Fingerboards mineral sands mine project: Expert Witness Statement (use of centrifuges)

Expert witness statement prepared by:
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CONTENTS

1. SUMMARY

1. I have given consideration to the use of centrifuges as a potential technical solution to avoid the need for tailings storage facilities at the proposed Fingerboards Mineral Sands Project. It is my opinion that:
   - Centrifuges are suited to dewatering mine tailings, but have not yet been proven on the use of mineral sands tailings.
   - Further demonstration is needed to provide adequate certainty that centrifuges represent a suitable technical alternative to tailings storage facilities at the Fingerboards site.
   - An acceptable alternative option be identified in the event that centrifuges prove to be unworkable at the Fingerboards site.
   - Further clarification is required on the safety aspects of the centrifuge is warranted, with respect to the level of containment provided by the centrifuge in the case of a failure of the mechanical parts, and also to the control of the centrifuge.
   - The proposed site location for the centrifuges should not be affected by mining operations at the relative distances between the centrifuge plant and the mining operations indicated in the Environmental Effects Statement.
   - The detailed engineering design should consider other sources of potential ground movement, and quantification of any resulting foundation settlement be considered from the perspective of safe and efficient operation of the centrifuge.

2. INTRODUCTION

2. I was requested by Environmental Justice Australia on 2 March 2021 (see Appendix B) to provide an expert witness statement on the use of geotechnical centrifuge modelling aspects of the proposed Fingerboards Mineral Sands Mine Project in Glenaladale, Victoria.

3. In this section I outline my particular areas of expertise and experience and note the instructions set out by Environmental Justice Australia.

2.1. Expert's qualifications, experience and expertise

4. My qualifications, experience and expertise are detailed in my CV (Appendix A). In brief, these include:
   - 1st Class Honours Degree in Civil Engineering from The Queen's University of Belfast in Northern Ireland (1997) and PhD Degree in Geotechnical Engineering from Trinity College Dublin in Ireland (2002).
   - 17 years working as an academic in geotechnical engineering, currently as an Associate Professor in the Centre for Offshore Foundation Systems within the Oceans Graduate School at The University of Western Australia (from 2012).
   - Research funding of $29.5M (~$3.8M as sole or lead investigator), $23.9M in competitive research grants and $5.6M in industry-sponsored research.
   - Over 150 publications (70 journal papers, 80 conference papers), mainly on offshore geotechnical engineering and reporting data from geotechnical centrifuge modelling studies. These papers have been cited more than 2,000 times.
   - 44 reports for industry projects, mainly centrifuge modelling studies for offshore geotechnical designs.
   - Director of the National Geotechnical Centrifuge Facility (www.ngcf.edu.au), the only geotechnical centrifuge facility in Australia, and the largest and busiest geotechnical centrifuge modelling facility in the world.
   - Commissioned geotechnical centrifuges in Ireland and Australia.
   - Chair of the Editorial Board of the International Journal of Physical Modelling in Geotechnics (Institute of Civil Engineers, UK), the only journal dedicated to single gravity and centrifuge modelling in geotechnics.
   - International member of the Scientific and Technology Committee of the Centrifugal Hypergravity and Interdisciplinary Experiment Facility (CHIEF), Zhejiang University, China.

5. My particular expertise relevant to this project is geotechnical centrifuge modelling.

2.2. Instructions

6. Environmental Justice Australia, acting on behalf of Submitter 813, sought my expert opinion on the use of centrifuges in the proposed Fingerboards Mineral Sands Mine Project on 2 March 2021. In particular, the request was for my opinion on:

    a. The appropriateness of the methods, including modelling, to evaluate the technical feasibility of the implementation of centrifuges as proposed.
    b. Whether the actual or likely risks arising from the use of centrifuges are identified and or appropriately assessed in terms of their level of risk.
    c. The appropriateness of the site selection for the centrifuges as proposed.
    d. Any other matters you identify which you consider relevant within the limits of your expertise, including any limitations of the geotechnical centrifuge modelling aspects of the EES.
    e. Any appropriate qualifications or conditions that should be attached to findings or conclusions, such as uncertainties or gravity of threats or impacts.

7. I have reviewed the Guide to Expert Evidence provided by Planning Panels Victoria and declare that I have made all the inquiries that I believe are desirable and appropriate and no matters of significance which I regard as relevant have to my knowledge been withheld from the Panel.

3. REVIEW OF DOCUMENTS

8. The documents that I have reviewed include those related to the use of centrifuges in the proposed Fingerboards Mineral Sands Mine Project (listed below) and various other journal and conference publications on the use of centrifuges in mining operations (listed in the references).

9. Fingerboards Mineral Sands Mine Project documents:

    a. Letter to the IAC from Kalbar dated 18 January 2021.
    b. Technical Note 01 'Implementation of centrifuges for water recovery and tailings management' dated 18 January 2021.
    c. Updated EES Chapter 3: Project Description dated 8 February 2021.
    d. Expert Witness Statement of Ivan Saracik dated 8 February 2021.

10. My expert opinion is presented in Section 4.

4. EXPERT OPINION

11. My expert opinion is expressed across two sections. The first (Section 4.1) sets out my opinion on the technical feasibility of the use of centrifuges for dewatering mineral sands tailings at the proposed Fingerboards Mineral Sands Mine Site. The second (Section 4.2) sets out my opinion on potential risks arising from the use of centrifuges at the proposed Fingerboards Mineral Sands Mine Site. I have noted instances where I disagree (either provisionally or in entirety) with statements in the documents listed in Section 3 and have identified aspects that I believe require further consideration and clarification.

4.1. Technical feasibility

12. Centrifuges are used mainly in separation industries, including food and beverage processing, pharmaceutical manufacturing and PVC production. They are also used in geotechnical research and commercial modelling studies, and in other areas where high centripetal accelerations are required.

13. In the context of mining industries, centrifuges have been proposed as an alternative to tailings storage facilities. There are numerous academic publications that discuss this concept and report results from laboratory and field scale studies (e.g. Mikula et al. 2009a; Mikula et al. 2009b; Nguyen et al. 2021).

14. The Nalco Test Report dated 5 May 2015 also report on the commercial use of Alpha Laval centrifuges in tailing management. The table from that report is reproduced here as Table 1, and includes 49 Alpha Laval centrifuges (up to the time of writing, 2015) installed at various mine sites mainly in Australia, Canada and Turkey. It is worth noting that the experience summarised in Table 1 relates to mining of oil sands, coal, nickel and borax, but do not include mineral sands. A review of the literature did not reveal any further experience in mineral sands mine sites. As such, I was unable to uncover any evidence of the application of centrifuges in managing tailings in a commercial mineral sands project.

15. In the context of mine tailings, the intent is to separate the solid and liquid portions of the tailings, such that the solid part can be returned to the mine voids. The conventional technique to achieve this is through the use of tailings storage facilities, where the tailings (often with added flocculent) are allowed to settle over time. The solid particles in the tailings are denser than the liquid and will fall vertically at a velocity that is a function of the density of the particles and the liquid in the tailings slurry, the viscosity of the liquid, the mean particle size of the solids and the acceleration (Stoke's law). In a settling pond the acceleration is that due to Earth's gravity, whereas in a centrifuge the acceleration is the centripetal acceleration caused by rotating the slurry (within a bowl) at high speeds. The acceleration level in the centrifuge is higher than that due to Earth's gravity by a factor that is a function of the radius of the centrifuge and the speed of rotation. For example, a 1 m diameter bowl centrifuge rotating at 1000 rpm would create a centripetal acceleration at the

circumference of the bowl that is approximately 560 times higher than Earth's gravity. The implication of this is that the solid particles in the slurry will settle (or separate from the free fluid) at a velocity that is approximately 560 times higher than it would be in a settling pond. This is the same principle that geotechnical centrifuge modellers use when they consolidate a soil sample from a slurry in a geotechnical centrifuge. In such a scenario the centrifuge is likely to have a much higher diameter (e.g. the two beam centrifuges at the NGCF in UWA have diameters of 3.6 m and 10.0 m) but would rotate at much lower speeds, such that the centripetal accelerations are typically no higher than around 200 times that due to Earth's gravity.

16. Hence, there is sufficient evidence that persuades me to agree with the claims made in Technical Note 01 'Implementation of centrifuges for water recovery and tailings management', supported by expert witness Ivan Saracik, that centrifuges present a potential technical solution to the problem of dewatering mineral sands mine tailings that avoids the need for tailings storage facilities. The only caveat to this is the lack of performance certainty in a commercial setting as described in the following.

17. However, as centrifuges have not yet been used for mineral sands tailings, some uncertainty remains on their performance and suitability for the proposed Fingerboards Mineral Sands Mine Project. An attempt to address this has been made by Alfa Laval through a laboratory scale pilot study that used tailings from the Fingerboards site (Laboratory Spin Test Report – Mineral Sands Slimes Tailings Dewatering test for Decanter Centrifuge, Rev A, dated 8 October, 2018). The study increased the moisture content of the slurry to a level that was deemed (by those that undertook the study) suitable for centrifugation. Results and photographs presented in that report show that spinning the slurry in a centrifuge produced a solid material that was between about 57 and 72 % suspended solids (depending on the centrifuge acceleration level adopted). The quality of the separated fluid (centrate) was not reported. Whilst I am encouraged by these findings, there was insufficient detail in the report for me to understand the processes adopted and how in turn that might differ from a field scale operation. For instance, the report does not include details on the centrifuge used, whether it is a scaled down replica of a commercial Alfa Laval centrifuge used in mining operations, the feed rate used etc. Furthermore, the study considered a single sample from the Fingerboards site, whereas testing a number of similar and dissimilar samples (e.g. with a different particle size distribution) from the site would have provided more certainty as to the suitability of the tailings from the Fingerboards site for dewatering through centrifugation. These details are undoubtedly available and should be made available such that relevant experts can form an opinion on whether this laboratory study sufficiently addresses the uncertainty created by the absence of prior commercial experience with mineral sands.

18. This of course is a chicken-and-egg scenario, as the experience cannot be gained without an operating mine site. References to "Results and previous installations/ trials on similar slurries" is made in the Alfa Laval study (Laboratory Spin Test Report – Mineral Sands Slimes Tailings Dewatering test for Decanter Centrifuge, Rev

A, dated 8 October, 2018). It would be beneficial if further details from those trials were made available, as this may allay the uncertainty that currently exists, provided that the trials are on comparable tailings. Should this option not be available, there are two other pragmatic options that could be pursued:

a. Seek the opinion of a tailings expert to understand potential differences between mineral sands tailings and (for example) oil sands or coal tailings (as centrifuges have been used in the management of oil sands and coal tailings). If at a material level the tailings behave in a similar manner, this would further point to their suitability for centrifugation. If however, their material characteristics and/or behaviour changes when agitated (e.g. Meiring, 2015) this may render them unsuitable for centrifugation. As my expertise does not include tailings behaviour I cannot comment further on this.
b. Conduct a pilot trial at an existing mineral sands mine site. This appears to be an option offered by Alfa Laval to potential customers. Obtaining performance data from an operating mineral sands site would reduce the uncertainty to (in my opinion) an acceptable level. This could be conducted at an existing site operated by Kalbar, or through a collaboration with a different mine site operator, which would not only benefit the proposed Fingerboards Mineral Sands Mine Project, but the industry more broadly.

19. If neither of the two above (or acceptable alternative) options are pursued and the project proceeds, raises the question: "*what are the alternative options should the centrifuge option prove to be unworkable, either from a technical or operating efficiency perspective, and would these alternative options have been considered acceptable at the planning stage?*"

4.2. Potential risks

20. The Alfa Laval centrifuge typically used for mine tailings management is a decanter centrifuge (see Figure 1). The principle of the decanter (or solid bowl) centrifuge is shown in Figure 2. Slurry is fed into the centrifuge through a feed chamber into the spinning rotor. The centripetal acceleration caused by the rotor rotation causes the solid portion of the slurry to settle on the inside wall of the rotor. A scroll that rotates within the rotor at a different speed that the rotor moves the accumulated solids to the solids discharge port. The taper towards the solids discharge end ensures that the separated liquid does not discharge with the solids, but discharges at the liquid discharge port located at the opposite end of the centrifuge.

Figure 1. The Alpha Laval P3 decanter centrifuge

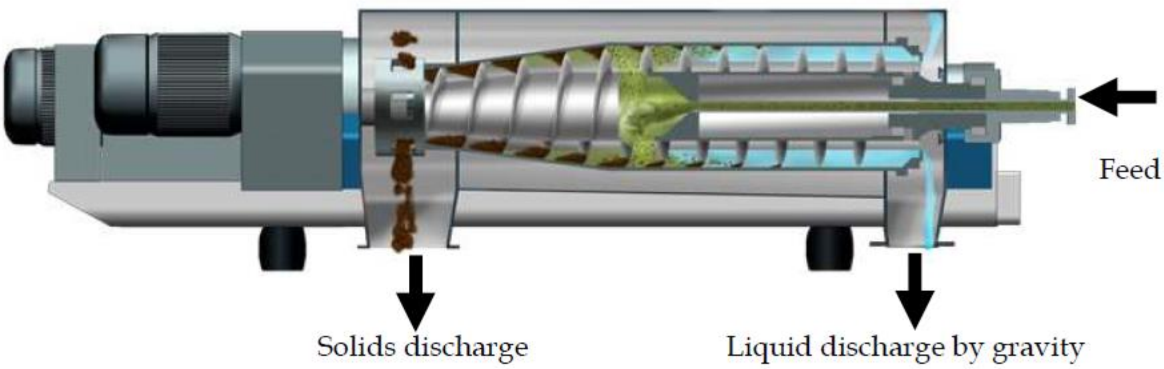

Figure 2. Cut-away section of a (Flottweg) decanter centrifuge showing the operating principle

21. I am comforted by the track record of Alpha Laval who have been providing centrifuges to many industries for several decades, including their decanter centrifuges to the mining industry (as summarised in Table 1).

22. A review of a recent webinar (https://www.youtube.com/watch?v=8FXxGXg7q4w) given by Alpha Laval's Mining and Minerals Industry Manager, Amol Chinchankar, provided an insight into the technical aspects of this centrifuge. The points that I consider relevant here are listed below:

    a. the centrifuges operate continuously (24/7);
    b. anti-vibrations pads are located between the centrifuge structure and the floor;
    c. vibration and temperature is monitored at or close to the main bearings;
    d. centrifuge rotation speeds are measured.

23. Details that I was not able to ascertain include:

a. Are the vibration, temperature and rotation speed measurements used in the centrifuge control loop. In other words, do these measurements trigger a warning or alarm status that would either alert an operator or initiate a shut-down sequence?
b. Are the centrifuges monitored continuously by an operator or is the control handled by hardware/software?
c. How sensitive is the operation of the machines to movements of the foundations?
d. What level of containment do the centrifuge provide in a catastrophic failure event?

24. I include the above four points as they relate to the safety of the machine and it is my opinion that answers to these questions should be sought, and that further detail on the overall safety features and design of the proposed centrifuge are provided.

25. Whilst the Alfa Laval decanter centrifuge appears to include vibration, temperature and speed monitoring, it is not yet clear how this information is used. Ideally it would form part of the centrifuge control system, such that if the sensor measurements moved beyond pre-set limits, the operator would be alerted, or a shut-down sequence initiated.

26. It is not clear how the centrifuge is balanced and what level of unbalance can be accommodated without compromising both the operation and safety of the machine. At the feed entry end of the centrifuge the material within the centrifuge will be a slurry which should distribute evenly around the perimeter of the rotor. However, closer to the solids discharge end of the centrifuge the material will be solid and potentially 'clumped', such that balance would appear more difficult to ensure. It is conceivable that the potential for the solids to clump together would be greater at higher differential rotational speeds (i.e. between the rotor and the scroll) and should the solids get restricted at the solids discharge port.

27. The various schematics in EES Chapter 3: Project Description (e.g. Figure 4.14) indicate that the centrifuges would be located on an upper floor that is supported by a framed steel structure. It is not clear how the centrifuges are fixed/anchored to the floor, and what level of support the floor provides. If the centrifuge was to become unbalanced (noting that the outer drum and the scroll rotate at different rotational velocities), how would this affect the loads applied through the legs of the centrifuge to the floor? Has/can the floor been designed to accommodate an unbalanced centrifuge?

28. Consideration should be given to the effect of foundation movement on the performance of the machine. Referring to the proposed locations of the centrifuges relative to mining areas, it appears that the centrifuge could be within approximately 125 metres of the active mining areas (see Figure 3.8 from EES Chapter 3: Project Description). Hence, it would appear unlikely that there would be foundation

movement due to active mining. A detailed design should consider other sources of foundation movement, e.g. due to stockpiling of the dewatered tailings cake or from loading of other nearby infrastructure.

29. To minimise the negative impacts arising from a catastrophic failure, it is typical for a geotechnical centrifuge to be contained within either a reinforced concrete or steel shell, an earth embankment or constructed underground. It would be prudent to ask for the design basis/assumptions regarding failure of the centrifuge, as the rotating rotor and scroll will have incredible inertia when rotating at the maximum speed of 1,800 rpm (for the Alpha Laval P3 decanter centrifuge).

30. Fixed beam geotechnical centrifuges comprise a swinging platform (the 'payload') at one end of a rotating beam, with a counterweight at the other end providing overall balance. In my experience of managing a large geotechnical centrifuge facility, there have been numerous instances where minor parts of the experiment or ancillary equipment broke free and were contained by the centrifuge enclosure. I am aware of two catastrophic failures in other geotechnical centrifuge facilities, one where the entire payload broke free (China) and the other where the counterweight broke free (USA). In the Chinese facility the payload ruptured the containment enclosure and travelled at considerable velocity before coming to rest, whereas in the US facility the counterweight broke through the 1 m thick enclosure wall and was only stopped by a secondary wall beyond this.

31. Although the frequency of such incidents are few relative to the number of geotechnical centrifuge facilities in operation, given the severity of such an occurrence – with significant potential for injury, loss of life and damage to property – it is important that this eventuality is considered and designed for. I note that the proposed design is for the centrifuge to be located within a building that does not appear to have any particular additional containment provisions. I further note that:

    a. the Alfa Laval centrifuge design differs considerably from the fixed beam geotechnical centrifuge described above as the decanter centrifuge design is more akin to a geotechnical drum centrifuge (geotechnical drum centrifuges require less containment than geotechnical beam centrifuges), and
    b. decanter centrifuges have been operating at numerous mine sites over many years.

    However, the Alfa Laval centrifuge operates at much higher speeds than typical geotechnical drum centrifuges, such that the centripetal acceleration, and hence inertia of the rotating mass is much higher and would necessitate greater containment provisions.

32. It is my provisional opinion that the concerns noted above represents a level of uncertainty and potential risk (at this point in time) that warrants further information. In particular it would be prudent to seek clarity on:

a. whether the Alfa Laval centrifuge is designed to provide full or partial containment in the event that the rotating parts broke free from the axes about which they spin, the bearings failed prematurely etc.;
b. how (or indeed if) the vibration, temperature and rotation speed measurements are used in the centrifuge control and what events are triggered if these measurements move beyond pre-set thresholds;
c. whether the foundations are designed to tolerate an un-balanced centrifuge;
d. the level of foundation movement that could be accommodated without negatively affecting operation of the centrifuge.

5. REFERENCES AND OTHER SOURCES OF INFORMATION

Klug, R. and Schwarz, N. (2019). Dewatering tailings: rapid water recovery by use of centrifuges. In Proceedings of the 22nd International Conference on Paste, Thickened and Filtered Tailings, Perth, Australia, 369-383, https://doi.org/10.36487/ACG_rep/1910_26_Klug

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Mikula, R.J., Munoz, V.A., and Omotoso, O. (2009a). Centrifugation Options for Production of Dry Stackable Tailings in Surface- Mined Oil Sands Tailings Management. Journal of Canadian Petroleum Technology, 48, 19–23, https://doi.org/10.2118/09-09-19-TN

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Nguyen, C.V., Nguyen, A.V., Doi, A., Dinh, E., Nguyen, T.V., Ejtemaei, M. and Osborne, D. (2021). Advanced solid-liquid separation for dewatering fine coal tailings by combining chemical reagents and solid bowl centrifugation. Separation and Purification Technology, 259, 118172, https://doi.org/10.1016/j.seppur.2020.118172

Wang, C., Harbottle, D., Liu, Q. and Xu, Z. (2014). Current state of fine mineral tailings treatment: A critical review on theory and practice. Minerals Engineering, 58, 113-131, https://doi.org/10.1016/j.mineng.2014.01.018

Appendix A: Curriculum Vitae, Conleth O'Loughlin

Name: Associate Professor Conleth O'Loughlin
[redacted]
Webpage: https://research-repository.uwa.edu.au/en/persons/conleth-oloughlin

Personal Statement

I am a geotechnical engineer and scientist, with extensive research and industry experience, specialising in geotechnical aspects of offshore energy developments. My research focuses on the safe and sustainable development of the world's offshore energy reserves, particularly offshore renewable energy wind and wave energy, but also the depleting supply of offshore hydrocarbons. I have significant experience in developing and managing large multi-party research programmes, with a particular focus on the transfer of university developed technology into industry practice. This research has been supported by $29.5M in funding, $23.9M in competitive research grants and $5.6M in industry-sponsored research, leading to more than 150 publications, 44 industry commissioned technical reports and 2 international patents. My research has informed the design of offshore infrastructure, been codified in design guidelines and in industry utilised software, and has been transferred to industry through commercialisation contracts.

In my role at The University of Western Australia I am an Associate Professor and Director of the National Geotechnical Centrifuge Facility (NGCF), have held roles as Deputy (and Acting) Director for the Centre for Offshore Foundation Systems, and serve on numerous governance committees including Chair of the NGCF management committee, the Centre for Offshore Foundation Systems management committee, the Faculty of Engineering and Mathematical Sciences International Scholarship Selection Committee, and various work, health and safety committees. I am the Chair of the Editorial Board of the International Journal of Physical Modelling in Geotechnics (UK Institute of Civil Engineers), Associate Editor and member of the Editorial Board for Géotechnique Letters (UK Institute of Civil Engineers), and have held several positions on local and international organising committees for various international conferencs.

Education

2002 PhD, Geotechnical Engineering, Trinity College Dublin, Ireland
1997 BEng, Civil Engineering (1st class Honours), The Queen's University of Belfast, Northern Ireland

Employment

2012 – present ***Centre for Offshore Foundation Systems (UWA): Associate Professor and Director of the National Geotechnical Centrifuge Facility***

- Overall responsibility for the National Geotechnical Centrifuge Facility, including managing the $1.6M annual budget, establishing and maintaining strategic directions, oversight on operational and personnel management. These centrifuge facilities and the capabilities of the team that operate and support them are held in the highest regard worldwide, with a high level of demand from within both academia and industry (typically booked for 12 months in advance).
- Responsible for industry centrifuge contracts including proposal writing, budgeting, project design, execution and reporting. The income from these projects since I took up my position is $2.9M over 22 projects.
- Leading academic research relevant to the offshore energy industries, particularly offshore anchoring systems and in-situ characterisation of the seabed.

- Chief investigator on numerous multi-party research projects supported by the Australian Research Council, Australian Renewable Energy Agency and the Western Australian state government, with global industry and academic partners.

2007 – 2012 Institute of Technology, Sligo, Ireland: Lecturer in Civil Engineering

- Established and managed the first and only geotechnical centrifuge facility in Ireland, including both fixed beam and drum testing modes - one of only three European research centres with a drum centrifuge.
- Founded and led the Geotechnical Research Group, comprising three academic staff, ten postgraduate students and two technicians.
- Developed and delivered undergraduate units in Civil Engineering.

2007 – 2008 Applied Ground Engineering Consultants: Principal Geotechnical Engineer

Led a team of eight geotechnical engineers and technicians in a highly specialised geotechnical consultancy firm. Selected project experience includes: soft ground design for primary road schemes, quality check of geotechnical interpretation and design for road improvement schemes and slope stability assessments for wind farm developments.

2006 – 2007 BMA Geoservices: Senior Geotechnical Engineer

Responsible for the management and direction of the geotechnical division. Selected project experience includes: earthwork checks for national road authority road scheme tender submissions, expert witness advice, feasibility studies for road construction over soft ground, geotechnical advice for mixed developments and scheduling/managing ground investigation contracts for urban development and road infrastructure projects.

2002 – 2006 Centre for Offshore Foundation Systems (UWA): Research Associate

- Established experimental databases derived from centrifuge tests on various anchoring systems including dynamically installed anchors, driven plate anchors and suction embedded plate anchors.
- Developed analytical models for predicting penetration of dynamically installed anchors.
- Developed the Dynamically Embedded Plate Anchor, a proprietary anchoring system for deep water.

2001 – 2002 Trinity College Dublin, Ireland: Assistant Lecturer (part time)

Responsible for the preparation and delivery of geotechnical engineering lectures at undergraduate level.

Selected Consulting Experience (2015-2021)

2020	Centrifuge modelling for the Perseus over Goodwyn offshore development, Woodside Energy
	Centrifuge modelling of Angolan offshore pipelines, BP
2019	Centrifuge modelling or rock berms as axial restraint for SME flowlines, Woodside Energy
	Physical modelling of anchor-pipeline interaction for Port of Hong Kong, IntecSea
2018	Technical report of the commissioning of the IMP centrifuge, Mexican Institute of Petroleum
2017	Development of pipeline free span monitoring instrumentation, Shell
2016	Physical modelling of the stability of offshore pipelines buried in rock, Technip
	Centrifuge modelling to support the development of the Delmar driven anchor, Delmar

	Centrifuge modelling of flowline-soil interaction for the Browse development, Woodside
2015	Physical modelling of the uplift resistance of buried pipelines with attachments, Technip
	Centrifuge modelling of chain-seabed interaction for the Browse development, Shell

Awards

- Three paper awards, including from ICE in the UK (Thomas Telford Premium Award; 2015, 2016) and from
  ASTM (C.A. Hogentogler Award; 2016).
- 2014 Australian Shell Innovation Challenge: category finalist
- 2013 Australian Gas Technology Innovation Award
- 2011 Engineers Ireland Excellence Awards: finalist in the best paper or presentation category
- 2005 University of Western Australia Innovation Challenge Competition

Research Funding

My total research input (see Appendix A) amounts to $29.5M, $23.9M in competitive research grants and $5.6M in industry-sponsored research. I have had past and current roles as Chief Investigator and workpackage leader on several international multi-party projects, including:

- Current Australian Research Council (ARC) Discovery Project on understanding the origin and engineering implications of Australian seabed crusts;
- Current ARC Linkage Project on suction caisson behaviour for offshore wind turbines;
- Current ARC Funded Hub for Offshore Facilities (which includes two international oil and gas majors – Woodside and Shell, and two international certification bodies – Lloyd's Register and Bureau Veritas);
- Current Australian Renewable Energy Agency Project on developing strategies for achieving cost reductions for commercial deployment of wave energy devices in large integrated arrays;
- Current Albany Wave Energy Research Centre, a recently awarded project that will support the commercial
  deployment of grid-connected wave energy devices offshore Albany, Western Australia;
- Previous Joint Industry Project 'RIGSS' (which includes three international oil and gas majors – Woodside, Shell
  and Total, and two international offshore site investigation companies – Fugro and Benthic);
- Previous European Funded FP7 offshore renewable wave energy project, 'GeoWAVE' (of which I was the architect and was the project coordinator whilst in my previous academic position);
- Previous ARC Discovery Project on multi-directional cyclic loading of anchors for floating wind turbines and wave energy converters;
- Previous ARC Linkage Project on optimising foundations for wave energy converters by considering strategies
  associating with extreme load avoidance and extreme load survival.

Research output and impact

My research output (see Appendix B) amounts to 150 papers in international journals and international conference proceedings (including 5 keynote papers), 2 book chapters, 44 industry commissioned technical reports and 2 patents. The impact of this research includes:

- The research output in the industry reports I have produced has the most immediate and significant impact, as it is used to either inform the design of offshore infrastructure or to develop in-house design tools and products that the sponsoring company uses in practice. Examples include:
  - numerous pipe-clamp mattresses centrifuge studies that have directly shaped the pipeline axial restraint designs for projects in West Africa, Gulf of Mexico and in the North West Shelf of Australia;
  - performance of rock berms in providing axial restrain to offshore flowlines (Senegal, West Africa)
  - numerous offshore pipeline-soil interaction studies for the Browse field (North West Shelf of Australia),
  - mooring chain-soil interaction in calcareous sediments (Browse field);
  - shallow foundation performance under cyclic tensile loading (Browse field);
  - performance of dynamically installed and driven anchors (for North West Shelf of Australia sediments);
  - pipeline buckling resistance in rock;
  - suction caisson response in Gulf of Guinea clay;
  - sliding pipeline end termination mudmat performance (Wheatstone field);
  - geometrical optimisation of 'skirted spudcan' foundations;
  - new in-house (TechnipFMC, UK) design guidelines for calculating breakout resistance of buried pipelines;
  - revised anchor designs (Delmar, USA) to optimise anchor performance in calcareous silts.
- Led the research to inform the performance of a new free-fall anchor concept for sand seabeds in the EU funded GeoWAVE project.
- Frameworks that I have developed through my research have been coded and made available to industry participants, e.g. interpreting free-fall penetrometer measurements to derive soil strength (in the RIGSS joint industry project), and a 'digital twin' tool for calculating the changing capacity of offshore foundation elements due to temporal and spatial changes in soil strength (in the ARC and industry funded Offshore HUB project)
- My research on dynamic penetration of torpedo anchors formed the basis for the verification agency Lloyds Register certifying torpedo anchors in the Campos Basin (Brazil) for the oil and gas operator PETROBRAS.
- Several of my research outputs have led to commercial outcomes:
  - I conceived, developed, patented and licenced a new offshore anchor design, which was sold under a joint commercialisation deal with UWA to leading global anchor provider Vryhof Anchors, an event that attracted widespread media coverage;
  - I developed (and patented) a new free-fall penetrometer tool for measuring the strength of the seabed, which has attracted interest from mining companies for using this technology to map the density and strength of tailings ponds;
  - Inertial Measurement Unit technology that I have developed for measuring the motion response of free-fall anchors and penetrometers has been adopted by offshore oil and gas operators to measure the fatigue response of free-span offshore pipelines.

Management / Governance Experience

- Director and Chair of National Geotechnical Centrifuge Facility Management Board

- Deputy (and acting) Director, and management committee member for Centre for Offshore Foundation Systems
- Chair of Editorial Board for International Journal of Physical Modelling in Geotechnics (UK Institute of Civil Engineers)
- Editorial Board for Géotechnique Letters (UK Institute of Civil Engineers)
- International member of the Scientific and Technology Committee of the Centrifugal Hypergravity and Interdisciplinary Experiment Facility (CHIEF), Zhejiang University, China.
- International Scientific Committee for the 7th International Conference on Physical Modelling in Geotechnics
- Local Organising Committee for the 8th International Conference on Physical Modelling in Geotechnics
- Local Organising Committee for the 1st International Symposium on Frontiers in Offshore Geotechnics (ISFOG)
- Member of Technical Committee 104: Physical Modelling in Geotechnics (International Society of Soil Mechanics and Geotechnical Engineering)
- Hogentogler Award Subcommittee D18.98 (American Society for Testing and Materials)
- UWA International Scholarship Committee (UWA Faculty of Engineering and Mathematical Sciences)

Appendix A: Research Funding

2020 Ove Arup & Partners Hong Kong Ltd, $246.3k
C.D. O'Loughlin, C. Gaudin
Pipeline Protection - Anchor Model Tests for Arup HK

Woodside Energy Ltd., $116.9k
C.D. O'Loughlin, P. Watson
Centrifuge tests to assess effectiveness of pipeline clamping mattresses for NWS pipeline

Australian Research Council Discovery Project, $400k
M.F. Bransby, C.D. O'Loughlin, S.H. Chow.
Crusty seabeds: from (bio-)genesis to reliable offshore design

Australian Research Council Industrial Transformation Research Hub, $5M
P. Watson, N. Jones, . Draper, M.F. Bransby, E. Cripps, C.D. O'Loughlin, J. Hansen, H. An, J. Doherty, G. Ivey, M.F. Randolph, W. Zhao, H. Wolgamot, L. Cheng, T. French, A. Mian, M. Small, A. Zammit-Mangion, M. Moores, D. Gunawan.
ARC Research Hub for Transforming Energy Infrastructure Through Digital Engineering

2019 Worley Parsons, $246.2k
C.D. O'Loughlin, C. Gaudin
Physical Model Test for Anchor Drop and Drag to support FEED level studies for locations around Lantau Island, Hong Kong

Technical University of Hamburg-Harburg TUHH. $85.6k
B. Bienen, C.D. O'Loughlin
Centrifuge tests to investigate piles and pile groups under axial and lateral loading

Central Queensland University. $16.5k
C.D. O'Loughlin, Y. Hu and S.N. Ullah
Innovative Green Foundation Systems for Renewable Wind Energy

Woodside Energy Ltd., $180k
C.D. O'Loughlin, P. Watson, F. Bransby
Senegal Development: Verification of Rock Berm as Walking Restraint

Fugro AG., $101.2k
C.D. O'Loughlin, P. Watson, B. Bienen, F. Bransby, H. Mohr
Cyclic Loading of Suction Bucket Foundations in Undrained Sand

Subcon Technologies, $109k
C.D. O'Loughlin, P. Watson
PCMs as axial restraint for BP flowline

2018 Western Australian Energy Research Alliance WAERA ex Woodside R2D3, $35k
P. Watson, C.D. O'Loughlin, Y. Hu
Follow up study on axial capacity of jetted conductors

Australian Research Council Linkage Project, $395k
B. Bienen, M.J. Cassidy, C.D. O'Loughlin, N. Morgan
Design guideline for suction caissons supporting offshore wind turbines

Lloyd's Register, $191.7k
B. Bienen, M.J. Cassidy, C.D. O'Loughlin, N. Morgan
Design guideline for suction caissons supporting offshore wind turbines

Technical University of Hamburg-Harburg TUHH. $62.78k
B. Bienen, C.D. O'Loughlin
Centrifuge tests to investigate suction caisson behaviour in layered soils

Technical University of Hamburg-Harburg TUHH. $49.5k
C.D. O'Loughlin, B. Bienen
Centrifuge tests to investigate shearing mechanisms in modified soils

Western Australian Energy Research Alliance WAERA ex Woodside R2D3, $15k
P. Watson, C.D. O'Loughlin, Y. Hu
Axial capacity of jetted conductors

2017 WA Department of Primary Industries and Regional Development, $3.74M
C. Gaudin, R. Lowe, S. Draper, C.D. O'Loughlin, H. Wolgamot, J. Hansen
Albany Wave Energy Project – Wave Energy Research Centre

Technical University of Hamburg-Harburg TUHH. $60k
B. Bienen and C.D. O'Loughlin
Centrifuge tests to investigate suction caisson behaviour in sand

DOF Subsea Asia Pacific Pte Ltd. $99.12k
C.D. O'Loughlin and D.J. White
Support free span monitoring of a pipeline in Shell's Malampaya project

Instituto Mexicano del Petróleo, $442.36k
M.F. Randolph, C. Gaudin, C.D. O'Loughlin, S. Stanier, Y. Tian
Design of Suction Piles for Submarine Systems Under Combined Loading and Deep Water Geotechnical Conditions

2016 Delmar Systems Inc., $252.05k
C. Gaudin and C.D. O'Loughlin
Centrifuge modelling of the DELMAR driven anchor

University of Western Australia Collaboration Awards, $20k
Y. Tian, C.D. O'Loughlin, M.J. Cassidy, L. Wang, J. Morton
Innovating offshore anchoring design to survive extreme sea states

2015 Australian Research Council Industrial Transformation Research Hub, $10M
White, D.J., Cassidy, M.J., Efthymiou, M., Ivey, G., Jones, N., Cheng, L., Draper, S., Zhao, M., Randolph, M.F., Gaudin, C., O'Loughlin, C.D., Gourvenec, S., Hodkiewicz, M., Cripps, E., Zhao, W., Wolgamot, H., Wyld, W., Chow, F., Flynn, J., Chen, X. and Myllerup, C.
ARC ITRH for Offshore Floating Facilities

Australian Renewable Energy Agency, $994k
Gaudin, C., Lowe, R., O'Loughlin, C.D., Hansen, J., Cassidy, M.J., Tian, Y., Fievez, J., Rafiee, A., Jay, B. and Taylor, D.
From single to multiple wave energy converters: Cost reduction through location and configuration optimisation

Australian Research Council Linkage Project, $610k
Gaudin, C., Draper, S., Wolgamot, H., O'Loughlin, C.D., Rafiee, A. and Fievez, J.
Novel wave energy foundation solutions to survive extreme loads

Wood Group Kenny, $205k
C. Gaudin and C.D. O'Loughlin
Browse FLNG development – Pipe soil interaction centrifuge testing

Technip UK Ltd., $170k
D.J. White and C.D. O'Loughlin
Pullout resistance of pipelines buried in rock

Shell Australia, $90k
D.J. White and C.D. O'Loughlin
Centrifuge modelling of chain-seabed interaction for the Browse development

Lloyds Register Group, $1M
Cassidy, M.J., Chow, S.H., Bienen, B., O'Loughlin, C.D. and Wolgamot, H.
Follow-on Funding for the Centre for Offshore Foundation Systems

POSCO, $80k
Hossain, M., Wang, D., Kim, Y., Randolph, M.F., Gaudin, C., O'Loughlin, C.D. and Cassidy, M.J. $80k
Prediction of Long-Term Displacements of Suction Piles for 3MW Offshore Wind Turbine and Effective Measures for Reducing Displacements

2014 Australian Research Council Discovery Project, $572k
Gaudin, C. Cassidy, M.J., O'Loughlin, C.D. and Hambleton, J.
Harnessing the power of oceans: anchors for floating energy devices

RIGSS JIP (multiple industry sponsors, $1.0M)
D.J. White, M.F. Randolph, L. Cheng, C.D. O'Loughlin, S. Draper and S. Stanier
Remote Intelligent Geotechnical Seabed Surveys

Technip UK Ltd. $55k
C.D. O'Loughlin and D.J. White
Uplift resistance of buried pipelines with fins

2013 Advanced Geomechanics ex Chevron, $136k
C. Gaudin and C.D. O'Loughlin
Investigation of PLET Foundation under cyclic horizontal & torsional loadings for Wheatstone development

Iluka Resources Ltd. $208k
C.D. O'Loughlin and A. Fourie
Investigating the viability of borehole mining in mineral sand deposits through geotechnical centrifuge modelling

Advanced Geomechanics ex Chevron, $12k
C.D. O'Loughlin
1-g mini-T-bar in intact tube samples

Advanced Geomechanics ex Woodside Energy Ltd., $130k
C.D. O'Loughlin, C. Gaudin and D.J. White
Browse LNG development 1-g axial pipe soil interaction tests

2012 EU FP7 Research for the Benefit of SMEs, $1.8M (UWA: $598k)
C.D. O'Loughlin
University of Western Australia – C.D. O'Loughlin, C. Gaudin; University of Dundee – J. Knappett, M. Brown; University College Cork – T. Lewis, W. Sheng;
Geotechnical design solutions for the offshore renewable wave energy industry

Australian Research Council Linkage Infrastructure Equipment Facilities, $300k
Sloan, S., Randolph, M.F., Carter, J., Daichao, S., Cassidy, M., Buddhima, I., White, D., Nasser, K.,

Willimas, D., Merifield, R., Kodikara, J., Airye, D., Einav, I., Abbo, A., Rujikiatkamjorn, C., Stanier, S., O'Loughlin, C.D., Dorival, P. Alexan, S.
A national facility for in situ testing of soft soils

Keppel Offshore and Marine Technology Centre, $74k
C.D. O'Loughlin and C. Gaudin
Centrifuge modelling to investigate the behaviour of a skirted spudcan with side and top opening during installation in clay overlying sand

Advanced Geomechanics ex Woodside Energy Ltd., $224k
C.D. O'Loughlin and C. Gaudin
Browse development, centrifuge modelling of skirted shallow foundations for dry tree units

Delmar Systems Inc., $129k
C. Gaudin, C.D. O'Loughlin, M.F. Randolph and M. Hossain, M
Centrifuge modelling for OMNI-MAX anchor in calcareous sediments

2010 IT Sligo President's Bursary Awards, €13k ($19k)
C.D. O'Loughlin
Geotechnical performance of dynamically installed anchors in soft clay

IT Sligo President's Bursary Awards, €13k ($19k)
C.D. O'Loughlin
The use of suction embedded plate anchors for mooring floating wave energy devices

IT Sligo Capacity Building Fund, €12k ($17k)
C.D. O'Loughlin and P. Naughton
Building the research capacity of the Geotechnical Research Group

2009 Enterprise Ireland FP7 Coordinator Proposal Preparation Support Scheme, €24k ($35k)
C.D. O'Loughlin
Support for preparing funding application to the "Research for the Benefit of SMEs" Call 3: FP7-SME-2010-1

2008 Enterprise Ireland Commercialisation Fund: Technology Development, €278k ($404k)
C.D. O'Loughlin
Dynamically Embedded Plate Anchor – a cost effective anchoring solution for the offshore energy industry

Higher Education Authority (Technology Sector Research: Strand 3), €300k ($435k)
C.D. O'Loughlin, P. Naughton
Geotechnical centrifuge modelling: developing innovative design solutions to complex engineering problems

Higher Education Authority (Technology Sector Research: Strand 1), €46k ($67k)
C.D. O'Loughlin
Use of full-flow penetrometers for measuring shear strength and consolidation characteristics of soft ground

2005 Australian Research Council Linkage Project, $157k
C.D. O'Loughlin, M.F. Randolph, P. Hefer
Project ID: LP0562561
Deep Penetrating Anchors – a cost effective anchoring solution for mooring oil and gas facilities in deep water

2004 Western Australian Energy Research Alliance R2D3 Grant
(Industry partner: Woodside Energy), $75k
C.D. O'Loughlin, M.F. Randolph

Project ID: OC00000477
Geotechnical behaviour of Deep Penetrating Anchors with emphasis on the response to cyclic loading

University of Western Australia Research Grant, $16k
C.D. O'Loughlin
Deep Penetrating Anchors: measurement of anchor velocity and soil displacement during dynamic penetration

University of Western Australia Research Grant, $16k
S. Gourvenec, C.D. O'Loughlin
Behaviour of footings under complex combined loading

Appendix B: Publications

Book chapters

BC1. O'Loughlin, C.D., Neubecker, S.R. and Gaudin, C. (2017). Anchoring systems: anchor types, installation and design. Encyclopaedia of Marine and Offshore Engineering, Wiley, doi: 10.1002/9781118476406.emoe534.

BC2. Gaudin, C. and O'Loughlin, C.D. (2017). Physical modelling of foundation systems. Encyclopaedia of Marine and Offshore Engineering, Wiley, doi: 10.1002/9781118476406.emoe537.

Published and accepted journal papers

J1. Han, C. Wang, D. Gaudin, C. O'Loughlin, C.D. and Cassidy, M.J. (2020). Capacity of Plate Anchors in Clay under Sustained Uplift. Ocean Engineering, accepted.

J2. Roy, A., Chow, S., Randolph, M.F. and O'Loughlin, C.D. (2020). Consolidation effects on uplift capacity of horizontal plate anchors in sand, Géotechnique, accepted.

J3. Roy, A., O'Loughlin, C.D., Chow, S. and Randolph, M.F. (2020). Inclined loading of horizontal plate anchors in sand, Géotechnique, accepted.

J4. Roy, A., Chow, S., O'Loughlin, C.D. and Randolph, M.F. (2020). Towards a simple and reliable method for calculating the uplift capacity of plate anchors in sand, Canadian Geotechnical Journal, accepted.

J5. Roy, A., Chow, S., O'Loughlin, C.D., Randolph, M.F. and Whyte, S. (2020). Use of a bounding surface model for predicting element tests and capacity of simple surface footings, Canadian Geotechnical Journal, accepted.

J6. Luo, L. O'Loughlin, C.D., Bienen, B., Wang, Y., Cassidy, M.J. and Morgan, N. (2020). Effect of the ordering of cyclic loading on the response of suction caissons in sand. Géotechnique Letters, 10(2), 303-310, doi: 10.1680/jgele.19.00031.

J7. Zhou, Z., White, D.J. and O'Loughlin, C.D. (2020). The changing strength of carbonate silt: parallel penetrometer and foundation tests with cyclic loading and reconsolidation periods. Canadian Geotechnical Journal, 57(11), 1664-1683, doi: 10.1139/cgj-2019-0066

J8. Chow, S.H., O'Loughlin, C.D., Zhou, Z., White, D.J. and Randolph, M.F. (2020). Penetrometer testing in a calcareous silt to explore changes in soil strength. Géotechnique, 70(12), 1160-1173, doi: 10.1680/jgeot.19.P.069.

J9. Chow, S.H., Diambra, A., O'Loughlin, C.D., Gaudin, C. and Randolph, M.F. (2020). Consolidation effects on monotonic and cyclic capacity of plate anchors in sand. Géotechnique, 70(8), 720-731, doi: 10.1680/jgeot.19.TI.017.

J10. Ragni, R., Bienen, B., O'Loughlin, C.D., Stanier, S.A., Cassidy, M.J. and Morgan, N. (2020). Observations of the effects of a clay layer on suction bucket installation in sand, ASCE Journal of Geotechnical and Geoenvironmental Engineering, (146)5: 04020020, doi:10.1061/(ASCE)GT.1943-5606.0002217.

J11. Zhou, Z., O'Loughlin, C.D., White, D.J. and Stanier, S.A. (2020). Improvements in plate anchor capacity due to cyclic and maintained loads combined with consolidation. Géotechnique, 70(8), 732-749, doi: 10.1680/jgeot.19.TI.028.

J12. Zhou, Z., O'Loughlin, C.D. and White, D.J. (2020). An effective stress analysis for predicting the evolution of SCR-seabed stiffness accounting for consolidation, Géotechnique, 70(5), 448-467, doi: 10.1680/jgeot.18.P.313.

J13. Ragni, R., Bienen, B., Stanier, S.A., O'Loughlin, C.D. and Cassidy, M.J. (2020). Observations during suction bucket installation in sand, The International Journal of Physical Modelling in Geotechnics, 20(3), doi: 10.1680/jphmg.18.00071.

J14. Huang, T., O'Loughlin, C.D., Gaudin, C., Tian, Y. and Lu, T. (2020). Drained response of rigid piles in sand under an inclined tensile load. Géotechnique Letters, 10(1), 30-37, doi: 10.1680/jgele.19.00028.

J15. O'Loughlin, C.D., Zhou, Z., Stanier, S.A. and White, D.J. (2020) Load-controlled cyclic T-bar tests: a new method to assess effects of cyclic loading and consolidation. Géotechnique Letters, 10(1), 7-15, doi: 10.1680/jgele.19.00030.

J16. Niemann, C. O'Loughlin, C.D., Tian, Y., Cassidy, M.J., and Reul, O. (2019). Response of pile groups in sand due to lateral cyclic loading. The International Journal of Physical Modelling in Geotechnics, 19(6), doi: 10.1680/jphmg.1800027.

J17. Zografou, D., Gourvenec, S., O'Loughlin, C.D. and Banimahd, M. (2019). Applicability of the strain accumulation procedure for the geotechnical foundation design of zero-radius bend triggers, Ocean Engineering, 186, doi: 10.1016/j.oceaneng.2019.05.044.

J18. King, L., Bouazza, A., Gaudin, C., O'Loughlin, C.D. and Bui, H.H. (2019). Behavior of geosynthetic reinforced piled embankments with defective piles, ASCE Journal of Geotechnical and Geoenvironmental Engineering, 145(11): 04019090, doi: 10.1061/(ASCE)GT.1943-5606.0002125.

J19. Hao, D., Wang, D. O'Loughlin, C.D. and Gaudin, C. (2019). Tensile monotonic capacity of helical anchors in sand: interaction between helices, Canadian Geotechnical Journal, 56(10), 1534-1543, doi: 10.1139/cgj-2018-0202.

J20. Colreavy, C., O'Loughlin, C.D., Bishop, D. T. and Randolph, M.F. (2019). Effect of soil biology and pore water chemistry on a lakebed sediment, Géotechnique, 69(11), 959-970, doi: 10.1680/jgeot.16.P.308.

J21. Zhu, F., Bienen, B., O'Loughlin, C.D., Cassidy, M.J., Morgan. N. (2019). Suction caisson foundations for offshore wind energy: cyclic response in sand and sand over clay, Géotechnique, 69(10), 924-931, doi: 10.1680/jgeot.17.P.273.

J22. Zhao, L., Gaudin, C., O'Loughlin, C.D., Hambleton, J.P., Cassidy, M.J. (2019). Suction caisson capacity in sand under inclined loading, ASCE Journal of Geotechnical and Geoenvironmental Engineering, 145(2): 04018107, doi: 10.1061/(ASCE)GT.1943-5606.0001996.

J23. Zografou, D., Gourvenec, S. and O'Loughlin, C.D. (2019). Vertical cyclic loading response of a shallow skirted foundation in soft normally consolidated clay, Canadian Geotechnical Journal, 56(4), 473-483, doi: 10.1139/cgj-2018-0179.

J24. Zografou, D., Gourvenec, S. and O'Loughlin, C.D. (2019). Response of normally consolidated clay under irregular cyclic loading and comparison with predictions from the accumulation procedure, Géotechnique, 69(2), 106-121, doi: 10.1680/jgeot.16.P.340.

J25. Zhou, Z. White, D.J. and O'Loughlin, C.D. (2019). An effective stress framework for estimating penetration resistance accounting for changes in soil strength from maintained load, remoulding and reconsolidation, Géotechnique, 69(1), 57-71, doi: 10.1680/jgeot.17.P.217.

J26. Zhu, F., Bienen, B., O'Loughlin, C.D., Cassidy, M.J., Morgan. N. (2018). The response of suction caissons to multidirectional lateral cyclic loading in sand over clay, Ocean Engineering, 170, 43-54, doi: 10.1016/j.oceaneng.2018.09.005.

J27. O'Loughlin, C.D. Cocjin, M., Gourvenec, S. and Stanier, S.A. (2018). A new approach to multi degree-of-freedom loading in a geotechnical centrifuge, ASTM Geotechnical Testing Journal, 42(5), doi: 10.1520/GTJ20180037

J28. Doherty, J.P., Gourvenec, S., Gaone, F.M., Pineda, J.A., Kelly, R., O'Loughlin, C.D., Cassidy, M.J. and Sloan, S.W. (2018). A novel web based application for storing, managing and sharing geotechnical data, illustrated using the National soft soil field testing facility in Ballina, Australia, Computers and Geotechnics, 93, 3-8, doi: 10.1016/j.compgeo.2017.05.007.

J29. Chow, S., O'Loughlin, C.D., Gaudin, C. and Lieng, J.T. (2018). Drained monotonic and cyclic capacity of a dynamically installed plate anchor in sand, Ocean Engineering, 148, 588-601, doi: 10.1016/j.oceaneng.2017.11.051.

J30. Bienen, B. Klinkvort, R.T., O'Loughlin, C.D., Zhu, F. and Byrne, B. (2018). Suction caissons in dense sand, part I: Installation, limiting capacity and drainage, Géotechnique, 68(11), 937-952, doi: 10.1680/jgeot.16.P.281.

J31. Bienen, B. Klinkvort, R.T., O'Loughlin, C.D., Zhu, F. and Byrne, B. (2018). Suction caissons in dense sand, part II: Vertical cyclic loading into tension, Géotechnique, 68(11), 953-967, doi: 10.1680/jgeot.16.P.282.

J32. Zhu, F., O'Loughlin, C.D., Bienen, B., Cassidy, M.J., Morgan. N. (2018). The response of suction caissons to long-term lateral cyclic loading in single layer and layered seabeds, Géotechnique, 68(8), 729-741, doi: 10.1680/jgeot.17.P.129.

J33. Nicolai, G., Ibsen, L.B., O'Loughlin, C.D., White, D.J. (2017). Quantifying the increase in lateral capacity of monopiles in dense sand due to cyclic loading, Géotechnique Letters, 7(3), 242-252, doi: 10.1680/jgele.16.00187.

J34. Chow, S.H., O'Loughlin, C.D., White, D.J. and Randolph, M.F. (2017). An extended interpretation of the free-fall piezocone test in clay, Géotechnique, 67(12), 1090-1103, doi: 10.1680/geot./16-P-220.

J35. O'Beirne, C., O'Loughlin, C.D. and Gaudin, C. (2017). A release-to-rest model for dynamically installed anchors, ASCE Journal of Geotechnical and Geoenvironmental Engineering, 143(9): 04017052, doi: 10.1061/ (ASCE)GT.1943-5606.0001719.

J36. Yuan, F., White, D.J. and O'Loughlin, C.D. (2017). The evolution of seabed stiffness during cyclic movement in a riser touchdown zone on soft clay, Géotechnique, 67(2), 127-137, doi: 10.1680/geot./15-P-161.

J37. Tom, J.G., O'Loughlin, C.D., White, D.J., Haghighi, A. and Maconochie, A. (2017). Soil failure mechanisms during uplift of buried pipes, with and without radial fins, Géotechnique Letters, 7(1), 60-67, doi: 10.1680/jgele.16.00142.

J38. Gaudin, C., Cassidy, M.J., O'Loughlin, C.D., Tian, Y., Wang, D. and Chow, S. (2017). Recent advances in anchor design for floating structures, International Journal of Offshore and Polar Engineering, 27(1), 44-53, doi: 10.17736/ijope.2017.jc673.

J39. O'Beirne, C., O'Loughlin, C.D. and Gaudin, C. (2017). Assessing the penetration resistance acting on a dynamically installed anchor in normally consolidated and overconsolidated clay, Canadian Geotechnical Journal, 54(1), 1-17, doi: 10.1139/cgj-2016-0111.

J40. Morton, J.P., O'Loughlin, C.D. and White, D.J. (2016). Estimation of soil strength by instrumented free-fall sphere tests, Géotechnique, 66(12), 959-968, doi: 10.1680/jgeot.15.P.038.

J41. Han, C. Wang, D. Gaudin, C. O'Loughlin, C.D. and Cassidy, M.J. (2016). Behaviour of vertically loaded plate anchors under sustained uplift, Géotechnique, 66(8), 681-693, doi: 10.1680/geot./15-P-232.

J42. O'Loughlin, C.D., Blake, A.P. and Gaudin, C. (2016). Towards a design method for dynamically embedded plate anchors, Géotechnique, 66(9), 741-753, doi: 10.1680/geot./15-P-209.

J43. Morton, J.P., O'Loughlin, C.D. and White, D.J. (2016). Centrifuge modelling of an instrumented free-fall sphere for measurement of undrained strength, Canadian Geotechnical Journal, 53(6), 918-929, doi: 10.1139/cgj-2015-0242.

J44. Colreavy, C., O'Loughlin, C.D. and Randolph, M.F. (2016). Estimating consolidation parameters from field piezoball tests, Géotechnique, 66(4), 333-343.

J45. Colreavy, C., O'Loughlin, C.D. and Randolph, M.F. (2016). Experience with a dual pore pressure element piezoball, The International Journal of Physical Modelling in Geotechnics, 16(3), 101-118, doi: 10.1680/ijpmg.15.00011. *Awarded the Telford Premium Award for best paper in 2016.*

J46. Blake, A.P., O'Loughlin, C.D., Morton, J.P, O'Beirne, C., Gaudin, C. and White, D.J. (2016). In-situ measurement of the dynamic penetration of free-fall projectiles in soft soils using a low cost inertial measurement unit, ASTM Geotechnical Testing Journal, 39(2), 235-251. *Awarded the C.A. Hogentogler Award for best paper in 2016.*

J47. O'Beirne, C., O'Loughlin, C.D. and Gaudin, C. (2015). Soil response in the wake of dynamically installed projectiles, Géotechnique Letters, 5(3), 153-160.

J48. Beckett, C., Fourie, A. and O'Loughlin, C.D. (2015). Centrifuge modelling of seepage through tailings embankments, The International Journal of Physical Modelling in Geotechnics, 16(1), 18-30.

J49. Chow, S.H., O'Loughlin, C.D., Corti, R. Gaudin, C. and Diambra, A. (2015). Drained cyclic capacity of plate anchors in dense sand: experimental and theoretical observations, Géotechnique Letters, 5(2), 80-85. *Awarded the Thomas Telford Premium Award for best paper in 2015.*

J50. O'Loughlin, C.D. (2015). Offshore Geotechnics at ICPMG 2014, The International Journal of Physical Modelling in Geotechnics, 15(2), 98-115.

J51. Hossain, M.S., O'Loughlin, C.D. and Kim, Y. (2015). Dynamic installation and monotonic pull-out of a torpedo anchor in calcareous silt, Géotechnique, 65(2), 77-90.

J52. O'Beirne, C., O'Loughlin, C.D., Wang, D. and Gaudin, C. (2015). Capacity of dynamically installed anchors as assessed through field testing and three dimensional large deformation finite element analyses, Canadian Geotechnical Journal, 52(5), 548-562.

J53. Blake, A.P. and O'Loughlin, C.D. (2015). Installation of dynamically embedded plate anchors as assessed through field tests, Canadian Geotechnical Journal, 52(9), 1270-1282.

J54. Blake, A.P., O'Loughlin, C.D. and Gaudin, C. (2015). Capacity of dynamically embedded plate anchors as assessed through field tests, Canadian Geotechnical Journal, 52(1), 87-95.

J55. Cassidy, M.J., Gaudin, C., Bates, L., Indraratna, B., Nimbalkar, S., O'Loughlin, C.D., White, D.J., Sloan, S.W. (2014). Advancing Australia's Facilities for Physical Modelling in Geotechnics. Australian Geomechanics Journal, 49(4), 3-12.

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Appendix B: Letter of Instruction

Environmental Justice Australia

2 March 2021

Associate Professor Conleth O'Loughlin
The University of Western Australia
35 Stirling Highway
Perth WA 6009

By email only: [redacted]

Dear Associate Professor O'Loughlin

Fingerboards Mineral Sands Mine Project, Glenaladale, Victoria

We act on behalf of [redacted], a not-for-profit community group formed in response to the proposed Fingerboards mineral sands mine project **(the project)**.

We write to you as a geotechnical engineer and scientist, and as an expert on geotechnical centrifuge modelling. The purpose of this letter is to seek your expert opinion on the geotechnical centrifuge modelling aspects of the project.

We request that your expert opinion be provided as an expert witness statement to be submitted to the Inquiry and Advisory Committee (IAC). We request that your expert report be provided by **noon** on **Wednesday 10 March 2021 (AEST)**. Further details are set out below.

References to Tab numbers in bold in this letter are to the documents in an electronic brief which we provide to you via DropBox [redacted]

Background

1. Kalbar Operations Pty Ltd (**Kalbar**) proposes to develop an open pit mineral sands mine covering an approximate area of 1,675 hectares within the eastern part of the Glenaladale mineral sands deposit in East Gippsland, Victoria. The site is located near the Mitchell River and approximately 2km south of Glenaladale, 4km south-west of Mitchell River National Park and 20km north-west of Bairnsdale.

2. The advertised proposal includes the development of an open pit mineral sands mine, two mining unit plants, wet concentrator plant, water supply infrastructure, tailings storage dam and additional site facilities (i.e. site office, warehouse, workshop, loading facilities and fuel storage). The proposed mining methods involve open pit mining to extract approximately 170 million tonnes (Mt) of ore over a projected mine life of 20 years to produce 8 Mt of mineral concentrate. Heavy mineral concentrate, separated into magnetic and non-magnetic concentrates, are proposed to be transported via road, rail or a combination of both for export overseas.

3. The project would require up to 9000 kilovolt-ampere (kVA) hours of power likely to be supplied from the electricity grid and water requirements of approximately 3 gigalitres per annum.

4. On 18 December 2016, the Minister for Planning issued a decision determining that an Environment Effects Statement (EES) was required for the project due to the potential for a range of significant environmental effects. The purpose of the EES is to provide a sufficiently detailed description of the proposed project, assess its potential effects on the environment and assess alternative project layouts, designs and approaches to avoid and mitigate effects (**Tab 1.1 / Scoping Requirements**).

5. An Inquiry and Advisory Committee (IAC) was appointed to review the EES and public submissions (**Tab 1.2 / Terms of Reference**).

6. The IAC was scheduled to commence public hearings in February 2021, however the commencement date for the public hearings was adjourned to enable parties to respond to a number of changes proposed by Kalbar including the addition of centrifuges.

7. The proposed changes to the project are set out in the following documents provided by the Kalbar:

    a. Letter to the IAC from Kalbar dated 18 January 2021 (pp1-2) (**Tab 2.1**);

    b. Technical Note 01 'Implementation of centrifuges for water recovery and tailings management' dated 18 January 2021 (**Tab 2.2**);

    c. Updated EES Chapter 3: Project Description dated 8 February 2021 (**Tab 2.3**);

    d. Expert Witness Statement of Ivan Saracik dated 8 February 2021 (**Tab 2.4**).

2. Further information on the proposed use of centrifuges remain outstanding (i.e. see the questions posed by the IAC on 25 February 2021 (**Tab 3.2 / IAC's Request for Further Information**).

3. The IAC will hold public hearings for 7 to 8 weeks commencing on 3 May 2021, after which it will produce a report for the Victorian Minister for Planning. Following receipt of the IAC's report, the Minister for Planning will then make an assessment as to whether the likely environmental effects of the project are acceptable (**Minister's Assessment**).

Instructions

4. We request that you undertake a review of the geotechnical centrifuge modelling aspects of the project (documents at paragraph [7] above) and prepare an expert witness statement providing your opinion on:

    a. The appropriateness of the methods, including modelling, to evaluate the technical feasibility of the implementation of centrifuges as proposed.

    b. Whether the actual or likely risks arising from the use of centrifuges are identified and or appropriately assessed in terms of their level of risk.

    c. The appropriateness of the site selection for the centrifuges as proposed.[1]

    d. Any other matters you identify which you consider relevant within the limits of your expertise, including any limitations of the geotechnical centrifuge modelling aspects of the EES.

    e. Any appropriate qualifications or conditions that should be attached to findings or conclusions, such as uncertainties or gravity of threats or impacts.

5. As an expert you are able to consider any such material you consider relevant to your enquiry. Please identify in your report any further materials you consult outside of the briefed materials.

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[1] **Note**: Figure 3.1 of Chapter 3 depicts the centrifuges directly after the Wet Concentrator Plant (WCP) whilst Section 3.6.1 of Chapter 3 states that the two centrifuge buildings will be located near active mining areas within which a Mining Unit Plant (MUP) is operating (i.e. away from the WCP)).

Expert Witness Code of Conduct

6. We have enclosed a copy of the *Guide to Expert Evidence provided by Planning Panels Victoria*, which is the relevant guidance for hearings before the IAC (**Tab 3.1**).

7. In preparing your final expert witness statement, please ensure that you:

   a. include your name, address, qualifications, experience and area of expertise;

   b. provide an up front summary of key issues, opinion and recommendations;

   c. include all instructions that define the scope of the statement (i.e. please include a copy of this letter of instruction dated 2 March 2021 as an appendix to your statement); and

   d. include details of any other significant contributors to the report (if there are any) and their expertise, and / or details and qualifications of any person who carried out any tests or experiments upon which the expert has relied in preparing the statement.

8. Further, please include the following declaration in your statement:

   'I have made all the inquiries that I believe are desirable and appropriate and no matters of significance which I regard as relevant have to my knowledge been withheld from the Panel.'

Important dates

9. To enable us to meet the Inquiry and Advisory Committee's filing deadline, we request that your Expert Witness Statement be provided by **noon** on **Wednesday 10 March 2021 (AEST).**

10. The IAC will conduct public hearings over a period of 7-8 weeks, commencing on 3 May 2021. [redacted] is likely to be scheduled to make their case in **early June 2021.** We will require you to be available to give evidence via video link before the IAC for half a day. Accordingly, please advise of the days on which you will **not** be available to give evidence before the IAC in the first weeks of June 2021.

11. We anticipate you will also be directed to meet fellow centrifuge experts for half a day in early-mid April. We will provide further information about the meeting of expert witnesses in due course.

(4)

Confidentiality

12. This request for a Supplementary Statement, as well as any correspondence relating to this request, is for the purposes of the Fingerboards mineral sands mine project EES process, including the public hearings before the IAC. It is therefore confidential and is protected by legal professional privilege.

Fees and Terms of Engagement

[redacted]

Please contact Virginia Trescowthick if you have any questions or require further information.

Yours faithfully

[redacted]

Virginia Trescowthick

Lawyer

(5)

Appendix C: Alfa Laval centrifuges used to dewater mine tailings

Table 1. Alfa Laval centrifuges used to dewater mine tailings (Source: Nalco Test report, dated 5 May 2015)

Site	Model	Technology	Bowl Diameter	Industry	Slurry type	Status
Rixs Creek, Bloomfield NSW, Australia	P3- 10070	Solid Bowl P3 tailings centrifuge	1000 mm	Coal	Coal tails	Operating
Rixs Creek, Bloomfield NSW, Australia	P3- 10070	Solid Bowl P3 tailings centrifuge	1000 mm	Coal	Coal tails	Operating
Rixs Creek, Bloomfield NSW, Australia	G2-125	Solid Bowl G2 centrifuge (modified for high wear protection)	720 mm	Coal	Coal tails	Operating
Rixs Creek, Bloomfield NSW, Australia	G2-125	Solid Bowl G2 centrifuge (modified for high wear protection)	720 mm	Coal	Coal tails	Operating
Rixs Creek, Bloomfield NSW, Australia	G2-125	Solid Bowl G2 centrifuge (modified for high wear protection)	720 mm	Coal	Coal tails	Operating
Kestrel Coal Mine, QLD, Australia	P3- 10070	Solid Bowl P3 tailings centrifuge	1000 mm	Coal	Coal tails	Process commissioning January 2020
Kestrel Coal Mine, QLD, Australia	P3- 10070	Solid Bowl P3 tailings centrifuge	1000 mm	Coal	Coal tails	Process commissioning January 2020
Kestrel Coal Mine, QLD, Australia	P3- 10070	Solid Bowl P3 tailings centrifuge	1000 mm	Coal	Coal tails	Process commissioning January 2020
Meandu Coal Mine, Stanwell Corporation, QLD, Australia	P3- 10070	Solid Bowl P3 tailings centrifuge	1000 mm	Coal	Coal tails	Commissioned, process/ floc optimisation ongoing

Site	Model	Technology	Bowl Diameter	Industry	Slurry type	Status
Meandu Coal Mine, Stanwell Corporation, QLD, Australia	P3- 10070	Solid Bowl P3 tailings centrifuge	1000 mm	Coal	Coal tails	Commissioned, process/ floc optimisation ongoing
Syncrude Tar Sands Mine, Alberta, Canada	P3- 10070 (branded as Lynx 1000 but identical)	Solid Bowl tailings centrifuge	1000 mm	Tar Sands	Tar sands tailings	Operating
Syncrude Tar Sands Mine, Alberta, Canada	P3- 10070 (branded as Lynx 1000 but identical)	Solid Bowl tailings centrifuge	1000 mm	Tar Sands	Tar sands tailings	Operating
Syncrude Tar Sands Mine, Alberta, Canada	P3- 10070 (branded as Lynx 1000 but identical)	Solid Bowl tailings centrifuge	1000 mm	Tar Sands	Tar sands tailings	Operating
Syncrude Tar Sands Mine, Alberta, Canada	P3- 10070 (branded as Lynx 1000 but identical)	Solid Bowl tailings centrifuge	1000 mm	Tar Sands	Tar sands tailings	Operating
Syncrude Tar Sands Mine, Alberta, Canada	P3- 10070 (branded as Lynx 1000 but identical)	Solid Bowl tailings centrifuge	1000 mm	Tar Sands	Tar sands tailings	Operating
Syncrude Tar Sands Mine, Alberta, Canada	P3- 10070 (branded as Lynx 1000 but identical)	Solid Bowl tailings centrifuge	1000 mm	Tar Sands	Tar sands tailings	Operating
Syncrude Tar Sands Mine, Alberta, Canada	P3- 10070 (branded as Lynx 1000 but identical)	Solid Bowl tailings centrifuge	1000 mm	Tar Sands	Tar sands tailings	Operating

Site	**Model**	**Technology**	**Bowl Diameter**	**Industry**	**Slurry type**	**Status**
Syncrude Tar Sands Mine, Alberta, Canada	P3- 10070 (branded as Lynx 1000 but identical)	Solid Bowl tailings centrifuge	1000 mm	Tar Sands	Tar sands tailings	Operating
Syncrude Tar Sands Mine, Alberta, Canada	P3- 10070 (branded as Lynx 1000 but identical)	Solid Bowl tailings centrifuge	1000 mm	Tar Sands	Tar sands tailings	Operating
Syncrude Tar Sands Mine, Alberta, Canada	P3- 10070 (branded as Lynx 1000 but identical)	Solid Bowl tailings centrifuge	1000 mm	Tar Sands	Tar sands tailings	Operating
Syncrude Tar Sands Mine, Alberta, Canada	P3- 10070 (branded as Lynx 1000 but identical)	Solid Bowl tailings centrifuge	1000 mm	Tar Sands	Tar sands tailings	Operating
Syncrude Tar Sands Mine, Alberta, Canada	P3- 10070 (branded as Lynx 1000 but identical)	Solid Bowl tailings centrifuge	1000 mm	Tar Sands	Tar sands tailings	Operating
Syncrude Tar Sands Mine, Alberta, Canada	P3- 10070 (branded as Lynx 1000 but identical)	Solid Bowl tailings centrifuge	1000 mm	Tar Sands	Tar sands tailings	Operating
Syncrude Tar Sands Mine, Alberta, Canada	P3- 10070 (branded as Lynx 1000 but identical)	Solid Bowl tailings centrifuge	1000 mm	Tar Sands	Tar sands tailings	Operating
Syncrude Tar Sands Mine, Alberta, Canada	P3- 10070 (branded as Lynx 1000 but identical)	Solid Bowl tailings centrifuge	1000 mm	Tar Sands	Tar sands tailings	Operating

Site	Model	Technology	Bowl Diameter	Industry	Slurry type	Status
Syncrude Tar Sands Mine, Alberta, Canada	P3- 10070 (branded as Lynx 1000 but identical)	Solid Bowl tailings centrifuge	1000 mm	Tar Sands	Tar sands tailings	Operating
Syncrude Tar Sands Mine, Alberta, Canada	P3- 10070 (branded as Lynx 1000 but identical)	Solid Bowl tailings centrifuge	1000 mm	Tar Sands	Tar sands tailings	Operating
Syncrude Tar Sands Mine, Alberta, Canada	P3- 10070 (branded as Lynx 1000 but identical)	Solid Bowl tailings centrifuge	1000 mm	Tar Sands	Tar sands tailings	Operating
Confidential (NDA in place) - Africa	P3- 10070	Solid Bowl tailings centrifuge	1000 mm	Base Metal	Tailings from mining of a base metal	Currently being commissioned
BHP Nickel refinery, WA, Australia	P2-505	P2 Solid Bowl Centrifuge	510 mm	Nickel refining	Nickel processing residue	Operating
BHP Nickel refinery, WA, Australia	P2-505	P2 Solid Bowl Centrifuge	510 mm	Nickel refining	Nickel processing residue	Operating
BHP Nickel refinery, WA, Australia	P2-505	P2 Solid Bowl Centrifuge	510 mm	Nickel refining	Nickel processing residue	Operating
Ambatovy Nickel refinery, Madagascar	P2-705	P2 Solid Bowl Centrifuge	650 mm	Nickel refining	Nickel processing residue	Operating

Site	Model	Technology	Bowl Diameter	Industry	Slurry type	Status
Ambatovy Nickel refinery, Madagascar	P2-705	P2 Solid Bowl Centrifuge	650 mm	Nickel refining	Nickel processing residue	Operating
Eti Maden, Turkey	P2-800	P2 Solid Bowl Centrifuge	740 mm	Borax Mining	Borax Tailings	Operating
Eti Maden, Turkey	P2-800	P2 Solid Bowl Centrifuge	740 mm	Borax Mining	Borax Tailings	Operating
Eti Maden, Turkey	P2-800	P2 Solid Bowl Centrifuge	740 mm	Borax Mining	Borax Tailings	Operating
Eti Maden, Turkey	P2-800	P2 Solid Bowl Centrifuge	740 mm	Borax Mining	Borax Tailings	Operating
Eti Maden, Turkey	P2-800	P2 Solid Bowl Centrifuge	740 mm	Borax Mining	Borax Tailings	Operating
Eti Maden, Turkey	P2-800	P2 Solid Bowl Centrifuge	740 mm	Borax Mining	Borax Tailings	Operating
Eti Maden, Turkey	P2-800	P2 Solid Bowl Centrifuge	740 mm	Borax Mining	Borax Tailings	Operating

Site	**Model**	**Technology**	**Bowl Diameter**	**Industry**	**Slurry type**	**Status**
Eti Maden, Turkey	P2-800	P2 Solid Bowl Centrifuge	740 mm	Borax Mining	Borax Tailings	Operating
Eti Maden, Turkey	P2-800	P2 Solid Bowl Centrifuge	740 mm	Borax Mining	Borax Tailings	Operating
Eti Maden, Turkey	P2-800	P2 Solid Bowl Centrifuge	740 mm	Borax Mining	Borax Tailings	Operating
Eti Maden, Turkey	P2-800	P2 Solid Bowl Centrifuge	740 mm	Borax Mining	Borax Tailings	Operating
Eti Maden, Turkey	P2-800	P2 Solid Bowl Centrifuge	740 mm	Borax Mining	Borax Tailings	Operating
Eti Maden, Turkey	P2-800	P2 Solid Bowl Centrifuge	740 mm	Borax Mining	Borax Tailings	Operating
Eti Maden, Turkey	P2-800	P2 Solid Bowl Centrifuge	740 mm	Borax Mining	Borax Tailings	Operating
Eti Maden, Turkey	P2-800	P2 Solid Bowl Centrifuge	740 mm	Borax Mining	Borax Tailings	Operating