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# Monitoring the Construction of a Large Diameter Caisson in Clay

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## Abstract

Large diameter caissons are a common solution for creating attenuation and storage for foul and storm water. This paper describes the monitoring undertaken on a 13 m external diameter caisson at Sloway Lane (Bridgewater, UK). The caisson was formed using a 1 m thick in-situ reinforced concrete section, and sunk through soft clay (Blue Lias) to a mudstone formation 20 m below ground level. This paper considers the construction process, describing an instrumentation system on the caisson shaft, used to enhance understanding of caisson sinking in clay. An innovative levelling system was developed and deployed, measuring caisson movements to within 1 mm. Load cells were placed on the outside of the wall, measuring the soil-structure interaction during sinking. All measurements were processed in real-time and used to guide the construction process on site, via a tablet, in conjunction with wireless connectivity.

## 1 Introduction

In the UK, severe flooding, combined with growing population density, leads to increased demand for improved water and wastewater services, particularly in urban areas. Large diameter caissons have become a common solution for constructing storage and attenuation tanks. The most common means of constructing such caissons in the UK is by using segmental elements and hydraulic jacks as kentledge (Allenby et al., 2009).

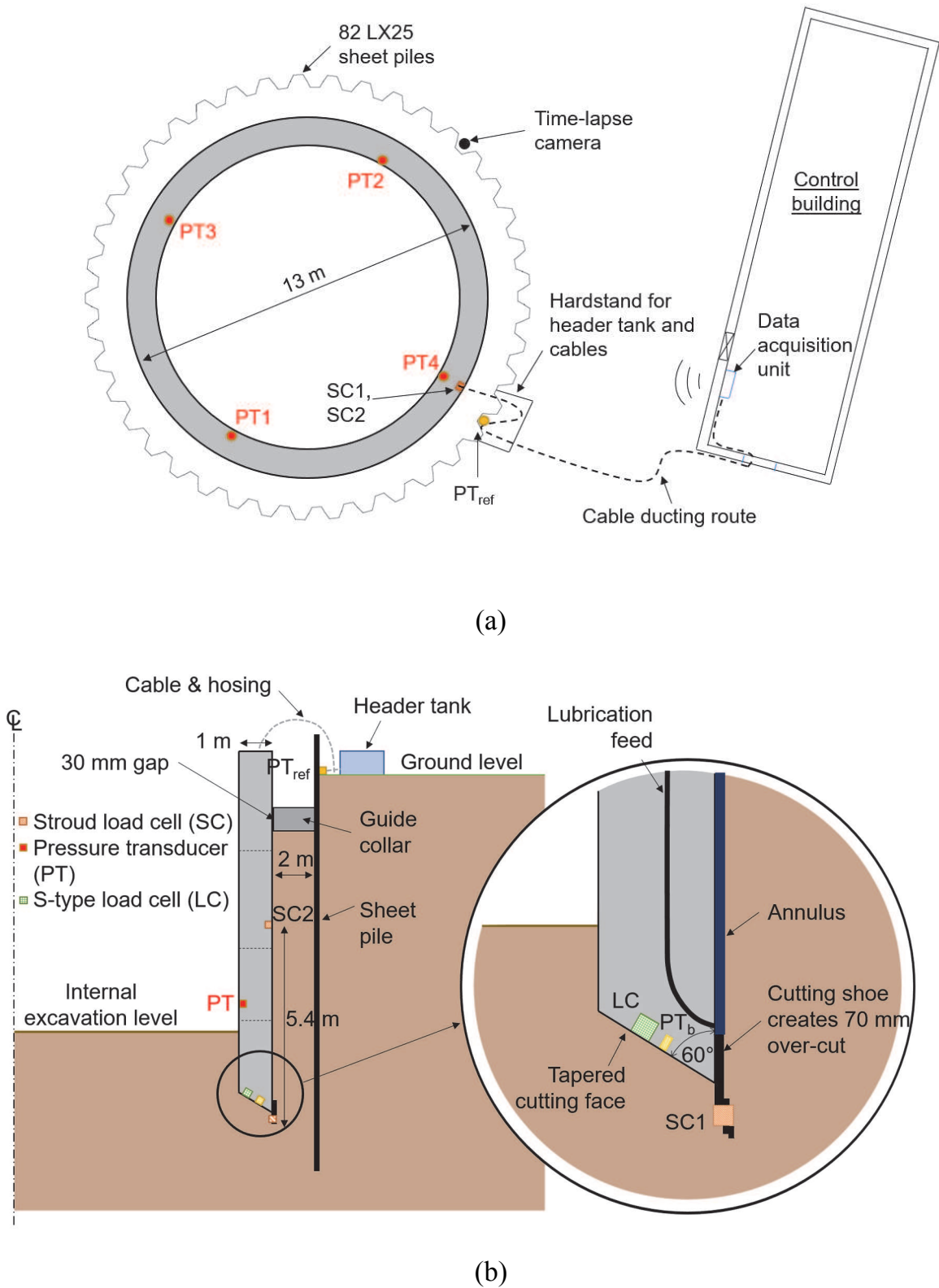
An alternative strategy of sinking caissons is to use in-situ reinforced concrete. The sinking process involves a subtle balancing between the resistance due to the soil-structure interaction (SSI) and the self-weight of the caisson walls. Accurate estimation of the interface friction is crucial to maintain controlled sinking: over-prediction leads to excessive and dangerous movements of the caisson; under-prediction could result in the caisson becoming wedged.

There is a lack of available literature concerning the SSI contact stresses that develop during the sinking process, in addition to the efficiency of the sinking process itself. Nonveiller (1987) identifies a sinking coefficient to characterise the sinking process, defined as the ratio of the total downward force (caisson self-weight) to the total upward resistance through SSI; a sinking coefficient  $>2$  is required for ‘safe sinking’.



**Fig. 1:** Sloway Lane caisson under construction

This paper describes the construction and monitoring of a 13 m external diameter, 20 m deep caisson installed at Sloway Lane, West Huntspill, UK (see Fig. 1). The caisson was constructed using a complex system of concurrent casting of 1 m thick concrete walls and excavation of the soil, both inside and beneath the caisson wall (Royston et al., 2016). A tapered edge ( $60^\circ$ ) is adopted at the base of the wall to provide control during caisson sinking, see Fig. 2. The self-weight of the concrete wall provides the kentledge for sinking the caisson. A 1 m thick wall was used to reduce the risk of reverse bearing during the internal excavation of the soft clay. The heavy wall allowed the caisson to sink into the ground, with the internal soil plug countering the external soil load. The caisson was founded 20 m below ground on firm mudstone strata.



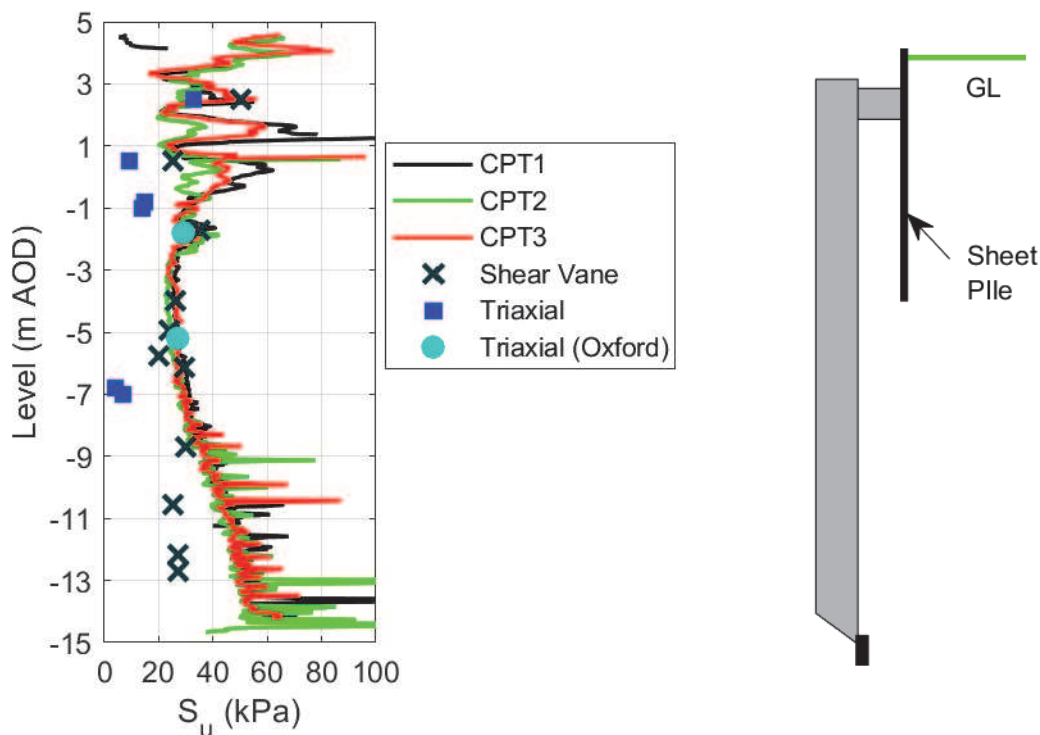
**Fig. 2:** (a) Plan of site layout, (b) Section through caisson

## 2 Monitoring Instrumentation and Installation

Measurements obtained during construction included settlement and tilt of the caisson, excavation level, and SSI contact stresses on the outer surface of the caisson. The aim of the monitoring system was two-fold: (i) to inform the construction process by providing real-time feedback to site engineers and operatives, and, (ii) to obtain a record of SSI contact stresses during the construction process, to form a basis for improved design methods.

Local geology comprises 20 m of soft normally-consolidated ‘Blue Lias’ clay, underlain by mudstone. Undrained shear strength,  $S_u$ , measurements determined from cone penetration tests (CPT,  $N_{kt} = 19$ ), hand shear vanes and triaxial tests are shown in Fig. 3. The newly constructed 13 m diameter caisson was located 8 m from the control building which houses a sewage treatment works and pumping systems (see Fig. 2).

The first two concrete wall pours, 2.4 m high each, were constructed within a circular cofferdam, 3 m below ground level on a concrete bearing pad. The bearing pad was subsequently broken out prior to caisson sinking. When the top of the caisson reached ground level additional pours were added, corresponding to 60 kPa of additional downward vertical pressure. A 1 m deep concrete guide collar was placed 3 m below ground level around the circumference of the caisson. This



**Fig. 3:** Site investigation

was constructed with a 30 mm gap, between caisson wall and guide collar, to maintain alignment during sinking.

The friction that develops, between the caisson wall and an undrained soil, can be high requiring large downward forces to sink the caisson. A technique for overcoming potentially high frictional stresses, originally patented by Ozerov (Ter-Galustov et al., 1966), involves creating an over-cut at the base of the caisson wall, with the subsequent void stabilised with bentonite. At Sloway the over-cut was created using a rolled steel cutting shoe, and the void filled by ‘TK60’ polymer (known to be more workable than bentonite).

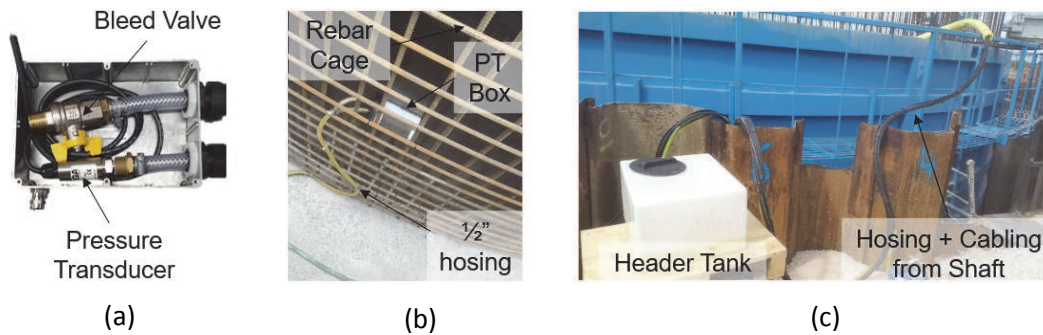
## 2.1 Level Detection System

The instrumentation installed on the caisson comprised a level detection system along with sophisticated load cells for measuring SSI during the caisson sinking process; see Fig. 2 for instrumentation layout. The load cells were designed for quick field deployment, to comply with the strict project timetable. Consequently, preparation time at site was minimised, with the installation of the instrumentation resulting in no time delays, or interference to the construction process. All cells and equipment were waterproofed to withstand severe environmental conditions. Cables were cast through the centre of the 1 m thick caisson wall to ground level, and brought to the control building through underground ducting. All sensors were continuously logged at a rate of 1 Hz and displayed wirelessly to the site team via a tablet (see Fig. 4).

The level detection system consists of four pressure transducers (Fig. 5) cast into the caisson wall at the quarter points (Fig. 2). All transducers,  $PT_1$  to  $PT_4$ , were linked by half inch wire reinforced hosing to a header tank and a fixed reference pressure transducer ( $PT_{ref}$ ) at ground level. The difference in pressure between  $PT_{ref}$  and  $PT_1$  to  $PT_4$  provides the level of the caisson at each location.



**Fig. 4:** Monitoring dashboard located in excavator during caisson sinking

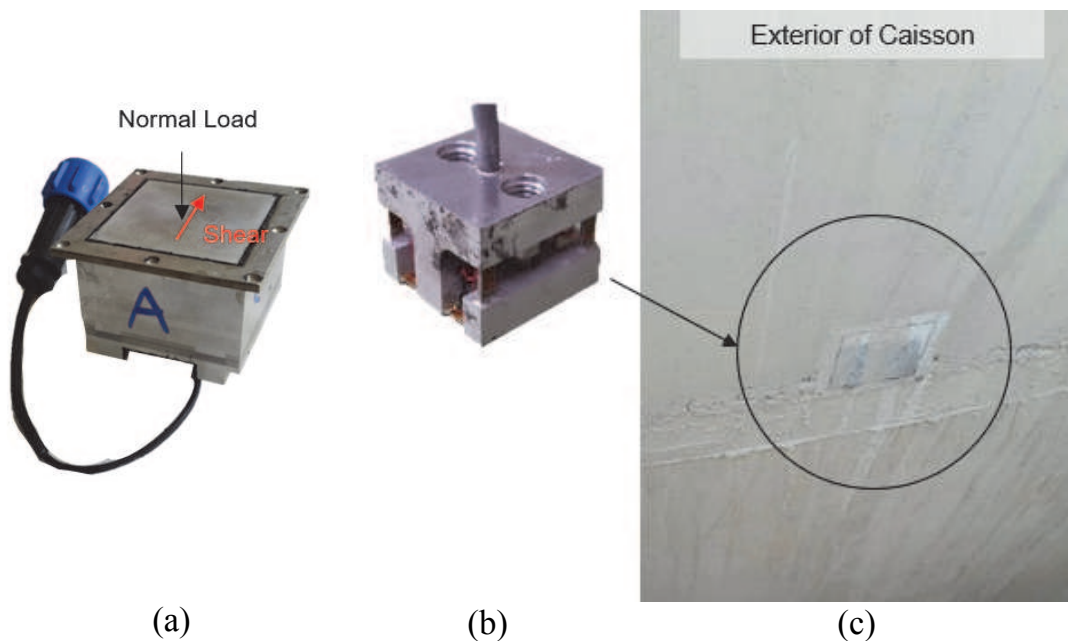


**Fig. 5:** Levelling system (a) PT housing, (b) Installation in wall pre-pour, (c) Header tank outside shaft

The pressure transducers were placed in an IP68 aluminium container, as shown in Fig. 5(a). A bleed valve was connected to the water line and placed in the enclosure beside the pressure transducer. This valve allowed the system to be de-aired (to ensure hydraulic conductivity); green dye was added to the water to aid identification of air in the system.

### 2.1.1 External Friction

External wall friction was monitored using a Cambridge type Stroud cell capable of measuring normal and shear stresses (Bransby, 1973). One load cell was placed in the cutting shoe. A second was placed 5.4 m above the leading cutting edge. The Stroud cell and its housing were cast into the caisson wall, as shown in Fig. 6.



**Fig. 6:** (a) Stroud Cell in custom housing, (b) Cambridge type Stroud cell, (c) Stroud cell housing cast in wall

The lower cell, SC2, measured the maximum friction, as it was in contact with the undisturbed ground during caisson sinking. The upper load cell, SC1, measured any residual stress developed between the caisson and the ground, given the creation of the over-cut. The cell housing was made from precision formed aluminium. Bearing plates were attached to the cell with silicone placed between the face and the housing (Fig. 6). An IP68 cable gland was placed at the back of the housing. The housing was filled with silicone grease to act as an additional barrier against hydraulic ingress.

## 3 Results

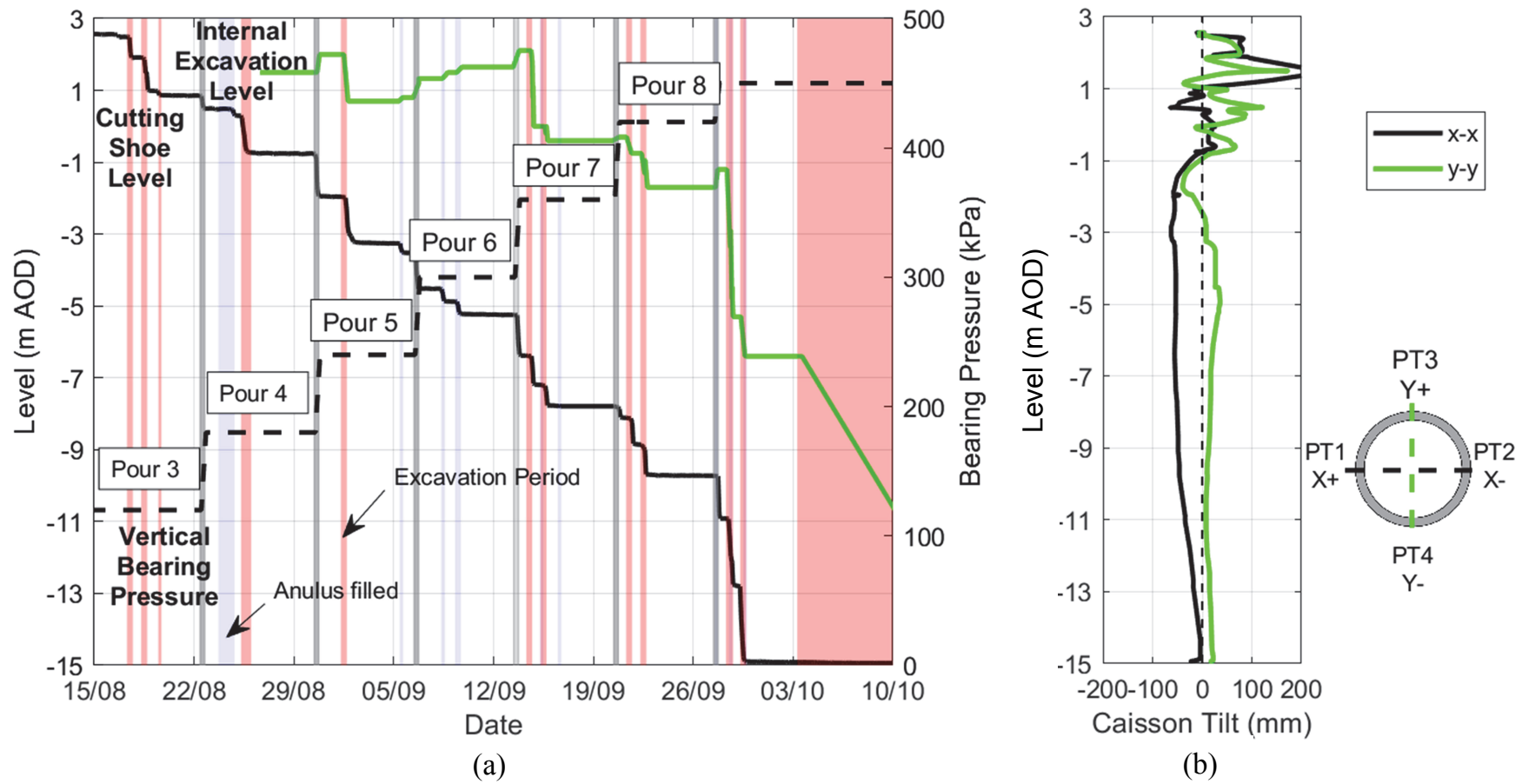
### 3.1 Caisson Movements

The movement of the caisson, and the actions that cause movement, is of interest during sinking. Fig. 7(a) displays the time history of caisson motion, showing vertical displacement, excavation level and downward vertical pressure applied from concrete pours. Caisson movement occurs as a result of three actions: (i) increasing caisson weight, (ii) internal excavation (pink), and (iii) pumping TK60 into the annulus (blue).

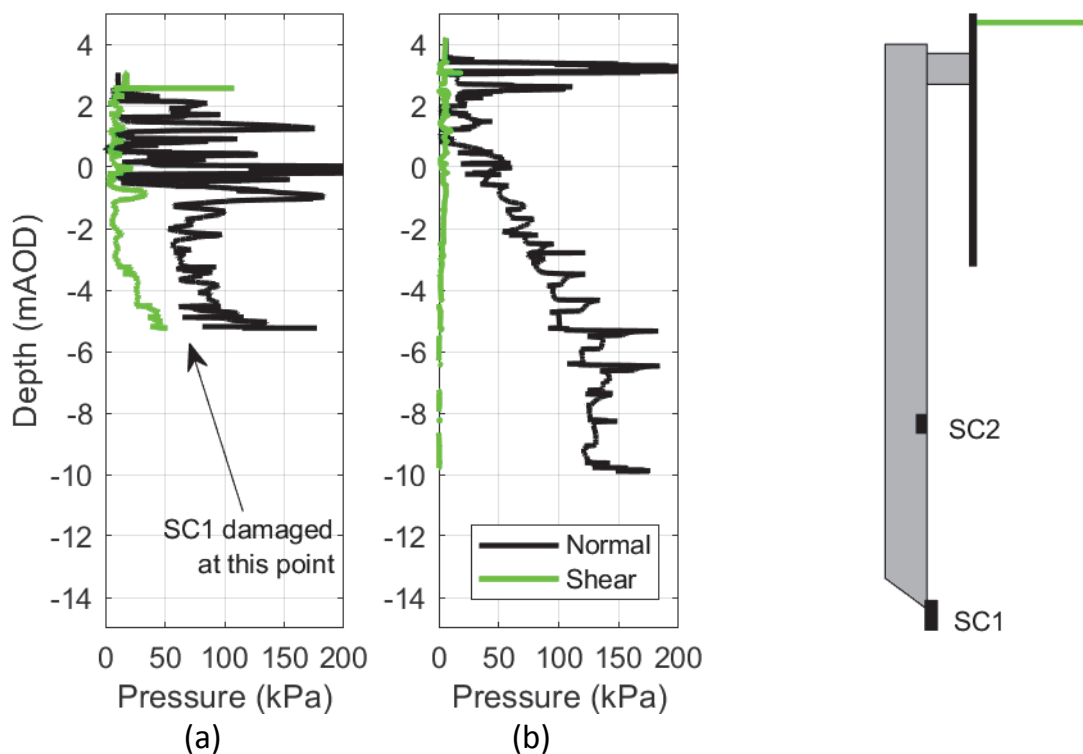
It can be seen that each wall pour results in a downward movement of the caisson. As the caisson moves downwards the internal soil heaves upwards for undrained conditions. The volume of soil displaced upwards is equal to the volume of the caisson wall which sinks into the ground. This was confirmed through the internal ground level measurements recorded before and after each pour.

From Fig. 7(a), a clear trend is noted; as additional pours are added the caisson penetrates further into the ground. The forces which resist the vertical load are: (i) bearing beneath the wall, (ii) internal overburden and, (iii) the internal and external friction between the wall and the soil. These forces move out of equilibrium when movement takes place.

Fig. 7(b) shows the difference in level across the caisson (i.e. “tilt”). This is vital information used by the site team for controlling the caisson sinking. A positive relative tilt value means the caisson is higher at that location. As the downward force increases and embedment becomes larger, tilting begins to reduce and fewer changes in direction are observed. The importance of vertical alignment at the beginning is highlighted by the larger tilting between 3 m AOD and -1 m AOD. As embedment increases the tilt becomes more difficult to correct, due to the soil inside the caisson. Each change in tilt corresponds to an action on the caisson. The caisson guide collar acts to maintain verticality of the caisson as sinking progresses.



**Fig. 7:** (a) Caisson and internal ground level movements, (b) Caisson tilting during sinking



**Fig. 8:** Normal and shear force at wall soil interface (a) SC1, (b) SC2

### 3.2 Soil-Caisson Interface Friction

The friction and normal stresses that develop on the caisson wall are shown in Fig. 8. The lower cell (SC1; Fig. 8), placed in the cutting edge and in contact with the clay, indicates the friction and normal pressure increase with depth. Unfortunately, this cell was damaged at -5.2 m AOD. The variations shown on SC1 are due to actions, such as pours and excavations, and the large tilts experienced at the beginning of sinking. The upper cell (SC2; Fig. 8) records minimal shear stress indicating no contact with the ground. The normal pressure on the cell corresponds to the pressure head from TK60 filling the annulus. These measurements confirm that the annulus remained open.

## 4 Concluding Remarks

This project focuses on design, construction and instrumentation of an open dug caisson in soft clay. The caisson was successfully installed in challenging ground conditions using in-situ reinforced concrete. This method uses the self-weight of the caisson to sink through the ground, with embedment of the caisson reducing risks such as internal heave of the soft clay. The following conclusions arise from the work;

- a) Each pour caused a large displacement of the caisson resulting in heave of the soil within the caisson. The soil forces resisting the caisson sinking are (i) bearing beneath the caisson wall, (ii) the soil overburden stresses, and (iii) wall friction
- b) Excavating inside the shaft resulted in caisson movement as the internal friction and the overburden load is reduced.
- c) The over-cut charged with fluid results in the annulus remaining open and no friction developing in soft clays.
- d) A complex monitoring system was successfully installed with no negative impact on construction activities. The system informed the site team of soil-structure interaction and caisson movements. Real-time information on caisson displacements was not previously available.
- e) The data obtained will contribute to the development of performance based design approaches and to further enhance the understanding so SSI on open dug caissons.

## Acknowledgements

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## References

- Allenby, D., Waley, G. & Kilburn, D. (2009)  
Examples of open caisson sinking in Scotland. *Proc. ICE-Geotech. Eng.* 162, 59–70.
- Bransby, P. L. (1973)  
Cambridge Contact Stress Transducers. Cambridge University, Department of Engineering.
- Nonveiller, E. (1987)  
Open caissons for deep foundations. *J. Geotech. Eng.* 113, 424–439.
- Royston, R., Phillips, B.M., Sheil, B.B. & Byrne, B.W. (2016)  
Bearing Capacity beneath tapered blades of open dug caisson in sand. Presented at the Civil Engineering Research in Ireland 2016.
- Ter-Galustov, S.A., Ponomarenko, A.I., Opershtein, V.L. & Ivanov, V.D. (1966)  
Experience in sinking an open caisson in a thixotropic lining. *Soil Mech. Found. Eng.* 3, 128–131.