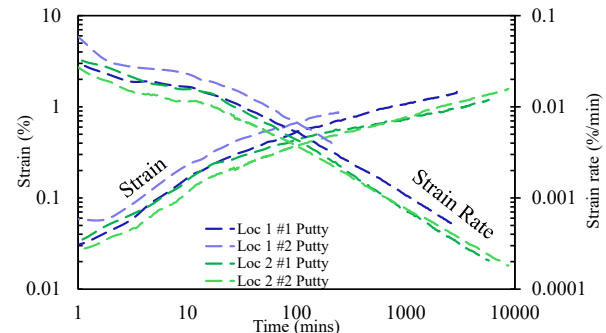


Figure 7. Creep Characteristics Putty Specimens

It is possible to draw the following conclusions:

1. The creep behaviour of the two intact Loc 1 chalk specimens is almost identical, resulting in nearly identical strain and strain rates, whereas for Loc 2 the 2 specimens behave differently with markedly different resulting strain and strain rates over time. However, it is worth noting that the depth difference between test specimens from Loc 2 is nearly 15m, whereas for Loc 1 it is 1.25m.
2. The intact Loc 1 chalk differs in behaviour from the Loc 2 chalk with markedly different resulting strain and rates of strain over time.
3. The creep behaviour of the putty chalk material from Loc 1 and Loc 2 is broadly the same with very similar resulting strain and rates of strain, albeit both are lower for the Loc 2 chalk when compared to the Loc 1 chalk.
4. The process of puttyfication of different age and density chalk from different locations appears to result, at least in

terms of secondary consolidation, in a very similar creep behaviour. Through puttyfication, the differences in behaviour between the Loc 1 and Loc 2 chalk closes, as does the difference between the different depth chalks from Loc 2.

5 DIRECT SIMPLE SHEAR

5.1 Direct Simple Shear (DSS) Intact Specimens

Constant volume testing on intact medium density chalk from Loc 1 using DSS apparatus was of limited success, even when using ridged platen interfaces and oversized top and bottom rings to prevent slippage at the platens. The high strength of the specimens prevented development of simple shear, with the chalk either failing at / near the platen interfaces or through sudden development of subvertical fracturing. No attempts were made to perform DSS with the higher density chalk from Loc 2.

5.2 Monotonic DSS Putty Specimens

Monotonic constant volume DSS were performed on samples of putty chalk from the medium density chalk at Loc 1.

The testing commenced with four monotonic DSS, comprising 2 pairs of tests, each pair being duplicate tests consolidated using 500 kPa and 700 kPa σ'_v . The putty for each pair was manufactured from medium dense chalk samples separated by 2m depth. The consolidation normal stresses were the equalised radial effective stress σ'_{rzf} representative of 2 different depths within the lower part of a theoretical pile and following the ICP '23 methodology presented in Jardine et al (2023). Following completion of the monotonic reference testing, a suite of four cyclic tests was performed at both of the chosen normal stresses.

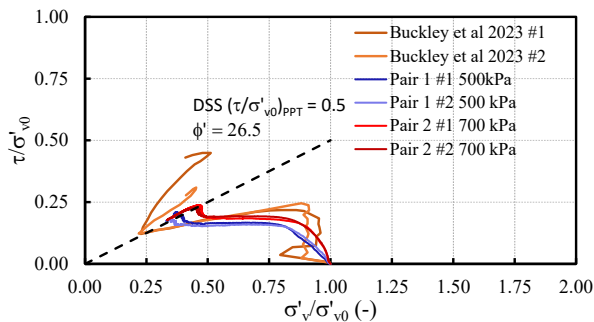


Figure 8. Constant Volume Monotonic DSS comparison combined with approximated results from ALPACA testing published by Buckley et al (2023)

As may be expected, the putty tests performed at higher normal stresses yielded high peak undrained shear strength (τ) and presented higher secant shear moduli (G). The stress paths of both pairs of tests exhibited leftward migration towards a phase transformation point (See Figure 8). For the Mono Pair 1 at 500 kPa the specimens appears to have started to initiate dilation, but did not progress. For the Pair 2 at 700 kPa normal stress, the same leftward drift was followed by a more significant attempt at dilation before then drifting leftwards down the yield surface.

The resulting τ/σ'_v ratios at 15% shear strain for both pairs of tests are very similar with associated ϕ' (assuming $c' = 0$ kPa) of between 26 and 29°, the average of which (27.5°) is slightly higher than the 26.5° phase transformation value presented for ALPACA putty chalk in Buckley et al (2023).

5.3 Cyclic DSS Putty Specimens

Two suites of cyclic testing consisting of 4 tests each were performed on the same putty batch as used for the monotonic tests. Suite 1 utilised 500 kPa σ'_v and Suite 2, 700 kPa σ'_v .

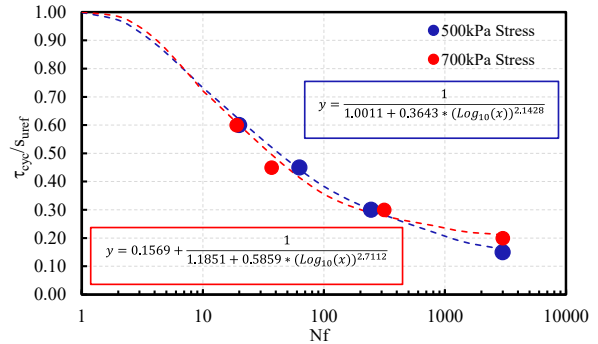


Figure 9. Interaction diagram for both Cyclic DSS Putty chalk suites with best fit functions.

Test termination criteria were following conventional offshore practice with failure through γ_{av} or γ_{cyc} exceeding 15%, when R_u approached 1, i.e., liquefaction occurred, or the test reached 3000 cycles, whichever occurred first. Reference values of τ were determined at 15% shear strain from an average of the pairs of monotonic reference tests. ASR was 0 for all tests, with CSR of 0.15, 0.3, 0.45 and 0.6 for the 500 kPa σ'_v suite and 0.2, 0.3, 0.45 and 0.6 for the 700 kPa σ'_v suite. A tentative interaction diagram of number of cycles to failure (Nf) vs shear stress normalized by the reference monotonic shear stress ($\tau_{cyc}/s_{u,ref}$) for the 2 completed suites is presented in Figure 9.

At 500 kPa σ'_v , the three highest CSR tests failed as R_u approached 1, while the lowest CSR test survived 3000 cycles and, during post-cyclic monotonic shear, exhibited strain hardening and transitioned fully into a dilative state, reaching 133 kPa at 15% shear strain with stiffness similar to the reference test. At 700 kPa σ'_v , the three highest CSR tests failed by reaching 15% γ_{cyc} , with low γ_{av} and R_u stabilising between 0.6 and 0.8. The lowest CSR test survived 3000 cycles but showed reduced stiffness (by 20%) and a near-vertical stress path in post-cyclic shear, deviating from the reference trend after 120 kPa

6 PUTTY ISOTROPICALLY CONSOLIDATED TRIAXIAL TESTING

Tests were performed on putty chalk specimens prepared from various structureless medium density chalk samples between 30 and 40m depth at Loc 1. All tests included vertically oriented bender elements which were fired at various intervals during consolidation to correlate with creep measurements and establish stability before shearing. As the ALPACA scenario required shearing to a minimum of 30% axial strain it was not possible to use local axial strain instrumentation for fear of the datum measurement pins causing early membrane rupture. Therefore local strain equipment was not employed, instead relying on external strain measurement.

Two monotonic tests were performed, consolidated effective confining pressures equivalent to those used for the DSS testing, i.e., 500kPa p'_0 and 700 kPa p'_0 . The subsequent single cyclic suite was performed with 500 kPa p'_0 and a reference s_u of 300 kPa approximated from the phase transformation point of the monotonic reference tests. See Figure 10. The frequency of cyclic loading was 10 seconds / 0.1Hz using research level but commercial cyclic loading frames, in accordance with conventional offshore

environmental loading approaches. This contrasts with the 30 second / 0.0333Hz loading frequency employed by Liu et al (2022).

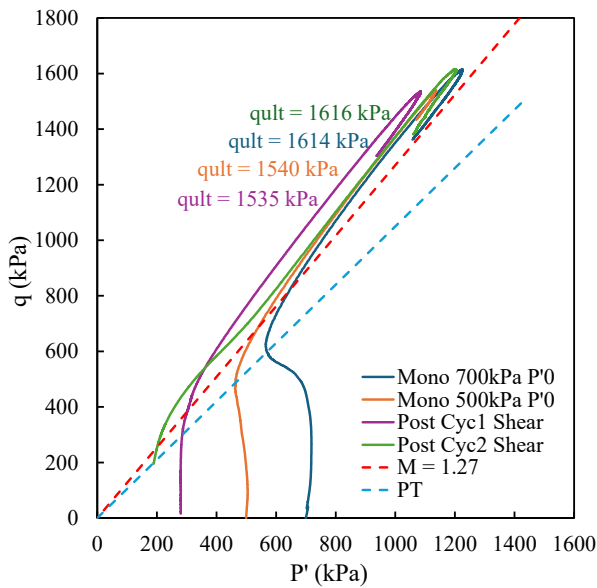


Figure 10. Stress paths of CIU monotonic and post cyclic shearing stages of cyclic CIU. Phase Transformation (PT) proposed by Liu et al (2022)

Failure for the 3 specimens which did not achieve 3000 cycles was through accumulation of average axial strain. A tentative interaction diagram based on this single suite of cyclic testing is presented in Figure 12. The data from this study is overlaid upon the interaction diagram proposed by Liu et al (2022). This study illustrates that for Loc 1 Putty Chalk exposed to 0.1Hz cycling, there is a lower resistance to cyclic loading and that transition from stable to meta stable conditions is relatively abrupt when compared to the behaviour observed by Liu et al (2022).

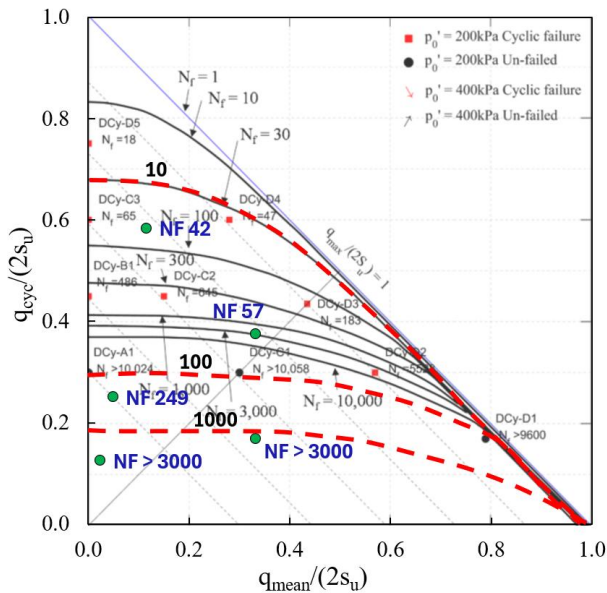


Figure 11. Tentative triaxial interaction diagram for Loc 1 Putty chalk overlaid on proposal by Liu et al (2022).

Two specimens (Cyc 1 and Cyc 2) survived 3000 cycles resulting in effectively zero strain in the case of Cyc 1 and only 2.5 average and 1% cyclic axial strain in the case of Cyc 2. The post cyclic shearing stages are presented in Figure 10. The resulting q_{ult} for Cyc 1 was 5 kPa lower than the monotonic

reference test and for Cyc 2, a 76kPa increase in q_{ult} resulted, reaching within 2kPa of the q_{ult} reported by Liu et al (2022). Barring the differences in the early contractive and dilative stages, all 4 monotonic shearing stages in this study showed a remarkable similarity with those from SNW putty presented by Liu et al (2022) in compression.

7 ISOTROPICALLY CONSOLIDATED DRAINED TRIAXIAL TESTING

These tests were performed on 50mm diameter medium density specimens from Loc 1 at p'_0 from 271 to 7000 kPa (this highest p'_0 being approximately $0.7 \times \sigma'_{vy}$ established in the CRS Oedometer). Specimens tested at p'_0 of 1000 and lower were not instrumented, although the external strain measurement was accurate to 1 micron. The higher p'_0 tests were fully instrumented with local axial and radial strain measurement equipment. Of the 10 tests performed, 6 were subcontracted by RGI to a research laboratory with suitable equipment pressure capacity.

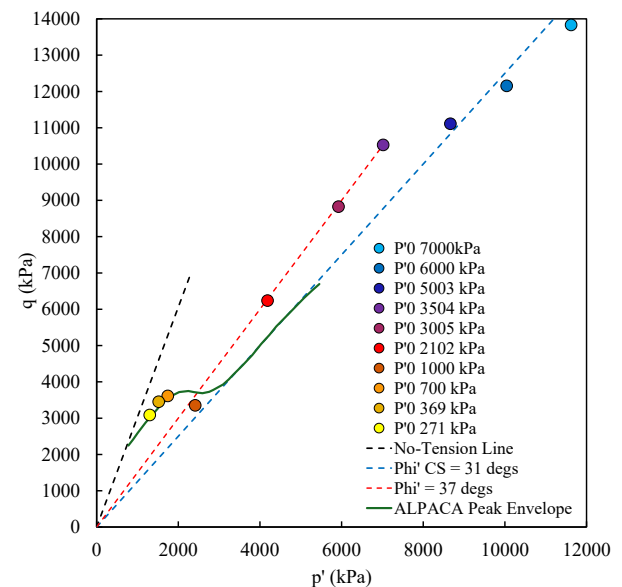


Figure 12. Peak failure conditions for series of CID including ALPACA peak envelope after Liu et al (2023).

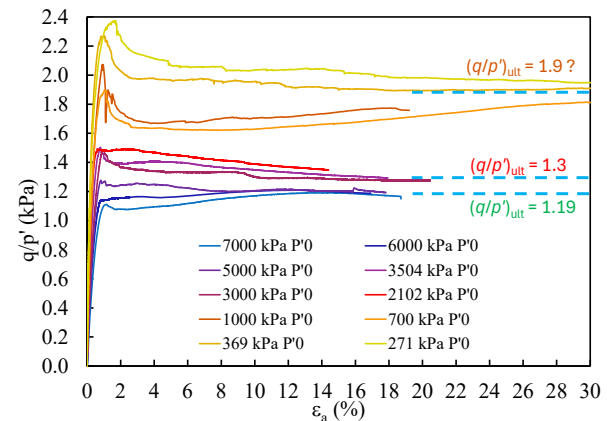


Figure 13. q/p' ratios for drained triaxial tests. Axial strains are external.

Figure 12 presents q_{peak} vs p' overlaid upon results reported by Liu et al (2023), illustrating that for higher p'_0 tests, the chalk at q_{peak} closely resembles the chalk critical state line at q_{peak}/p' ratio of 1.25 and $\phi' = 31^\circ$, failing in a ductile fashion. Something not observed by Liu et al (2023), yet identified in

this study on the medium density Loc 1 chalk was a transitional zone for tests with p'_0 of between 2000 and 3500 kPa which have a q_{peak}/p' ratio of 1.5 representative of $\varphi' = 37^\circ$. These developed a shear band during failure. For tests with $p'_0 < 1000$ kPa, the q_{peak}/p' ratios average 1.1 representative of $\varphi' = 54^\circ$. These developed brittle failure planes.

Figure 13 presents q/p'_{ult} ratios against external axial strain suggesting that for all tests with $p'_0 > 2000$ kPa, q/p'_{ult} ratios are < 1.3 ($\varphi' = 32$) and for the tests with p'_0 of 5000, 6000 and 7000 kPa q/p'_{ult} is approximated by 1.19, representative of $\varphi' = 30$. For the lower pressure tests the results appear to be converging towards an average q/p'_{ult} ratio of 1.9, although by 30% axial strain this is not fully achieved.

8 CONCLUSIONS

This study presents a comprehensive laboratory characterisation of medium-density chalk recovered from a North Sea offshore site, with comparisons made to the extensively studied Saint Nicholas at Wade (SNW) chalk featured in the ALPACA programme. The results confirm that while the North Sea chalk shares key behavioural features with SNW chalk, particularly in high-pressure drained triaxial testing where convergence towards a critical state line with $\varphi' \approx 31^\circ$ was observed, there are also significant divergences that justify the need for site-specific investigation.

High-pressure one-dimensional consolidation tests revealed a strong pressure dependency in both intact and putty chalk, with destructuration reducing compression indices but not swelling indices, which remained consistent across intact and remoulded states. Creep behaviour varied with density and depth in intact chalk but was notably homogenised following destructuration, suggesting a convergence of behaviour in the putty state.

DSS testing of intact chalk was of limited success, largely due to the strength of the material preventing the specimens from going into simple shear. The use of this apparatus for intact chalk of greater than low density is therefore unlikely to be successful. DSS testing of putty chalk demonstrated typical contractive and dilative phases under both monotonic and cyclic loading.

Triaxial testing on intact chalk further confirmed the ductile–brittle transition dependent on confining pressure, with brittle failure prominent below 1000 kPa, ductile response above 3500 kPa and a transitional behaviour in between. Undrained cyclic testing on putty specimens yielded post cyclic shearing behaviour almost identical to SNW chalk. The resistance to cyclic loading at both 500 and 700 kPa effective stresses did not align with prior ALPACA data, potentially due to the slower rate of application of cyclic loading performed for the ALPACA research compared to the conventional offshore environmental loading rates employed in this study. It is the researcher's assertion that model testing which imposes cyclic loading closer to real world conditions is advantageous.

Application of research quality testing in commercial laboratories may pose a challenge unless the laboratory has sufficient proven experience in chalk sample handling, preparation and testing.

Replication of ALPACA type testing methodologies, or indeed, accommodation for additional methodologies not used routinely in the ALPACA testing, such as lubricated end platens for triaxial tests or locally instrumenting small diameter specimens are likely to be challenging for laboratories unless they have been involved in such work before. Careful choice of laboratory testing partner is therefore essential.

As with all advanced testing programmes, regardless of very careful planning and preparation, a high degree of pragmatism and adaptability is required when undertaking such a study. As different materials reveal their behaviour, adjustments to proposed tests and methodologies are often required and this necessitates an intense and collaborative working environment for client, contractor and laboratory expert(s) to operate within.

Overall, this study reinforces the necessity for bespoke chalk testing when applying ALPACA-derived methodologies to offshore sites. While broad behavioural parallels exist, nuanced differences in compressibility, creep, and cyclic response highlight the importance of tailoring testing approaches to match the specific geomechanical context of each site.

9 ACKNOWLEDGEMENTS

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