13th Australia New Zealand Conference on Geomechanics – Acosta-Martínez & Lehane (Eds.)
© 2019 Australian Geomechanics Society, Sydney, Australia, ISBN 978-0-9946261-0-3

Geotechnical interfaces on Optus Stadium

K.L. Cook, S. McGinn & M. Straughton
Arup Pty Ltd, Perth, Australia

ABSTRACT: Large multidisciplinary projects require multiple stakeholders to perform in their area of expertise, but also interface with other stakeholders. The relationship between the parties is required to be managed through effective communication in a way that provides a safe, efficient and honest working environment; capitalizes on the cumulative benefit of diverse expertise and minimise project delays and cost overruns. The stadium provided an opportunity for stakeholders to work through geotechnical challenges arising primarily from uncontrolled fill and soft soil. The site conditions and construction methods led to challenges around controlling vertical and lateral ground movements. These were addressed collaboratively, particularly with regards to ground improvement and pile design and assessment. The paper provides insight into the complexity of interface management on large multidisciplinary projects.

1 INTRODUCTION

1.1 *Optus Stadium*

The 60,000 seat, multipurpose sporting and entertainment venue is constructed on the Burswood Peninsula, to the east of the Perth metropolitan central business district in Western Australia.

The stadium and sporting precinct encompass 45ha of parkland, bounded by a railway to the north, river and lake to the west, golf course to the south and roads and railway station to the east (Fig. 1).

The three tier stadium was founded on 2694 piles. The piles were 350mm and 400mm square reinforced precast concrete piles. Pile caps connected the piles to the stadium structure and supported a suspended slab. The piles were driven to founding level in the dense sand of the Kings Park Formation.

Construction of the sporting precinct surrounding the stadium necessitated forms of ground improvement to control short and long term settlement including concrete and reinforced concrete controlled modulus columns (CMCs); dynamic compaction, surcharging, and polystyrene fill in a variety of locations. Parts of the site were surcharged as an early works contract.

2 SITE CHARACTERISTICS

2.1 *Geological and geomorphological setting*

The Optus Stadium site is located in the Perth Basin, on the Burswood Peninsula. The elevation at the site is approximately + 5m AHD, with a gentle slope from east to west. A manmade lake exists to the west of the stadium.

The geological profile comprises several layers. The pile founding layer is the dense, sandy Kings Park Formation (KPF). Overlying this is the alluvial Sandy Channel Deposits, approximately 1 to 10m thick, unhelpfully titled as they contain both sand and clay in varying proportion. Overlying this is the Swan River Alluvium (SRA), varying between 0 and 25m in thickness. The SRA occurs in numerous paleochannels, the deepest of which occur in the south west of the site, near the Camfield brewery.

Figure 1. Optus Stadium during construction, looking east.

This is a dark grey silt and clay ranging from soft to firm, at depth. Key geotechnical parameters include an undrained shear strength in kPa of 15+1.5z, with z as meter depth of SRA and creep parameter, C_a, of 0.045 were adopted. Uncontrolled fill, composed of various materials up to 4m thick, has been placed over the SRA during refuse landfilling in the mid 20th century.

The potential for vertical and lateral ground movement in SRA, due to movements incurred due to construction activities and the natural ongoing consolidation and soft soil creep, posed significant challenges during the project.

2.2 *Groundwater*

The groundwater at the site is shallow, typically between 1-3m below ground level and varying up to 2m seasonally. The general groundwater gradient is to the west and south west, towards the river. The accelerated flow of groundwater into the Swan River as a result of construction activities was required to be minimised, due to the risk of contaminants within the uncontrolled fill layer.

2.3 *Site history*

The site occupies a peninsula to the east of the Perth. Prior to European settlement, the peninsula was a significant Aboriginal site. Following European settlement, the land was used for a variety of purposes including as tailings for over-river operations, rubbish tip and golf course.

The construction process began with site works across the stadium and precinct by an early works contractor. This process included ground improvement by means of surcharging with vertical drains as shown in Figure 2 and installation of ground monitoring instrumentation. This surcharging procedure was handed over to the main contractor in late 2014 (Fig. 2).

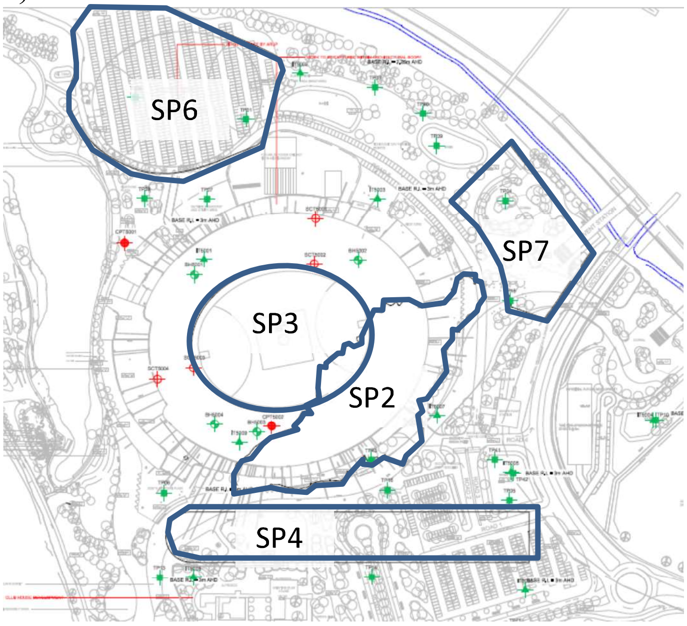

Figure 2. Site layout and early works surcharging (August 2014 layout), separable portions (SP) show the surcharge areas.

3 PROJECT ROLES

Numerous parties were involved during in the main construction period from October 2014 to December 2016. Optus Stadium was constructed as a Public Private Partnership (PPP) which involved the state government, Design Build Finance and Operate Consortium and the main contractor.

The geotechnical scope of work for the stadium was subdivided into roles as responsibilities as per the contractual agreements arranged by the main contractor.

The subcontracts listed show the main parties that were involved in geotechnical packages of work:

- Piling contractor (design and construct)
- Earthworks contractor
- Ground improvement contractor (design and construct)
- Instrumentation monitoring (install and monitor)
- Civil and building design services engineering consultancy

The State engaged an Independent Verifier to review and comment on the geotechnical engineering aspects of the project to provide additional validation that the technical solution proposed satisfied the project technical requirements, and minimised long term risk to the structure and precinct.

The additional parties that were involved in the geotechnical packages included parties providing input, comment or working from information provided by one of the parties, for example structural engineers, architect.

Due the complexity of the division of responsibilities, a part time geotechnical interface manager was required, with the role commencing in March 2015.

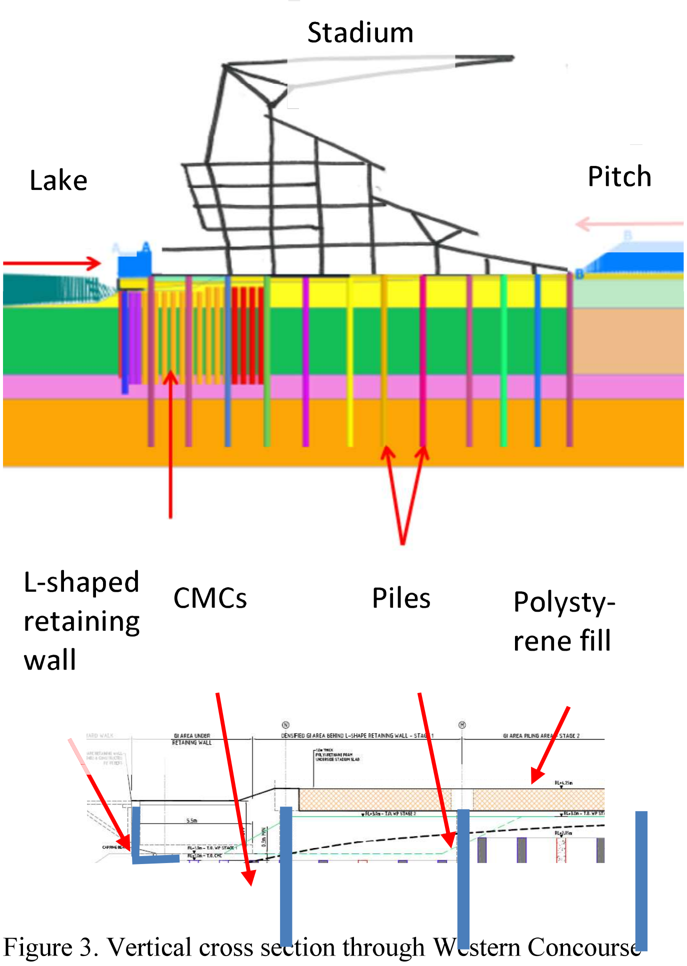

Figure 3. Vertical cross section through Western Concourse

4 INTERFACES

An interface is an overlapping concern for multiple parties. For example, this may be site investigation information, ground level, rig movements, foundation and structure details, actions on structures, assumed soil material properties or monitoring information. There were a large number of complex geotechnical interfaces on Optus Stadium, all space and time-dependent.

The first type of interfaces were predominately spatially-constrained, e.g. various construction activities in a small area. Numerous interfaces occurred in the Western Concourse, near the lake side of the stadium. Within this area, the boardwalk; retaining wall; ground improvement works; piling works; sub-structure construction; landscaping and fixtures all needed to be designed and constructed (Fig. 3), in a short timeframe to meet the project deadline. While this was one of the most geotechnically complex regions of the site, the original construction programme involved the early construction of the Western Concourse as site access was from the east, meaning construction of the stadium was preferred to progress from west to east. Due to competing project construction requirements, the construction of this area needed to be re-programmed, resulting in multiple workfronts taking place with suboptimal spatial and time intervals to allow ground movements to take place. A re-programme, however, allowed pre-cast piles to be installed after CMCs and the retaining wall.

To validate that the vibrations from pile installation and the CMC installation method did not compromise the long term performance of the CMCs, a representative portion of the CMCs were static load tested.

Permissible deformation performance criteria had been determined for different areas around the site, and included total vertical settlement, vertical differential settlement and total horizontal deflection. The geotechnical performance criteria are shown in Table 1 and Figure 4. At the edge of geographical boundaries, there may be interfaces between two areas which have differing performance criteria. The criteria must be agreed between parties.

For example, the location where there was a transition from improved ground to the piled area for the stadium required a relieving slab to minimise differential settlement and reduce the risk of a step and trip hazard forming over time. Steps had been observed at the golf club house, and anecdotally at Burswood Dome. Information had to be shared between the slab designer and ground improvement contractor as to the estimated settlement over time.

Spatial interfaces include situations that were temporary and isolated. An example is where CMC installation was conducted near a high voltage (HV) cable. Resulting ground movement from CMC installation posed a risk to cable damage. This risk was mitigated by exposing the cable and using expansion loops, such that any movement during CMC installation would not tension the HV cable.

Another example was the exclusion of parts of the site for a longer period of time. This restricted when work could start and stop in certain areas and limited access for plant and equipment. E.g. the Northern part of the site was used as a nursery for plants.

There were spatial constraints outside of the site boundaries, which were subject to different criteria. For example, Perth Transport Authority (PTA) had settlement performance criteria adjacent to and for railways, applicable to the north of the stadium.

This spatial boundary also extended vertically through the soil and up to the top of the structure (overhead working due to the outward-sloping façade was a constraint for rig movements).

There were also interfaces that were predominately a function of time, due to the sequential nature of construction and time-dependency of soil properties.

The sequential nature of construction is outlined in the Western Concourse example above. Each construction activity caused ground movements and actions that impacted the subsequent activities. Raising the ground level to install the piles and the stadium ground floor slab caused vertical and lateral displacement of soil. CMC installation caused lateral (predominately) displacement of the soil. Following CMC installation, the L-shaped retaining wall was constructed after part of this movement had taken place and had to accommodate any residual movement. After the retaining wall was installed, piles were installed, which had to accommodate all residual movements from earlier construction phases. Changes to the sequence and/or timing of these activities would have resulted in different actions on the various elements to be allowed for in their design.

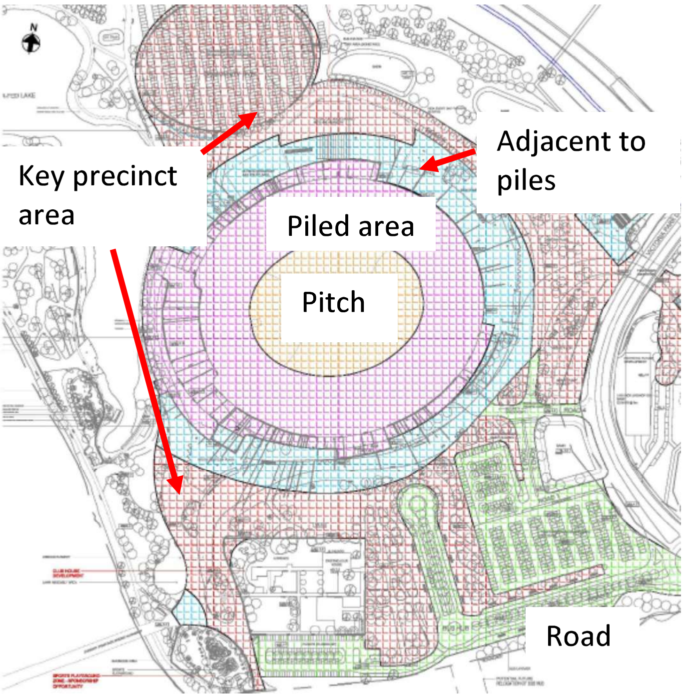

Figure 4. Site layout and geotechnical performance criteria zones (August 2014 layout).

Table 1. Geotechnical performance criteria (abridged)

Area	Max Post Construction Vertical Settlement mm	Max Post Construction Horizontal Movement mm	Max Differential Settlement
Pitch	100	50	1:250
Piled area	N/A	300	N/A
Adjacent to piles	300	50	1:100
Road	300	150	1:100
Key precinct area	300	150	1:100

Soil behaviour changes with time and loading, particularly in material such as SRA. An example is vertical soil displacement over time as a result of a surcharge load; a combination of immediate settlement, consolidation settlement and creep. As only parts of the site were surcharged, there was additional length of surcharge toe and lateral displacements occurred near the toe of the surcharge. Due to the compressible nature of the SRA and variability of in situ fill, adding fill to raise levels, thereby adding surcharge, was minimized where possible to control long term vertical and lateral settlements. One mitigation to control long term settlements included the installation of polystyrene fill beneath the stadium ground floor slab.

Another geotechnical interface existed between structural elements within the ground, e.g. pile and pile cap. Often these elements are designed and constructed by differing parties, such that materials, construction and operating displacement tolerances and actions all need to be communicated. For example, verticality limitations of the driven pile installation procedure needed to be clearly understood when designing for driven piles through steel sleeves. If there is time delay in construction and another process causes lateral movement of the pile or sleeve (or CMC), this could affect driveability due to misalignment and/or slab connection.

There are also interfaces where decisions have a large effect on the whole system, for example time, space, loading and land usage. An example of this an increase to ground levels, which subsequently influences loading, drainage, services and ground improvement. Figure 6 shows changes in levels between two key precinct layout revisions. Another is variation of the designated usage of the land, for example installation (or not) of a pool, movement of the pedestrian landing for the Matagarup Bridge and reorientation of the bus hub.

Figure 5. Concurrent activities on site, this picture shows 4 concrete trucks, 2 CMC rigs, auger rig and low loader truck.

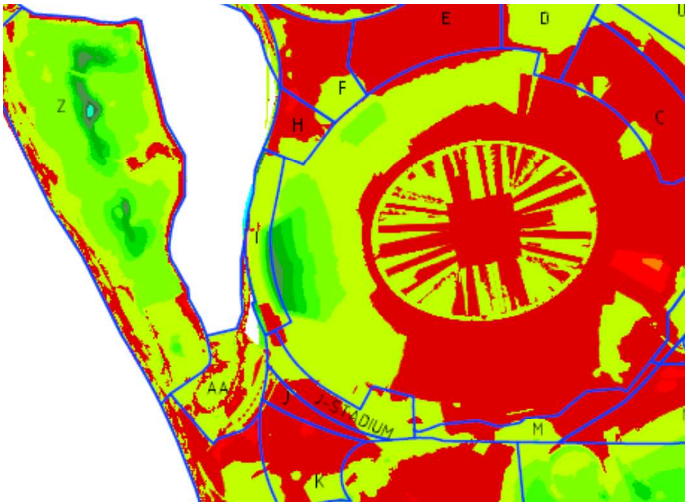

Figure 6. Example of the change in in ground levels between two revisions of design precinct layout, dark red is 0m, dark green is +3.5m

Key interfaces for geotechnical design and analysis includes adequate description and properties of soil layers, consolidation history, material parameters, construction staging, loading and tolerances, some of which formed assumptions in analysis for the various designers. Where possible, these assumptions were agreed and documented, often in the form of shared analysis inputs, processing and results. Any new learnings and information, including monitoring data, were shared amongst the project team. This was balanced by the understanding that in some cases, the requirements for the designers differed, which could lead to the use of assumptions that best fit the designer's specific scenario being modelled.

With construction being a dynamic activity, it is essential that the interface manager has detailed technical knowledge in order to be able to assess information and evaluate impacts if and when the situation changes.

As each party has a separate but integrated responsibility on the project, appropriate communication tools were required to achieve the best project outcomes. These are discussed in the section below.

5 INTERFACE MANAGEMENT

Interface management is the process whereby overlapping interests and concerns of parties are identified, planned and agreed. Information between parties is be communicated and controlled, accurately and efficiently.

Within this project, the following framed the interface management process: roles and responsibilities, communication protocols, reporting requirements, conflict resolution and timeliness.

The interface management objectives were addressed through face to face workshops between multiple parties, regular and ad-hoc meetings, phone calls and teleconferences, emails, request for information(RFI) register, communication database Aconex as well as email filing, BIM (and other) models, formal and informal written reports, sketches, drawings workflow processes (separate to Aconex), datasets, co-location of staff and handovers.

The RFI register was the main tool for recording communications and agreements between parties. During the most complex phase of design, it was circulated weekly as a record of agreement information, capturing changes during the week. Over a four month period, due to the complexity of the ground conditions and staging sequences, there were almost 1000 items including queries, actions and comments that required closing out. It formed a tool for tracking progress amongst the multiple contractors and prioritizing actions.

When an interface required further discussion, teleconferences between multiple parties were arranged. In some cases, large workshops were convened where parties presented on their topic and technical matters were agreed. This process allowed face to face discussion and promoted faster agreement and fostered an environment of collaboration where expertise and diversity of thought could be brought to resolve complex inter-dependent problems.

In highly complicated interfaces, staff co-located into another party's office to minimise the barriers to effective communication and provide maximum cost, time and quality efficiencies. To maintain responsibility in terms of who owns and developed the information, this output of the co-location process was recorded in a formal report at the completion.

Another tool in highly complex interfaces was the use of workflows, represented in Gantt charts, flow diagrams or sketches (Fig. 8), for information transmittal. This was particularly useful in the case of pile design in the Western Concourse, due to close proximity of piles and CMCs (Fig. 9) and where pile ordering was occurring in parallel with design to expedite construction.

6 RECOMMENDATIONS

Interfaces on construction projects constantly change in reaction to both planned and unplanned events and are both time and space-dependent. Responsibility needs to reside clearly with one single, overarching party that understands technical and contractual matters from start to finish. As each party brings their unique skills and experience, the best project outcomes arise from the cumulative experience of all parties. This is achieved through collaboration and effective interface management.

The following technical observations in relation to interface management were specifically observed with relation to geotechnical components.

Total deflection criteria are not always the most effective manner to transfer and communicate information regarding actions on structural elements arising from lateral ground movements. In this case, it would have been more effective to place deflection criteria on differential lateral deflections. This correlates directly to the shear force and moment that would be experienced by the structural members such as piles embedded in a slow-moving soil continuum. For example, a lateral ground movement of 50mm applied uniformly to a pile, would not impose any moment or shear force to an unconnected pile. The depth and displacement profile at which imposed movements are applied greatly influence the imposed shears and moments in a pile.

Early agreement of key assumptions and the sensitivity on the performance of structural and geotechnical systems is critical. On a soft soil site, agreement of input parameters relating to soil settlement and creep minimizes the discrepancies between the design assumptions of multiple parties. Back analysis of the ground monitoring data from early works surcharging led to insight on soil parameters. Overarching responsibility of a single party assists in agreement of assumptions, in the case of multiple designers.

Timing of construction is critical in geotechnical design and analysis. Communication of a construction sequence and input from geotechnical professionals into the planning of this schedule can provide opportunities to implement design solutions that can save time and cost.

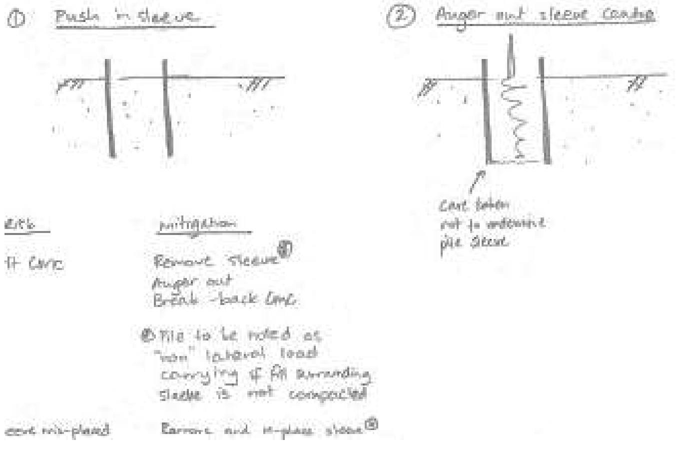

Figure 8. Example part of workflow of construction sequence for piled sleeve in Western Concourse.

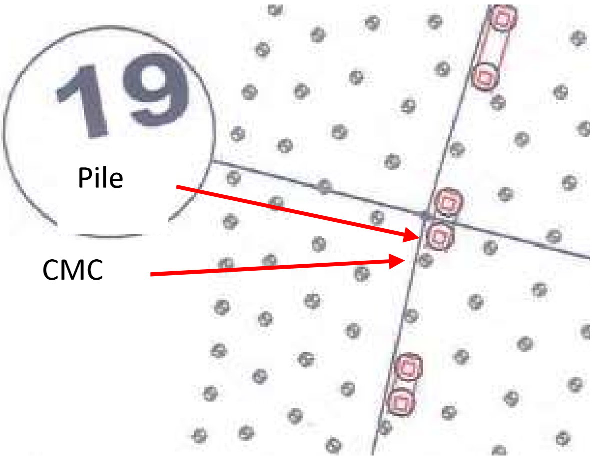

Figure 9. Example of layout of piles and CMCs in the Western Concourse.

Digital systems are only as useful as the number of people that understand how to use them, the accuracy of the information they contain and speed at which it can be accessed and disseminated. Aconex was excellent for record keeping, but cumbersome due to due to the time required to add new users and navigate the system. Repetition of information in Aconex for recording keeping purposes (e.g. a summary Aconex of multiple emails discussing design inputs, for example) was inefficient as a process. The BIM model for collation of information was not able to be easily used on site as it was not envisaged to be used for this purpose from the outset. Paper drawings were more efficient and agile. In addition, some of the geotechnical software was not easily accessible to all parties. The level of comprehension with the software, inputs, processes and outputs, varied. The level of interoperability of the digital tools was not conducive to their use in a robust workflow. Therefore, work-arounds were needed.

The following assisted with the success of this project from a more generic interface management perspective: appropriate procurement strategy, recognition of the importance of interface management; qualified and informed decision makers; continuity of staff and a positive team culture that aligns behaviours towards successful project outcomes.

- Consider procurement strategies and division of responsibilities at the start of projects. This could assist in clarification of roles, risk allocation and interface responsibilities and minimise time to clarify responsibility when scope variations arise.
- Identifying early the requirement for interface management and rigorous information control. This sped up the design and construction process as information was easily attainable.

- Appointing those that have appropriate and relevant technical and contractual experience. In complex projects where decisions have irreversible consequences, it is important that decision makers have appropriate skills to understand both geotechnical opportunities and risk and cost, time and quality implications.
- Keep key people involved and informed, particularly when things do not go to plan. Informed people can contribute to the solution. Co-locate staff where possible.

  Optus Stadium project team had an extraordinarily high staff retention, which maximized information retention, fostered working relationships and led to a collaborative problem-solving and opportunity-identifying culture.
- Minimise the “us vs them” culture. Incentivise parties to work together, e.g. through large group workshops, multiple party milestone targets.

7 CONCLUSIONS

Interfaces are constantly changing, as they are time and space dependent. Responsibility needs to be clearly with one single, overarching party that understand technical and contractual matters and from start to finish. As each party brings their unique skills and experience, the best project outcomes arise from the cumulative experience of all parties.

In the case of the Optus Stadium, this was achieved through collaboration and coordinated interface management, with efficient and technically robust solutions, involving specialist geotechnical expertise and use of advanced soft-soil and soil-structure analytical techniques. The combination of engineering excellence and practical, cost-effective construction management resulted in solutions which were best for the project, and facilitated delivery ahead of programme.

8 ACKNOWLEDGEMENTS

We would like to gratefully acknowledge the contributions of a wide range of people both in the development of this paper and support during this project. First and foremost to our families, for always being there.

The State government, in particular Bill Bell and Multiplex, in particular Tim Perry, Marco Neves, Ged Gallagher and Denis Crowley for the excellent working relationship and the opportunity to publish. State government reviewers, Eric Hudson-Smith and Doug Stewart. The subcontractors and subconsultants for their working relationship and endeavour to collaborate on the challenging site, GFWAMB, Wagstaff, BG&E, CMW, Aurora and Hassell, Cox Architecture and HKS. The geotechnical and building teams at Arup for all their hard work and effort, there are too many people to mention by name.

The whole project team worked tirelessly to get the project over the line.