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# In-flight strain measurement using fibre optics in a geotechnical centrifuge

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## 1 INTRODUCTION

In geotechnical centrifuge modelling, quantifying deformation is critical for understanding system behaviour, but conventional methods like strain gauges are limited to discrete measurement points. Distributed fibre optic sensing (DFOS) based on Rayleigh backscatter provides a transformative alternative, enabling continuous strain measurement along the entire length of a fibre. Systems such as the Luna ODiSI 7000 series interrogator analyse the backscattered light spectrum from a laser pulse to compute strain with sub-millimetre spatial resolution, offering a high-definition view of deformation mechanisms (Froggatt & Moore, 1998; Luna Innovations, 2023).

This technique has been successfully validated in geotechnical applications, including the assessment of traffic-induced rail strains (Wheeler et al., 2018) and in structural health monitoring (Liu et al., 2021). Recent advancements have further refined its use for centrifuge modelling by compensating for pressure and temperature effects (Eichhorn et al., 2024). This paper details the integration of a Rayleigh backscatter-based DFOS system for real-time, in-flight strain monitoring in a large-beam geotechnical centrifuge, demonstrating its capability to capture complex, distributed strain phenomena.

## 2 CENTRIFUGE FIBRE INTEGRATION

Successful integration of the DFOS system requires strategic component placement to withstand high-g conditions. The ODiSI interrogator, containing the laser and processor, was mounted in the centre stack of the centrifuge, where it experiences reduced acceleration compared to the swing. A durable standoff cable was run along the centrifuge arm to connect the interrogator to a remote module placed on the testing platform, where the fibre optic sensors were plugged in (Figure 1). To prevent damage from shear or compression, the fibre is often protected with a thin furcation tube at key transition points.

In-flight communication with the interrogator is managed from the control room via an Ethernet connection, allowing for remote start/stop commands and real-time data streaming. However, essential pre-flight setup, including sensor taring and file naming, must be completed before the centrifuge is in motion, as these parameters cannot be adjusted remotely.

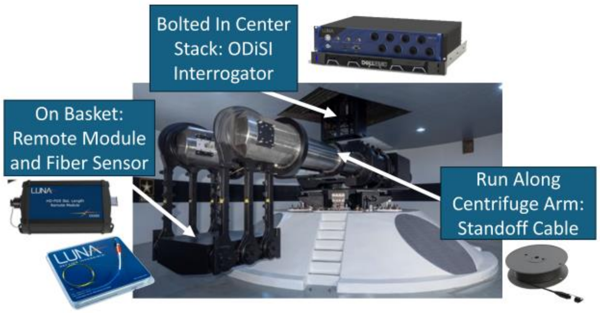


*Figure 1. Layout of LUNA ODiSI interrogator, standoff cable, remote module, and fibre.*

Accurate strain measurement requires careful application and calibration. Since optical fibre is sensitive to both mechanical strain and temperature, which produce indistinguishable spectral responses, a co-located reference fibre must be installed to isolate the mechanical strain if temperature change is anticipated. This reference fibre is mechanically decoupled by encasing it in a protective sleeve, ensuring it measures only temperature-induced strain ($\varepsilon_{thermal}$). This thermal component is then subtracted from the total strain measured by the bonded sensing fibre to yield the true mechanical strain ($\varepsilon_{mech} = \varepsilon_{total} - \varepsilon_{thermal}$).

To correlate specific points on the continuous fibre with physical locations on the model, the "touch to locate" function may be used. By applying a localised touch or a transient thermal change (e.g., with an ice cube), distinct markers are created along the fibre's length in the software. This effectively turns the continuous sensor into a series of virtual discrete points, allowing for spatial mapping and co-location of the strain data to reference objects or structures in the experimental setup.

## 3 COMPARISON BETWEEN FIBRE AND STRAIN GAUGES

Two aluminium and two steel rectangular plates of identical geometry (L=305 mm x W=50 mm x T=3.175 mm) were instrumented to measure strain due to bending along their longitudinal axis. One aluminium plate and one steel plate were equipped with conventional full-bridge strain gauges, while the companion aluminium and steel plates were instrumented with optical fibre (Figure 2).

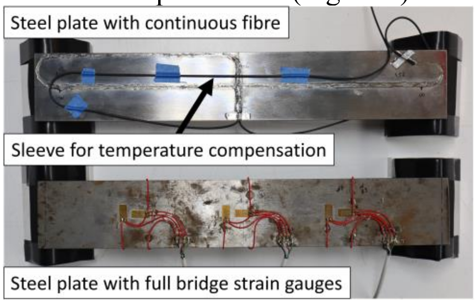


*Figure 2. Steel plate with fibre (top) and strain gauge (bottom). Sleeve for co-located temperature compensation can be seen running the width of the plate.*

The plates were positioned on identical inverted V-supports at the geometric centre of the centrifuge platform in the direction of spinning to eliminate radial acceleration gradients. The plates were offset 10.2cm and 25.4cm, respectively, from the centre of the swing platform. This configuration ensured that measured strains resulted solely from self-weight bending under elevated gravity, with minimal contribution from Coriolis or tangential forces due to the symmetric placement. Centrifugal acceleration was applied in five discrete stages (10 g, 20 g, 30 g, 40 g, and 50 g), with strain measurements recorded at each level (Figure 3).

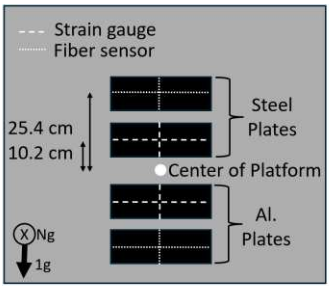


*Figure 3. Experimental set-up of instrumented plates on centrifuge platform.*

A centrifuge was chosen over a load-frame to validate the sensors in an environment representative of a full-scale application. A static load-frame only applies a direct force, whereas the centrifuge creates a complex stress state through self-weight (body forces) and introduces environmental factors like vibration, testing the true performance and survivability of the entire instrumentation system.

## 4 RESULTS AND CONCLUSIONS

Preliminary results from the validation study confirm that fibre optic sensors (FOS) provide strain measurements with an accuracy comparable to conventional strain gauges. The primary advantage of the FOS system is its ability to deliver a continuous, high-resolution strain profile along an entire structural element. For instance, by instrumenting both the top and bottom surfaces of a plate, the full bending behaviour can be calculated.

In conclusion, fibre optic instrumentation is a transformative tool for geotechnical centrifuge research. While both FOS and traditional strain gauges are fragile and require precise installation, FOS provides unique insight into distributed mechanical behaviour. Although additional data processing, including calibration, temperature compensation, and interpolation to address local data gaps, is required, the resulting measurements provide strain gradients and bending response, significantly enhancing the data-gathering potential of centrifuge modelling.

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