

# Real-Time Monitoring to Inform the Construction of Large-Diameter Caissons

Brian Sheil<sup>1</sup>, Ronan Royston<sup>1,2</sup> and Byron Byrne<sup>1</sup>

<sup>1</sup> Department of Engineering Science, University of Oxford, Oxford, UK.

<sup>2</sup> Ward and Burke Construction Ltd, UK.

brian.sheil@eng.ox.ac.uk, ronan.royston@stcatz.ox.ac.uk,  
byron.byrne@eng.ox.ac.uk

**Abstract.** Large-diameter open caissons are a widely-adopted solution for deep foundations, underground storage and attenuation tanks, pumping stations, and launch and reception shafts for tunnel boring machines. The sinking process presents a number of challenges including maintaining verticality of the caisson, controlling the rate of sinking, and minimizing soil-structure frictional stresses through the use of lubricating fluids. A bespoke monitoring system has been developed at University of Oxford to provide early warning of adverse responses during the sinking phase (e.g. excessive soil-structure interface friction). The monitoring system was trialled on a recent pilot project in the UK involving the construction of a 32 m internal diameter, 20 m deep reinforced concrete caisson. This paper describes the monitoring system that was developed and its impact on the construction process of the pilot project. Early indications are that real-time feedback of live construction data has a major impact on the efficiency and safety of the construction process.

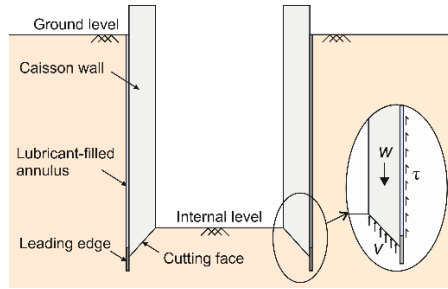
**Keywords:** Construction, caisson, monitoring, soil-structure interaction

## 1 Introduction

Monolithic reinforced concrete caissons have a large number of geotechnical applications. The construction process involves a complex system of concurrent casting of the concrete walls and excavation of the soil inside and beneath the caisson thereby allowing the caisson to sink into the ground under self-weight. Surprisingly, there is a paucity of literature on the design and performance of large-diameter caissons. Tomlinson (1986) and Nonveiller (1987) represent the earliest investigations into the sinking process. Case histories have been documented by Puller (2003), Safiullah (2005) and Abdrabbo and Gaaver (2012). More recently, the mechanisms associated with the sinking process have been explored using numerical simulations (Wang et al. 2014) and laboratory testing (Royston et al. 2016). This paper describes the challenges associated with the construction of large-diameter open caissons. A bespoke monitoring system was developed at University of Oxford to address these challenges and the impact of the monitoring system on a UK pilot project is described.

## 2 Design and construction challenges

The sinking stage of the construction process for large-diameter caissons involves subtle balancing between the downward weight of the caisson walls,  $w$ , and upward resistance generated from soil-structure interaction. The latter comprises bearing stresses,  $v$ , acting on the angled ‘cutting face’ at the base of the caisson, and frictional stresses,  $\tau$ , acting on the exterior surface of the caisson (see Fig. 1). A steel ‘leading edge’ is used to create an annulus surrounding the structure, which is filled with lubricant to limit friction build-up during the construction process. The development of frictional contact stresses is therefore dependent on (a) the (short- and long-term) stability of the lubricant-filled annulus, and (b) the effectiveness of the lubricant in minimizing friction in the event that the annulus collapses. An accurate estimation of these contact stresses is essential to optimize design (e.g. wall thickness) and reduce risk (e.g. failure to sink caisson). However, a rational and experimentally-verified procedure to measure, calculate or predict soil-structure contact stresses, and their development, along the soil-structure interface does not exist for this problem.



**Fig. 1.** Problem definition

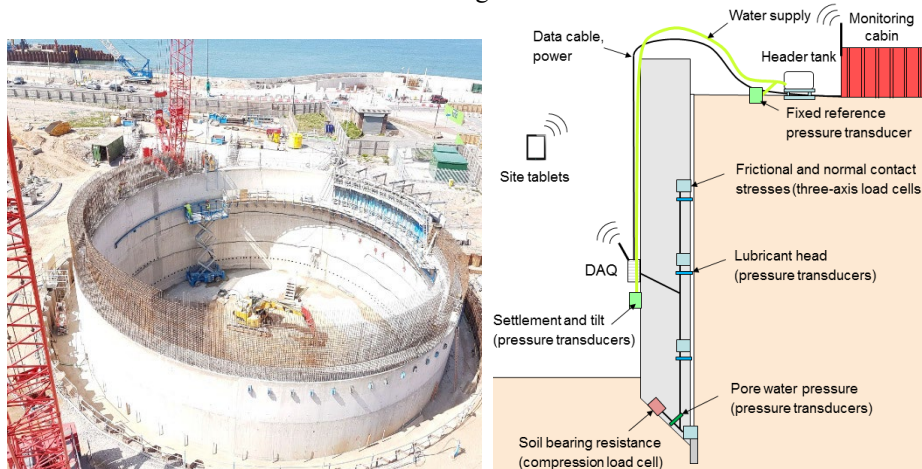
The caisson sinking process is mainly controlled through excavation of the ‘internal level’. Uniform excavation of the internal level is desirable to maintain verticality of the caisson. This is achieved by excavating different ‘sectors’ iteratively within the caisson. Alternatively, excavation can be focused in specific areas to re-correct tilts that have been induced by sudden drops in caisson elevation. A prerequisite for this process is timely feed-back of the caisson elevation / verticality. Traditionally, however, feed-back takes the form of manual surveys of the caisson resulting in infrequent feed-back which is also susceptible to human error.

## 3 Pilot monitoring system: Anchorsholme Park, UK

A caisson monitoring system was developed at University of Oxford to measure and monitor (a) the settlement and tilt of the caisson, (b) frictional and normal contact stresses that develop on the exterior face of the concrete walls, and (c) bearing pressures and pore water pressures that develop on the cutting face during the sinking process. The monitoring system was deployed on a live construction site at Anchorsholme Park,

UK (see Fig. 2). This project involved the construction of a 32 m internal diameter, 20 m deep reinforced concrete caisson in dense sand.

All instrumentation were cast directly into the concrete walls for protection against mechanical damage while the data acquisition system (DAQ) was located within an IP68 enclosure mounted on the caisson wall. The caisson level detection system comprised four pressure transducers (PTs) located at quarter points around the caisson circumference. These PTs were connected, via wire-reinforced hosing, to a header tank and a fixed reference PT at ground level (see Fig. 2). The header tank and hosing was filled with a mixture of de-aired water, anti-freeze and dye (the lattermost aided identification of air in the system). Pressure measurements relative to the fixed reference point outside the caisson enabled tilt and average elevation to be determined.



**Fig. 2.** Layout of pilot monitoring system at Anchorsholme Park, UK

Normal and frictional contact stresses on the external wall face were monitored using three-axis load cells fitted within bespoke waterproofed aluminium housings with a ‘sensing’ area of 100 mm × 100 mm. Lubricant pressures were monitored using PTs connected to open ‘ports’ in the wall. Measurements of the stress acting on the tapered cutting face beneath the caisson wall included the total bearing (normal) stress and the pore water pressure. An ‘S-type’ compression load cell was used to measure the total bearing stress. The load cell was fitted within a waterproofed aluminium housing with a 150 mm × 150 mm bearing area. The pore water pressure was measured using a PT fitted with a porous stone filter cap which had a high resistance to air entry.

A local wireless network was set up to provide real-time (1 Hz) feed-back of the live construction data to site engineers and operatives via tablets. Caisson tilts and elevation (accurate to < 1 mm) were provided directly to the excavator operators thereby eliminating the need for an otherwise dedicated site engineer for this purpose (see Fig. 3). Intermittent manual surveys were still conducted to verify accuracy. At formation level (i.e. end of sinking), the maximum tilt of the caisson was ~0.14°. Feedback of the frictional stresses and lubricant pressures on the external surface of the caisson were used

to monitor conditions in the annulus surrounding the caisson. Measurements of the lubricant pressures showed immediate decay after initial pumping into the annulus. This was due to filtration of the lubricant into the surrounding soil indicating an incorrect lubricant viscosity. Annulus closure can lead to a build-up of frictional stresses during the sinking process; the consequences of a failure of this type are enormous (caisson can become entirely wedged). Monitoring feedback was used to refine the viscosity to ensure lubricant pressure (and therefore annulus stability) was maintained. This was subsequently verified by the frictional contact stress measurements.

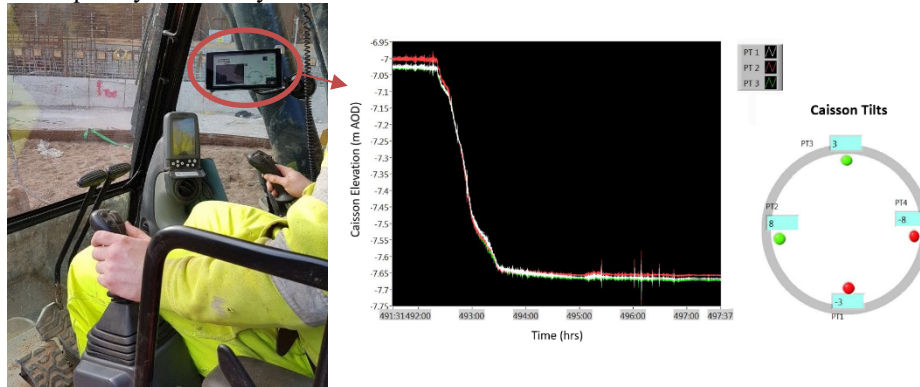


Fig. 3. Feed-back of caisson elevations via tablet in excavator

## 4 Conclusions

A bespoke monitoring system has been developed at University of Oxford to inform the construction of large-diameter caissons. For the pilot project considered here, the monitoring system had a significant impact on the economy and safety of the construction process. Additional developments underway include integration of wireless sensor networks, event-driven decision-making, and anomaly detection.

## References

- Abdrabbo, F. and Gaaver, K., 2012. Challenges and uncertainties relating to open caissons. *DFI Journal-The Journal of the Deep Foundations Institute*, 6(1), pp. 21-32.
- Nonveiller, E., 1987. Open caissons for deep foundations. *Journal of geotechnical engineering*, 113(5), pp. 424-439.
- Puller, M., 2003. Deep excavations: a practical manual. Thomas Telford.
- Royston, R., Phillips, B.M., Sheil, B.B. and Byrne, B., 2016. Bearing capacity beneath tapered blades of open dug caissons in sand. *Proceedings of CERI 2016 conference, Ireland*.
- Safiullah, A.M.M., 2005. Geotechnical problems of bridge construction in Bangladesh. *Japan-Bangladesh Joint Seminar on Advances in Bridge Engineering*. (Vol. 10, pp. 135-146).
- Tomlinson, M.J. 1986. *Foundation design and construction*. Harlow, Longman.
- Wang, J., Chai, L.S. and Wu, H., 2014. Numerical Simulation on the Sinking Process of Open Caisson with Particle Flow Code (PFC). *Advanced Materials Research*, pp. 831-834.