Theoretical analysis of OCR on sampling disturbance in soils with varying plasticity

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1 Introduction

The issues associated with soil sampling and the consequential effects of sampling disturbance on measured soil properties have been a longstanding concern in geotechnical engineering. Disturbance-induced stress relief and fabric alteration may significantly bias measured stiffness, strength and compressibility, leading to unsafe or overly conservative designs. To quantify sample quality, recompression-based indicators such as the Sample Quality Designation (SQD) [1] and the normalised volumetric strain $\Delta e/e_0$ [2] during reconsolidation to in-situ stress have been widely adopted.

Previous studies have mainly focused on high-plasticity clays, while more recent work has extended sample quality evaluation frameworks to low-plasticity intermediate soils. Notably, the authors' preliminary triaxial and oedometer tests on synthetic soils revealed a $\Delta e/e_0$–PI relationship contrary to that reported by De Jong et al [3], as illustrated in Figure 1. This divergence was observed under Best Practice Disturbance (BPD), which simulates only the minimal disturbance induced by specimen extrusion and trimming in a high-quality sampling and testing program. A key distinction between these studies lies in the overconsolidation ratio (OCR) of the tested soils. Although the influence of soil plasticity on sampling disturbance has received some attention, the role of OCR remains inadequately investigated.

The research employs constitutive element simulations of various disturbance scenarios-including Best Practice Disturbance (BPD) and a modified Ideal Sampling Approach (ISA)-under different OCR conditions. By analysing the post-disturbance volumetric responses and compression behaviour of different soils, this study elucidates sample quality indicator ($\Delta e/e_0$) is governed by two competing mechanisms of soil's susceptibility to disturbance and compressibility, whose relative dominance is controlled by the OCR, ultimately providing a theoretical explanation for the contradictory $\Delta e/e_0$–PI trends reported in the literature.

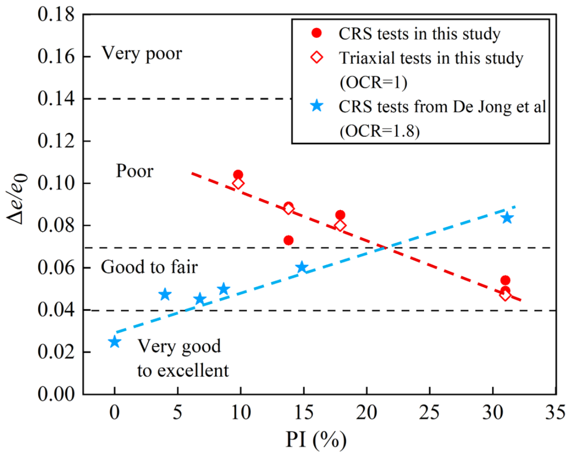

Figure 1. Comparison of $\Delta e/e_0$–PI relationships of different soil mixtures under Best Practice Disturbance (BPD) from this study and previous research [3].

2 Methodology

2.1 Constitutive model and soil materials

The constitutive model adopted here follows the Unified Model framework [4, 5], incorporating superloading [6], subloading [7] and stress-induced anisotropy. It is an associated-flow elastoplastic model with Cam-Clay-type parameters complemented by structure, overconsolidation and anisotropy evolution parameters.

Four synthetic soil mixtures with varying plasticity index (PI =10 %–31 %) were prepared by blending silica silt and kaolin clay at different mass ratios, designated as 0S100K, 40S60K, 60S40K, and 80S20K (e.g., 40S60K denotes 40 % silica silt and 60 % kaolin clay). Following extraction from the consolidation cylinder, specimens were trimmed and prepared for a series of laboratory tests, including constant rate of strain (CRS) oedometer tests, anisotropically consolidated undrained compression tests, and unloading–reloading triaxial tests. These tests were used to determine the constitutive parameters, as summarised in Table 1.

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Table 1 Material parameters of the four soil mixtures.

Material parameters	0S100K	40S60K	60S40K	80S20K
Compression coefficient λ	0.196	0.116	0.065	0.038
Swelling coefficient κ	0.058	0.037	0.016	0.011
Critical state parameter M	0.99	1.09	1.15	1.42
Reference void ratio e_0	1.26	0.84	0.66	0.41
Poisson's ratio ν	0.35	0.32	0.3	0.3
Degradation of over-consolidation rate m	4.5	2.5	1.2	0.45
Degradation parameter of structure a	0.3	0.75	1	1.4
Evolution parameter of anisotropy b_r	0.04	0.16	0.28	0.32
Initial degree of overconsolidation $1/R_0$	1.0	1.14	1.8	1.96
Initial degree of structure (fabric) R_0^*	0.71	0.68	0.61	0.58
Initial anisotropy ζ_0	0.42	0.62	0.72	0.83

2.2 Simulation procedure

Sampling disturbance was simulated using stress–strain paths applied to a single soil element. Three OCR levels were considered (OCR = 1, 1.8, 3.6) to represent normally consolidated and overconsolidated states. From the established in-situ state, two disturbance scenarios were applied:

Best Practice Disturbance (BPD): stress relief (Path 2⟶3) followed by a small strain-controlled compression–extension–compression cycle (±0.5 %) representing disturbance from sample preparation (Path 3⟶4).

Modified ISA (tube sampling): following the classical Ideal Sampling Approach (ISA) [8] where a centreline element undergoes a compression–extension–compression strain history during penetration followed by undrained deviator-stress removal (Path 2⟶5). Here, ISA was applied at two strain amplitudes (1.5 % and 3 %), and the same BPD disturbance was superimposed to capture the complete process from field sampling to specimen preparation.

After disturbance, the element was K_0-consolidated to the in-situ stress state, and $\Delta e/e_0$ was computed as the sample quality indicator.

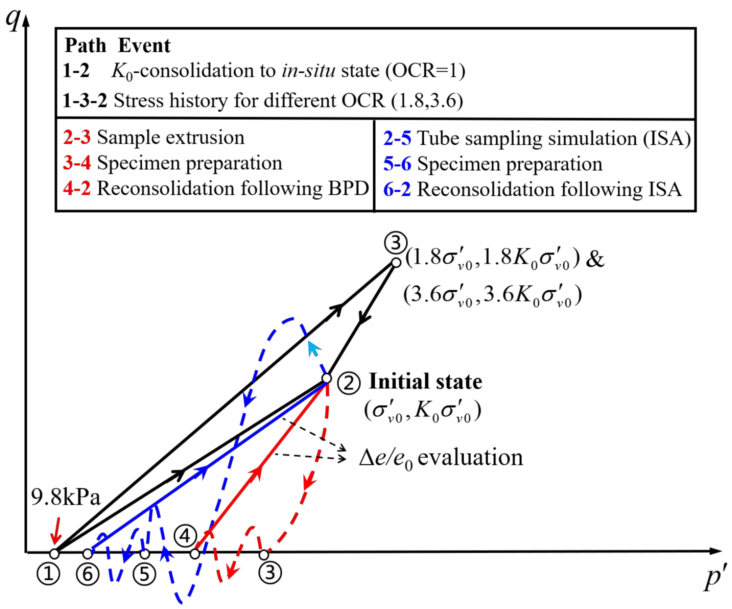

Figure 2. Stress path of theoretical simulation procedure.

3 Results and discussion

3.1 Effects of OCR on disturbance-induced stress loss

This loss in p' is quantified and plotted in Figure 3 as a percentage loss in the mean effective stress $\Delta p' / p'_c$, where p'_c is the initial mean effective stress at the end of consolidation, $\Delta p'$ is the effective stress loss during sampling stage. Overall, the degree of effective stress loss increases with both increasing disturbance level and decreasing soil plasticity. However, the influence of OCR is also critical. As the OCR increases, the loss of effective stress decreases for all soil mixtures, indicating a reduction in their susceptibility to sampling disturbance. Notably, at high OCR (3.6), low-PI soils (60S40K, 80S20K) exhibit less effective stress loss under severe disturbance (ISA ±3 %) than under moderate disturbance. This is attributed to the strongly dilatant behaviour of low-PI soils at high OCR, where the stress path deviates to the right during initial ISA compression, leading to a mitigation of effective stress loss at the end of the disturbance simulation.

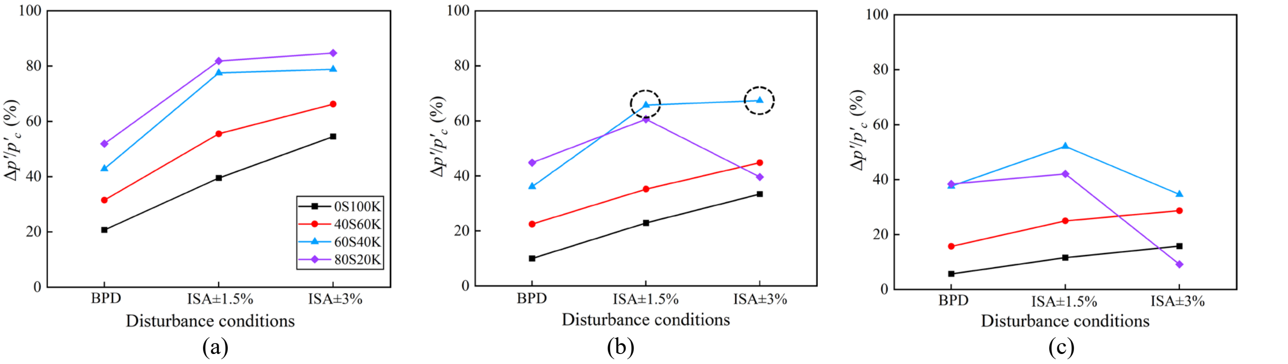

Figure 3. Loss of mean effective stress during BPD and modified ISA disturbance for four soil mixtures of different OCR: (a) OCR=1; (b) OCR=1.8, (c) OCR=3.6.

3.2 Post-disturbance recompression behaviour

As illustrated in Figure 4, an increase in OCR leads to a reduction in $\Delta e/e_0$ for all soils, resulting in a downward shift of the $\Delta e/e_0$-PI curves. Under BPD disturbance (Figure 4a), the relationship aligns with experimental findings from Figure 1: $\Delta e/e_0$ decreases with PI at OCR=1, whereas it increases with PI at OCR=1.8. As disturbance intensifies (e.g., ISA ±1.5% and ±3%), this positive correlation at OCR=1.8 becomes less pronounced, as the 60S40K soil mixture exhibits the highest $\Delta e/e_0$ value (poorest sample quality). At OCR=3.6, all $\Delta e/e_0$ values are minimal, and the influence of PI becomes negligible, with all samples rated as “very good to excellent” across different disturbance levels.

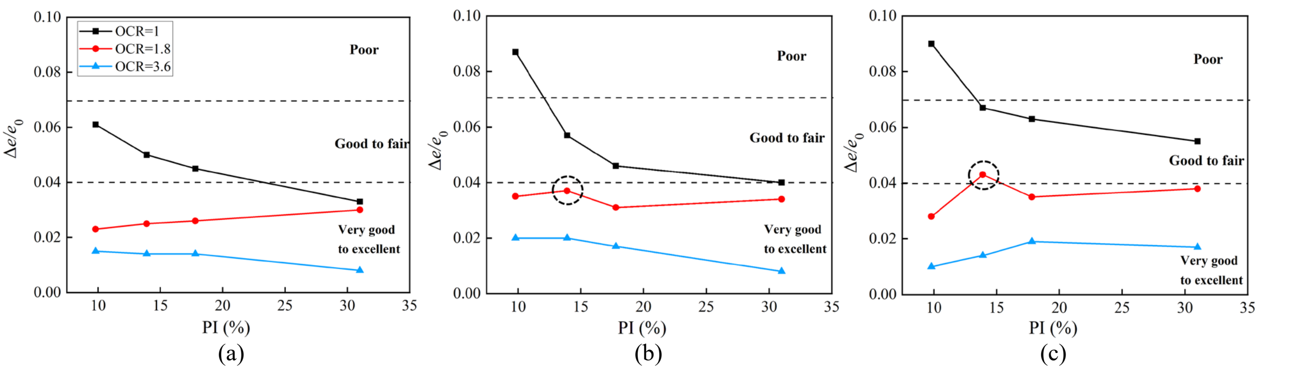

Figure 4. The effects of OCR on Δe/e0-PI relationship for four soil mixtures under different disturbance condition: (a) BPD; (b) ISA±1.5%; (c) ISA±3%.

Figure 5 illustrates the effects of BPD disturbance on the e-log σ'_{vc} curves of the four soil mixtures under different OCR. The compression curves of disturbed soils, can be distinctly divided into two regions—the recompression region and the virgin compression region—separated by the pseudo preconsolidation pressure ($pseudo-p'_c$). At OCR=1 (Figure 5a), the $pseudo-p'_c$ of low-PI soils (60S40K, 80S20K) falls below the *in-situ* vertical effective stress (σ'_{v0}), whereas those of the high-PI soils exceed σ'_{v0} . Consequently, the reconsolidation path for sample quality assessment in low-PI soils partially lies within the virgin compression region, thereby contributes to their higher $\Delta e/e_0$ values. However, at higher OCR, the $pseudo-p'_c$ of all soils exceeds the *in-situ* vertical effective stress. Under such conditions, the entire compression path for evaluation remains within the recompression region. Therefore, the $\Delta e/e_0$ is governed primarily by the soil's initial stiffness, resulting in a lower $\Delta e/e_0$ for low-PI soils due to their higher stiffness.

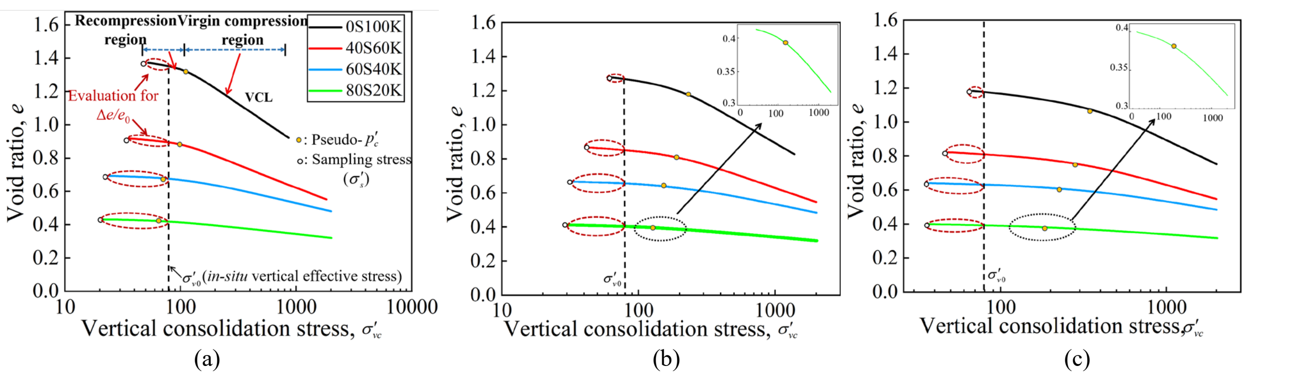

Figure 5. The effects of BPD disturbance on e-log σ'_{vc} curves of four soil mixtures with different OCR: (a) OCR=1; (b) OCR=1.8, (c) OCR=3.6.

Based on the experimental and numerical results, the trend of $\Delta e/e_0$-PI for soils across a wide OCR range was schematically summarized in Figure 6. As established, high-PI soils exhibit low susceptibility to disturbance but high compressibility (lower initial stiffness), whereas low-PI soils exhibit the opposite behaviour—high susceptibility to disturbance but low compressibility. The OCR fundamentally determines which of these two competing mechanisms governs the sample quality metric. Specifically, an increase in OCR reduces a soil's susceptibility to disturbance while enhancing its stiffness. Consequently, in low-OCR soils, disturbance effects dominate the recompression magnitude, resulting in a negative $\Delta e/e_0$-PI correlation. Conversely, in high-OCR soils, soil compressibility dominates recompression magnitude, leading to a positive trend between $\Delta e/e_0$ and PI. It can be inferred that if the OCR of soils is large enough, $\Delta e/e_0$ would be minimal, rendering the influence of PI negligible. This theoretical framework effectively explains the seemingly contradictory $\Delta e/e_0$-PI trends observed in this study and previous works.

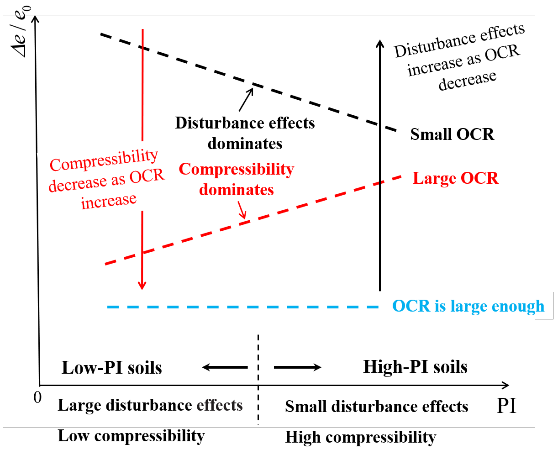

Figure 6. Schematic illustration of the $\Delta e / e_0$ -PI trend for disturbed soils with different OCR.

4 Conclusion

This study systematically investigated the influence of OCR on the sample quality evaluation of disturbed soils with varying PI through a theoretical approach based on constitutive element simulation. A detailed analysis of two competing mechanisms governing the sample quality indicator, Δe/e0 was conducted. The main conclusions are summarized as follows:

The relationship between the sample quality indicator (Δe/e0) and the plasticity index (PI) is not intrinsic. Instead, it is governed by the relative dominance of two competing factors: the soil's susceptibility to disturbance and its compressibility (or initial stiffness). Specifically, high-PI soils exhibit low susceptibility but high compressibility, while low-PI soils exhibit the opposite characteristics.

The OCR serves as a pivotal factor that controls which mechanism dominates the Δe/e0-PI relationship. An increase in OCR diminishes a soil's susceptibility to disturbance while enhancing its stiffness. In low-OCR soils, susceptibility to disturbance is the governing factor, resulting in a negative Δe/e0-PI relationship. Conversely, in high-OCR soils, compressibility becomes dominant, leading to a positive Δe/e0-PI relationship. This theoretical framework clarifies the contradictory trends observed between the present test data and previous studies.

5 References

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