

Bayesian Model Calibration of a Triaxial Specimen Using Surface Displacement Data

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INTRODUCTION

Precise measurement of soil deformation across a wide range of strains is vital for geotechnical engineering applications. Traditional **triaxial tests** are limited in their ability to accurately capture small strain behaviour, presenting a significant challenge. **Digital Image Correlation (DIC)** offers a non-contact and cost-effective solution for detailed surface displacement measurements, but the challenge lies in converting this data into actionable soil predictions.

This study addresses this issue by employing **Bayesian model calibration** in a detailed case study using a Finite Element Model (FEM) of a **triaxial** sample. By employing the modified **Cam-Clay** soil parameters, the **Bayesian** approach quantifies uncertainties and refines parameter estimates dynamically, enhancing the prediction of soil behaviour under various stress conditions.

METHODOLOGY

In order to replicate the surface data measured by **DIC**, Abaqus FEA is used to model a drained **axisymmetric** triaxial test. Data is assimilated using **Monte Carlo** simulations, specifically using **Latin Hypercube sampling** and four **Cam-Clay** parameters are varied to ensure a wide spectrum of scenarios within the framework.

- λ - Logarithmic Hardening Modulus
- κ - Logarithmic Bulk Modulus
- M - Critical State Ratio
- **OCR** - Over Consolidation Parameter

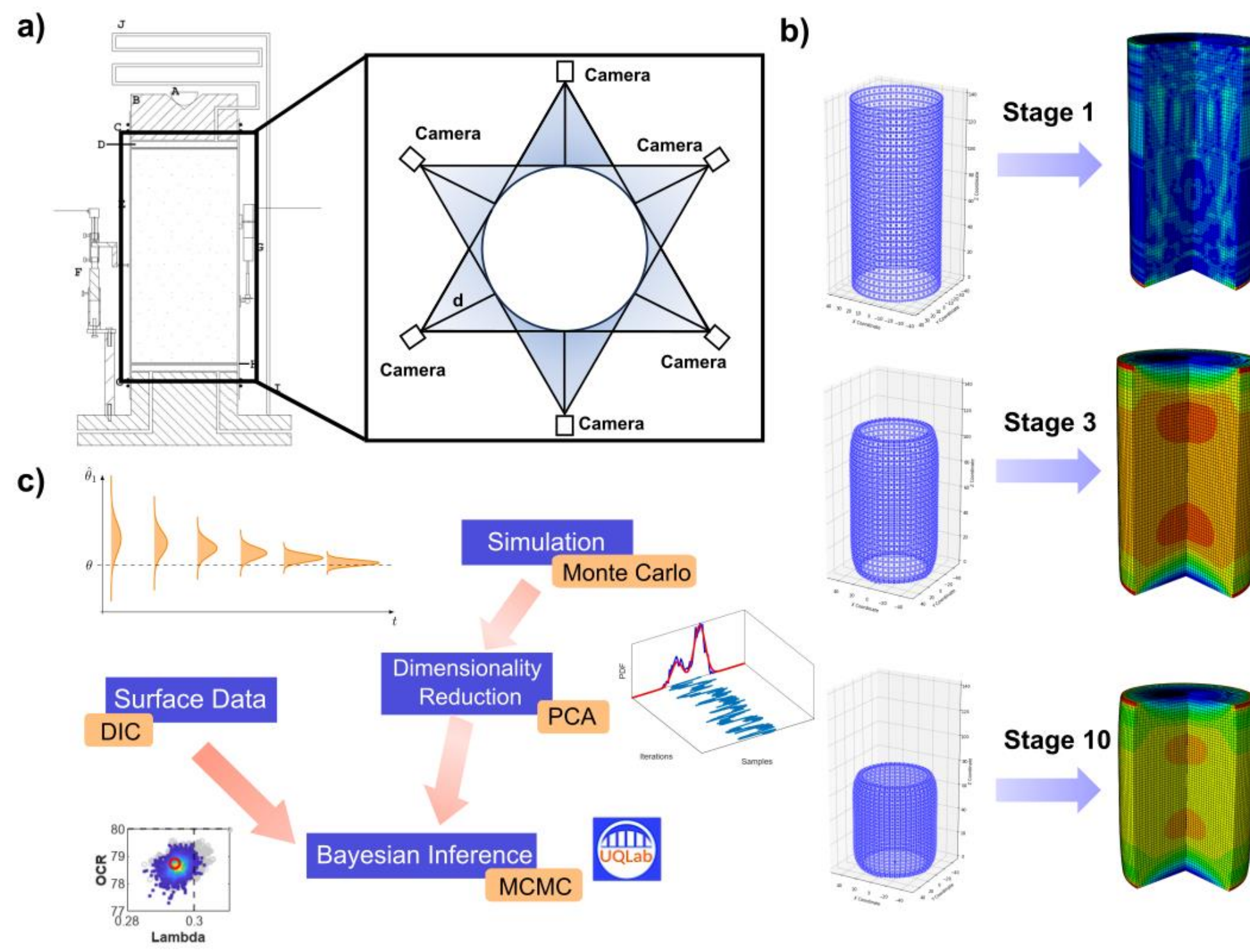
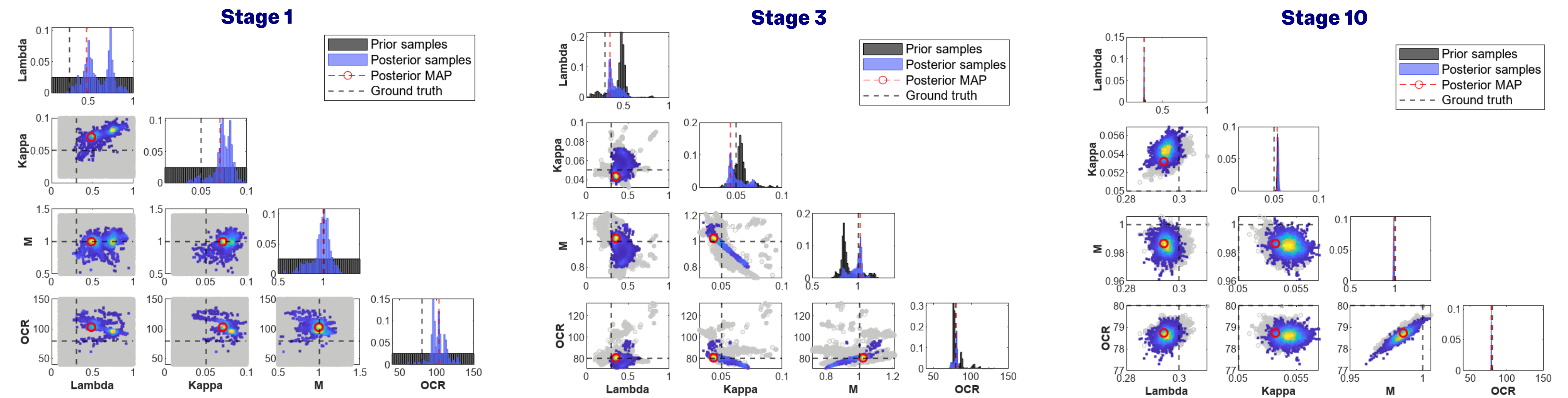


Figure 1. a) A typical DIC setup measuring surface deformations of a Triaxial test; b) Using the surface data generated alongside FEA simulations; c) Bayesian model calibration framework.

Figure 3: Scatter corner plots showing the confidence intervals for the four calibration parameters at three stages of the simulation in a four-dimensional Euclidean space.



Based on the variance in the data, it was concluded that 500 samples was sufficiently large to confidently assess the **posterior distributions** of the different parameters. Data was collected along the surface of the model encompassing reaction forces and deformations. These metrics were chosen to reflect observations and measurements typical of real-life **triaxial tests**, ensuring the model's applicability and repeatability in laboratory settings.

RESULTS

The **Bayesian model calibration** was employed to refine the **Cam-Clay** model parameters, based on the **Bayesian** statistics, integrating prior knowledge with observed data.

$$\pi(\theta | x) = \frac{\pi(x | \theta) \cdot \pi(\theta)}{\pi(x)}$$

- $\pi(\theta)$ - Prior Distribution
- $\pi(x | \theta)$ - Likelihood of observing data
- $\pi(\theta | x)$ - Posterior Distribution
- $\pi(x)$ - Normalising constant

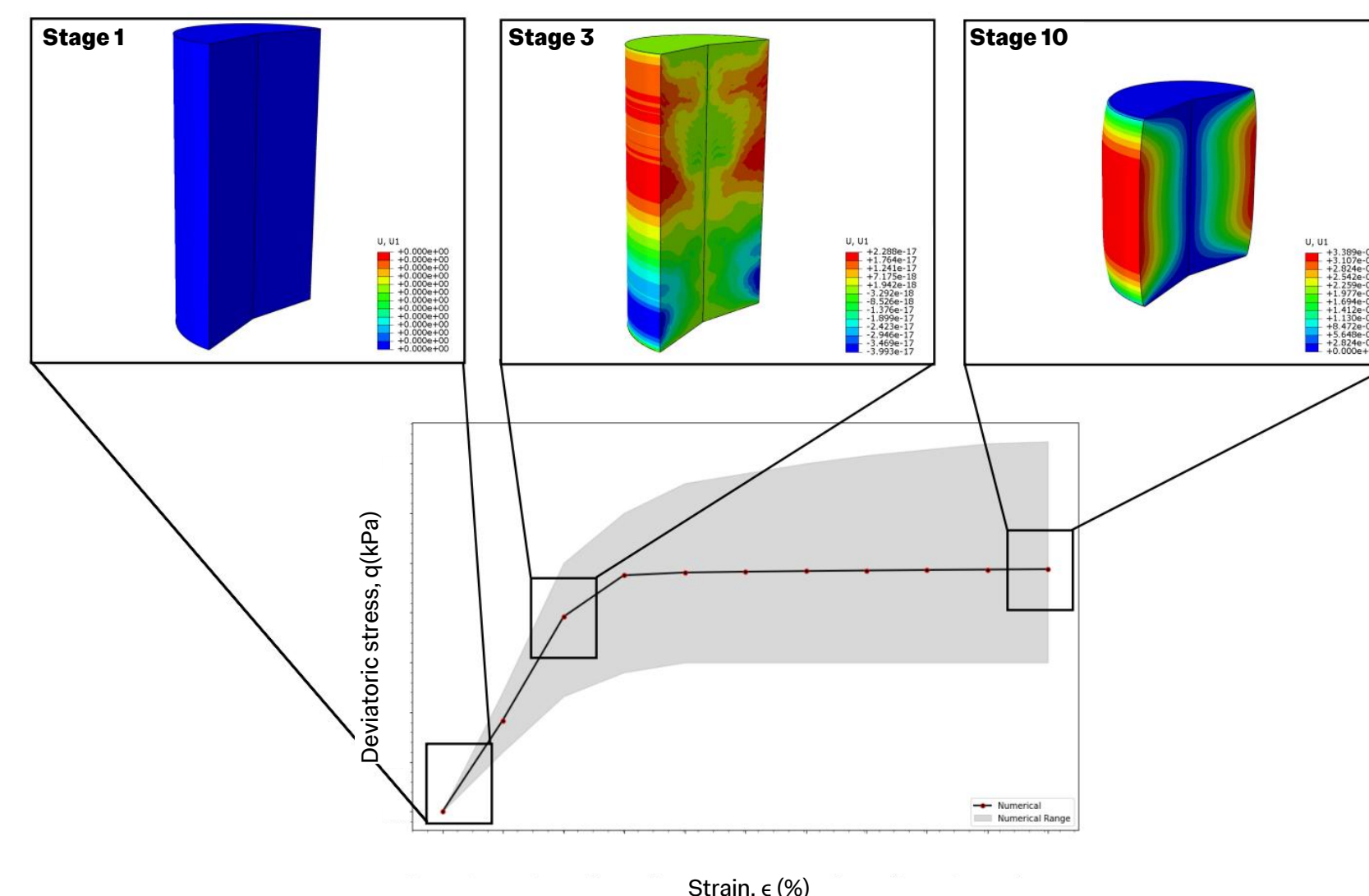


Figure 4: Stress-strain diagram highlighting the model at different stages of the simulation.

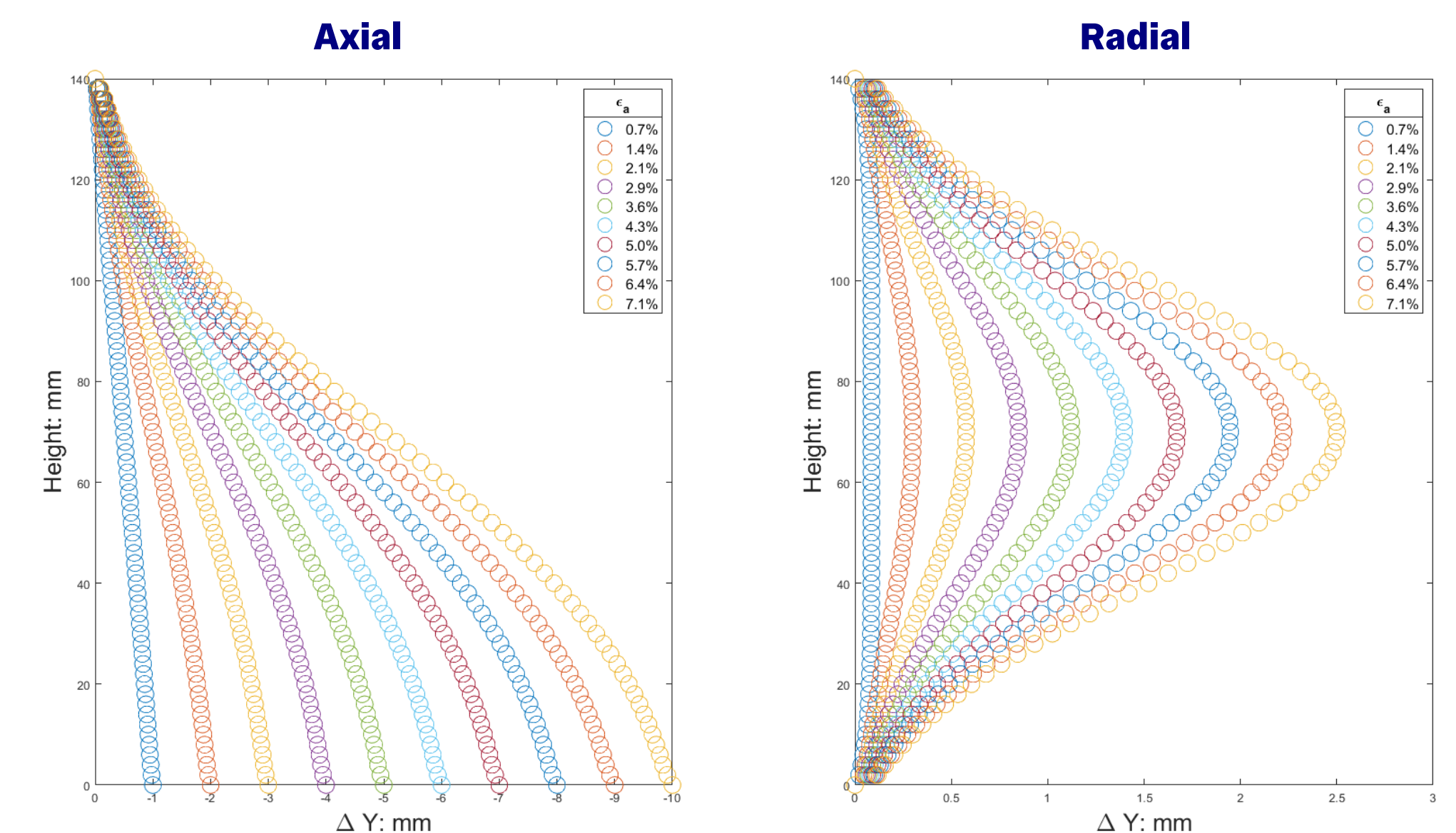


Figure 5: Plots for the axial and radial deformation at each stage of the simulation.

CONCLUSION

This research has highlighted the potential of **Bayesian model calibration** in improving the precision and reliability of soil behaviour predictions. By focusing on key metrics such as deformation and reaction forces, predictions for soil behaviour under various loading conditions can be made, with the ability to capture **non-uniformities** and detailed element responses.

With the integration of the **digital image correlation** into the **Bayesian** framework, the method has the potential to revolutionise the measurement and analysis of small strains in **triaxial** samples. Further exploration of applications into **fissured** soil samples and **hollow cylinder apparatus** provide promising possibilities for future research and engineering applications.