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# PLANNING FOR THE FUTURE – GROUND IMPROVEMENT TRIALS AT THE PORT OF BRISBANE

## ABSTRACT

The Port of Brisbane is located at the mouth of the Brisbane River at Fisherman Islands in Brisbane. In recent years, Port land has seen rapid development as a result of increased trade growth. This growth in the South East Queensland region is expected to continue for the next 25 years and beyond. The expansion and development of future Port land will see the reclamation of about 235 ha of existing tidal flats bounded by the FPE (Future Port Expansion) Seawall which was constructed to contain the reclamation. The reclamation will be carried out using channel maintenance dredging materials consisting of river muds capped with sand, as has been the past practice. The seabed conditions, however, are significantly different in the seawall area because of the high water table, in-situ compressible clays over 30 metres deep and the increased thickness of up to 7 to 9 metres of river muds to be deposited into the reclamation.

Whilst historically it has taken about 10 years for reclaimed land to be available for commercial use, it is currently anticipated that this timeline will have to reduce to less than 5 years to meet demand. Therefore

there is a critical need to accelerate the consolidation of the reclaimed land as traditional surcharging used at the Port in the past will not meet the future development timelines. In order to optimise various ground improvement techniques and assess their suitability for the local conditions, the Port of Brisbane Corporation invited expressions of interest from specialist ground improvement contractors for the design, supply and installation of ground improvement techniques to carry out full scale trials in the existing reclaimed land. Based on this process three internationally known contractors were appointed to conduct trials using wick drains and vacuum consolidation. Relevant performance criteria were established to assess performance throughout the design and installation phases to enable a successful Trialist and system or systems to be selected next year to start the broad-scale roll-out programme.

Port of Brisbane Corporation and Coffey Geotechnics wish to acknowledge the professional and cooperative manner in which the three Trialists, namely, Van Oord, Boskalis Australia and Austress Menard have gone

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Above, Aerial view of the Port of Brisbane showing the reclamation areas including the trial areas.

about their works during the design and installation phases. This paper was first presented at the Coasts & Ports 2007 Conference, Melbourne, Australia in July 2007 and is published here in an adapted version with permission.

## INTRODUCTION

The Port of Brisbane is located at the mouth of the Brisbane River at Fisherman Islands. In recent years, the modern purpose-built Port has seen rapid development as a result of increased trade growth. This growth in the South East Queensland region is expected to continue for the next 25 years and beyond. The expansion and development of future Port land is critical to ensure that the Port's facilities can expand at a rate to meet this growth. In 1999 the Port embarked on plans to investigate the expansion of a 235 ha area immediately to the east of the existing reclaimed area.

In 2002, an Alliance Contract was formed between Port of Brisbane Corporation (PBC), geotechnical consultants Coffey Geotechnics (CG), coastal engineers WBM Oceanics, civil consultants Parsons Brinckerhoff and constructor Leighton Contractors, to deliver

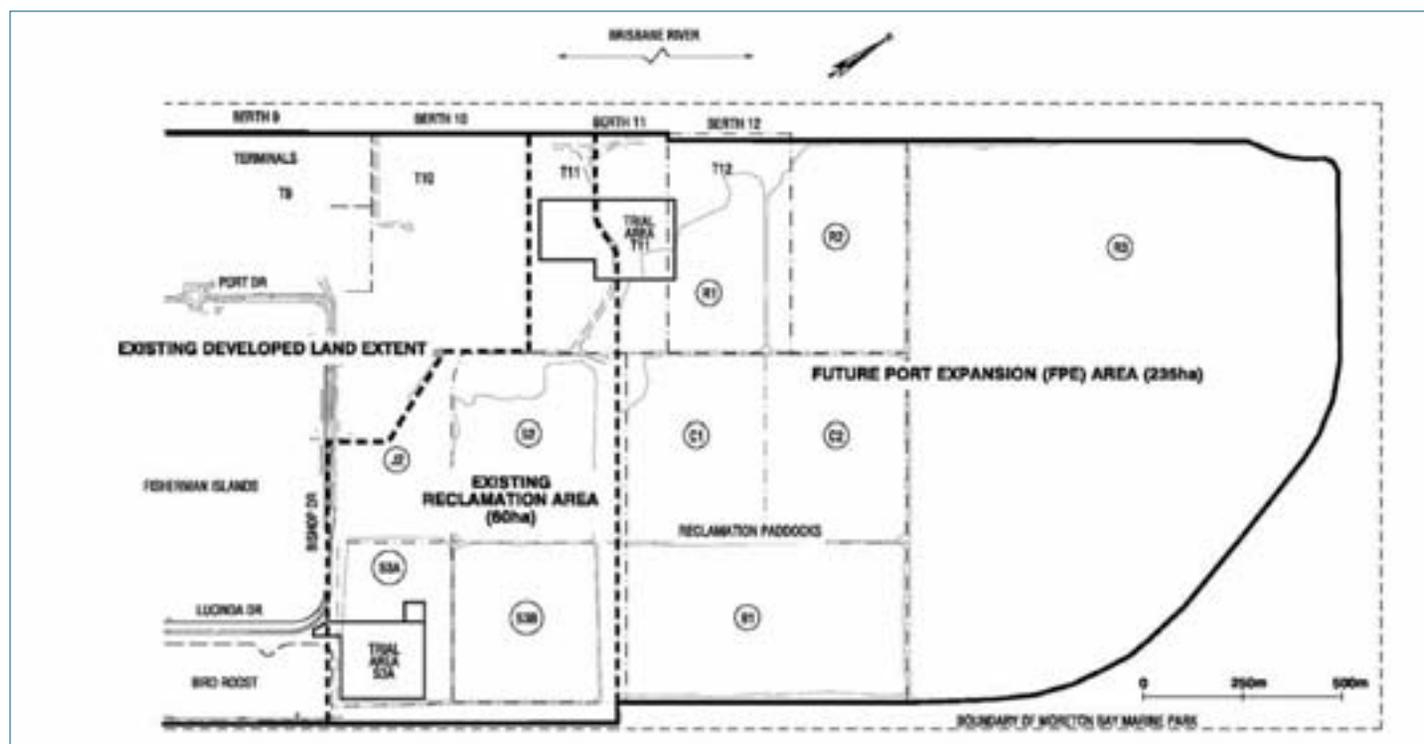


Figure 1. Site layout.

the Future Port Expansion (FPE) Seawall, a 4.6 km long perimeter rockwall which encloses the future expansion area. The Seawall construction, being the first stage in the expansion process, was completed in early 2005 (Ameratunga *et al.* 2003 and Andrews *et al.* 2005). PBC has since engaged CG as their geotechnical advisor for development of the reclamation areas.

### CREATION OF NEW PORT LANDS

The Seawall allows for the containment of the progressive reclamation of about 235 ha of existing sub-tidal flats. The reclamation will be carried out using channel maintenance and berth dredging materials consisting of several metres of river mud capped off with sand. At the existing reclamation area (Figure 1) approximately 60 ha remains to be developed (in 2006-2007), but is at a more advanced state of filling and capping than the FPE area. The subsurface conditions in the seawall area and the existing reclamation area are significantly different from the developed areas (Figure 1), because of the high water table, in-situ compressible clays over 30 m thick and the increased thickness

of up to 7 m to 9 m of river muds to be deposited into the reclamation. Generally consolidation timings for these undeveloped areas are predicted to be well in excess of 50 years if surcharging is the only treatment employed, as has been past practice. Settlements in the range of 2.5 m to 4 m are also forecast. Given the pressures of creating additional usable Port land in time frames approximately half of those achieved in the past, a decision was taken that new techniques to speed up the consolidation process need to be employed to meet the land development timings.

### TREATMENTS TO SPEED UP LAND CREATION

Clearly, filling the reclamation areas with sand sourced from the Moreton Bay channels instead of dredged mud would reduce the total thickness of soft clay and therefore minimise the impacts of filling the reclamation areas.

However, as PBC must maintain navigable depths in its river channels and berths, some 500,000 m<sup>3</sup> of mud on average is

dredged annually and must be disposed of in an environmentally friendly manner within the Port's reclamation areas.

Substantial research and investigation by PBC and CG into local and overseas practices of treatment of soft soil found that two main groupings of techniques are available to treat and improve the reclamation sediment and in-situ soils.

### Groupings of available ground treatments

Apart from conventional surcharging, techniques to improve the ground can be grouped into two main areas, namely:

1. Consolidation of the soft highly compressible soils by installing vertical drains or using vacuum consolidation with surcharging or;
2. Improve, reinforce or stabilise the soils to reduce settlements and improve shear strength and stiffness.

The suite of techniques falling under group 1 comprises the installation of vertical drains, including sand drains or prefabricated vertical drains (PVDs), in a square or triangular pattern, generally spaced at 1 m to 2 m.



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obtained his BSc degree from the University of Sri Lanka, MEng from AIT, Bangkok and PhD from Monash University in Australia. He has over 30 years experience and is currently a Senior Principal at Coffey Geotechnics Pty Ltd, Queensland. His expertise is in the areas of soft soils, construction and numerical analysis, and he works predominantly on infrastructure and marginal lands projects.



**CYNTHIA DE BOK**

received her BSc and MSc in engineering geology, from the Delft University of Technology (TU Delft), the Netherlands. She joined Coffey Geotechnics Pty Ltd, Queensland in 2004 and initially worked on the Wivenhoe Dam project before taking on the challenge of the geotechnical design and coordination activities for the Port of Brisbane's Ground Improvement Trials.



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holds a civil engineering degree and a PhD in engineering from the University of Queensland and is a Fellow of the Institution of Engineers, Australia. He has been involved with port planning, design and construction activities at the port for over 25 years. A recent highlight was the 4.6 km long FPE Seawall project, enclosing a reclamation area of 235 hectares. Bill currently has technical oversight of all engineering development works for the Port of Brisbane Corporation.

Vacuum consolidation is a process whereby a vacuum pressure is applied to an area already installed with pvd's to potentially increase their effectiveness. Generally all techniques here require the application of a surcharge loading to squeeze water out of the soft clay soils. Such loading must be equal to or in excess of the service loading the developed land will be subjected to. In vacuum consolidation, the vacuum pressure applied contributes to the surcharge loading, and therefore actual surcharge heights are reduced. An additional important advantage of the vacuum is the isotropic nature of the vacuum pressure and the correlated improvement of the stability under preloading, reducing considerably the risk of slope failure resulting from the surcharge.

Methods falling under group 2 include stone columns, piling the ground, mass mixing the soils, or local mixing of the soils over some form of grid by soil mixing. Where a grid of columns, piles, or in-situ mixed columns is used, a bridging mattress may be required across the site to transfer the surface loadings into the discrete soil supports. Significantly less or no surcharging is required with these techniques, and they generally provide a significant time saving. However, these treatments are typically more costly. In certain parts of the world, freezing of the ground can even be considered as a viable solution.

**Selection of Preferred Treatment Solutions**

Consideration was given to the most likely treatment technique applicable for use in a broad scale application. The conclusion was that the techniques available under group 1 would most likely be best suited for broad scale treatment. In addition they would pose no boundary differences with present sites, where land consolidation techniques using surcharging alone have occurred. With relevance to the Port of Brisbane reclamation area, group 1 techniques i.e. PVDs, shaped as the preferred treatment over vacuum for mass application, primarily because of the necessity of a 15 m deep cut-off wall to mitigate the local site conditions (i.e. the occurrence of sandy layers) at the paddocks. Conversely, the vacuum consolidation process and solutions

available under group 2 are considered to have merit in special situations such as edge treatments for berths or surcharge stability. The mixing of techniques from both groups, however, poses difficulties at transition zones which would need to be carefully considered.

**EXISTING GROUND CONDITIONS AND DESIGN PARAMETERS**

**Target service loading and settlement criteria**

Historically, ground treatment for the Port's developed existing reclamation area was designed for an in-service settlement criterion after construction of 150 mm in 20 years. This criterion was associated with nominated design service loadings applied to the adopted finished design pavement levels as follows:

- 36 kPa at marine terminal areas
- 15 kPa at warehousing areas and road corridors.

In planning for the future, however, PBC is considering increasing the design service loading of the marine terminals for future berths up to 50-60 kPa. Further, new land zoning of integrated logistics has been created, sandwiched between the marine terminals and warehousing zones, with an applicable design service loading of 36 kPa. This new zone covers areas previously gazetted as warehousing and subjected to a design service load of only 15 kPa. The increased service loadings, if adopted pose further challenges to the land development process in the new areas. Current thinking is that PBC may need to adopt two acceptance target service criteria in future as follows:

- Where the total thickness of compressible clays and mud is less than a nominated thickness, say 10 m to 15 m, retain 150 mm residual settlement in 20 years of service;
- Where the total thickness exceeds the nominated thickness adopt an increased target of 250 mm in 20 years of service.

Currently it is considered that a target of 150 mm of residual settlement may not be feasible when using group 1 techniques,

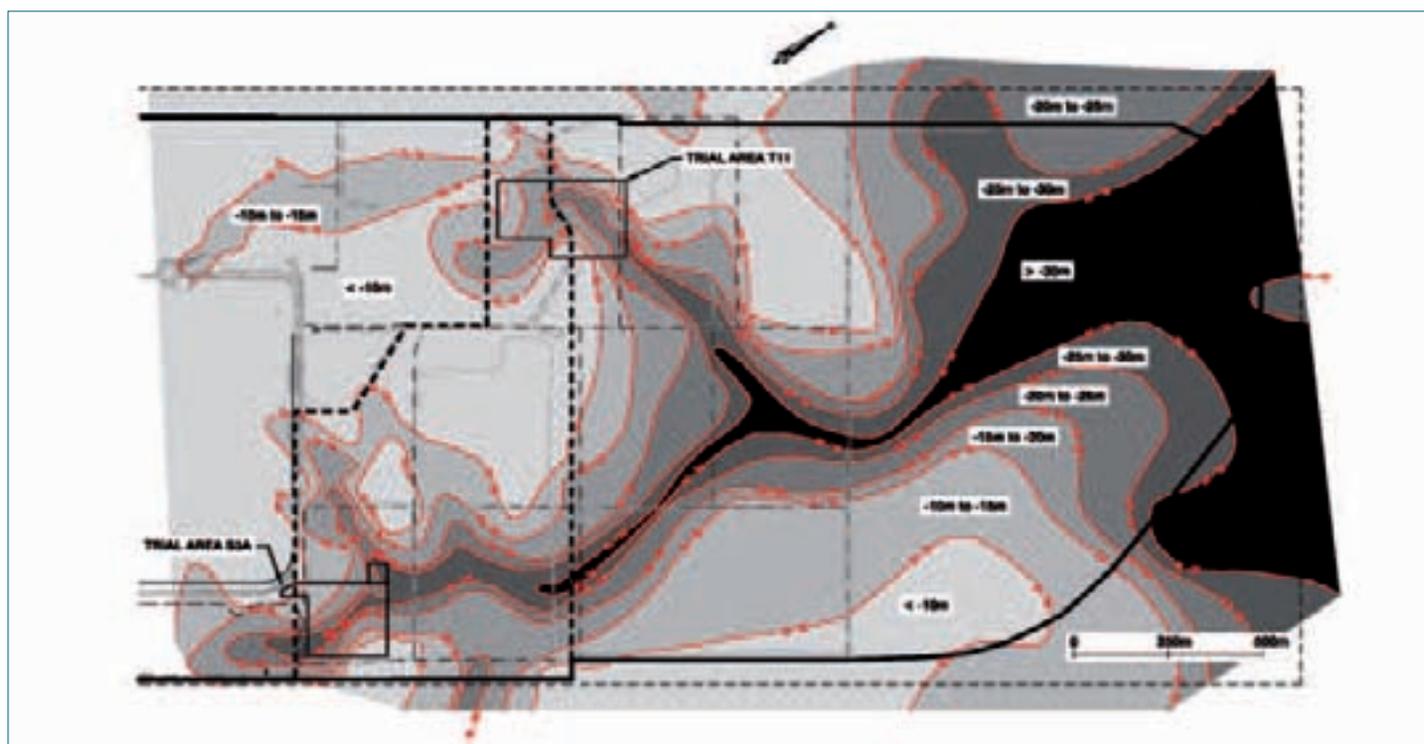


Figure 2. Basal surface of Holocene layer (in m RL, with RL 0m equal to Low Water Port Datum).

particularly where soft compressible clay thicknesses including mud can total in excess of 30 metres. In such cases the creep settlement contribution from the deeper layers, which may be only slightly over-consolidated with respect to the design service loading, may be significant and may not be easily built out.

### Geological Units

In the existing reclamation and FPE areas, four distinct geological units have been recognised and they are listed from the top down in Table 1 and are described below.

The most compressible units at the site are:

- Recent unit (dredged mud layer)
- Holocene unit (clay layers)

In Figure 2 the basal surface of the Holocene unit underlying the study areas is shown in relative levels. The final design surface elevations of the paddocks vary from 6m to 9m RL.

#### *Recent sediments*

These materials generally consist of modern dune and beach deposits and dredged fill. The soil types consist of silt, clay and fine to

**Table 1. Geological Units**

Unit	Description
Recent	Dredged mud, marine and dune sands with layers of silt and clay. This material may include fill, including dredged fill.
Holocene	Normally consolidated marine clay, silt and sand.
Pleistocene	Generally over-consolidated clay, sand and gravel.
Tertiary	Weathered basalt bedrock of the Petrie Formation.

coarse grained sand with interbedded layers of silt and clay. Shell layers may also be present. Material dredged from the river channels are deposited in the paddocks from a single point discharge, generating variable profiles in deposited materials.

#### *Holocene sediments*

Previous investigations have subdivided the Holocene sediments into an Upper and Lower layer of low strength silty clay with shell bands ("marine clay") separated by a discontinuous layer of sand. The Upper Holocene layer generally consists of sand layers interspersed with layers of soft clays and silts. Sand layers or lenses are relatively few or absent within the Lower Holocene layer.

#### *Pleistocene sediments*

The Pleistocene layer is an older alluvial deposit below the Holocene deposit and comprises mainly over consolidated, very stiff to hard clays and medium dense to dense sands and gravel immediately overlying the bedrock. The compressibility of these materials is relatively low compared to the soft/firm clays of the Holocene deposit.

#### *Tertiary basalt*

The weathered basalt bedrock of the Petrie Formation underlies the site and is described as grey-green clay (extremely weathered basalt) grading downwards into dark grey to black, moderately to slightly weathered basalt.

### Preliminary Geotechnical Parameters

Based on initial ground investigations of the study areas an average set of geotechnical material parameters for the dredged mud and the Holocene clay was chosen. It also enabled the creation of basic soil models at the various study sites. These details were included in the documentation package to be issued to the various prospective Contractors to enable them to undertake system selection and preliminary designs and provide associated pricing applicable to their systems and solutions. Creating such details would enable CG and PBC to make fair comparisons between any proposals received for ground improvement works.

These investigations also indicated low values for the coefficient of consolidation ( $c_v$ ), compared to previous results for the dredged mud layer and the Lower Holocene layer. The  $c_v$  relates to the dissipation rate of water from the clay and therefore together with the clay thickness and presence of sand layers determines the consolidation time. Settlement information from other older reclamation paddocks tends to indicate higher rates of dissipation, likely to be due to greater distribution of sand lenses within the dredged mud layer.

### METHODOLOGY FOR SELECTION OF OPTIMAL GROUND IMPROVEMENT SYSTEM

After due consideration of all known available ground treatment techniques, PBC decided to invite Expressions of Interest (EOI) from specialist ground improvement Contractors, either local or from overseas, interested in providing services for the design, supply, installation and monitoring of suitable specialist ground improvement systems to the existing reclamation areas at the Port of Brisbane.

#### Expressions of interest

The EOI document indicated that such systems should enable the reclaimed areas to be developed by the Port in a considerably shorter time frame than that achieved by surcharging alone, providing acceptable in-service settlements and at the same time

resulting in cost effective and optimum treatment solutions. Whilst the EOI document permitted any and all solutions, it did indicate that vertical drains including PVDs and sand drains were likely solutions. Sand drains were included on account of the ready availability of sand at the Port sourced from the bay shipping channels.

To enable the actual performance and cost of any proposed ground treatment solution put forward by Contractors to be evaluated, the EOI document proposed that one or two suitably qualified short listed Contractors would be selected and allowed to trial their systems on a four (4) hectare site. The documentation sought that Contractors provide preliminary costed designs and forecasts within their proposals for their systems of ground improvement based on the initial geotechnical parameters and basic soil models provided by CG and PBC and other relevant information contained in the EOI documentation.

#### Assessment of proposals received

At the closing of EOI submissions, eight proposals were received. Proposals were received from both local and overseas Contractors. Overseas Contractors from The Netherlands, Germany, France and SE Asia were keen to offer their respective expertise. The submissions received generally supported the use of PVDs as the preferred solution for the Port sites.

The EOI document contained six selection criteria that Contractors were advised would have their proposals assessed against. These criteria are listed in Table II.

PBC and CG assessed all Proposals received by scoring them against the selection criteria. This resulted in the short-listing of three preferred proposals. These three submissions could not be substantially separated in terms of the selection criteria, with all three offering PVD solutions. Two of the three Contractors offered vacuum consolidation systems as possible solutions in addition to PVDs.

#### Trials scheme adopted

PBC decided that there was considerable merit in trialling all three Contractors rather

than further reducing the number of trials and trialists from 3 to 2 or even to 1. Also, plans to develop future Berths 11 and 12 and associated backup lands further advanced as the EOI process progressed. Accordingly PBC decided to expand the trials scheme previously proposed to include three trialists and trial PVDs over 3 sites of 3 ha each with a further special edge area of 2.5 ha set aside for a vacuum consolidation trial. The successful trialists included three international companies: Van Oord, Boskalis Australia and Austress Menard (Menard). Contracts were subsequently successfully negotiated with each Trialist.

In addition, a scheme of assessment for the Trials during the design and construction phase was established and agreed with all three trialists. These criteria are largely based on expanding upon the criteria contained in Table II. It is further proposed to place a control or reference surcharge embankment, fully instrumented but without PVDs, for performance comparison purposes.

### TRIALS PROGRAMME

A 3 ha site was provided to each Trialist for PVD installation. Each Trialist was given the opportunity to propose a trial scheme which would generally enable maximum learnings for each. The design proposals put forward by the companies have shown a large degree of thought and individualism. The trials utilise several different PVDs, varying both in core and filter type and a range of different spacings.

Boskalis is also trialling its BeauDrain-S vacuum consolidation system, which is an Australian first. Menard is trialling their proprietary vacuum consolidation system along a special edge site. The system proposed includes a cut-off wall around the perimeter of the site to cut off the effects of sand lenses in the upper Holocene layer. This is the first such application in Australia. A Menard vacuum system, without a cut-off wall, is currently installed in the Ballina By-Pass Project, located in New South Wales, Australia.

**Table II. EOI assessment criteria**

Criteria	Issues
Overall Price	One of the key factors in the assessment will be the all-up price for the ground improvement treatment system, i.e. including all surcharging costs, monitoring, etc.
Past experience as designer & installer of ground improvement systems	A Proponent who has a demonstrated history as a proven ground improvement specialist with sound results in projects similar to that to be undertaken at the Port of Brisbane will be ranked highly against this criterion. This will also include expertise of personnel nominated to work on the project(s).
Ability to meet or exceed design criteria and timings nominated	Proponents who can deliver the works to PBC's preferred timelines whilst meeting the set criteria for the project will be ranked highly against this criterion. Ability to identify all risks and provide acceptable contingency measures will also rank highly.
Proponent's Financial capacity	Proponents will need to demonstrate an adequate financial capacity to undertake the project to be ranked highly against this criterion.
Warranties or Performance Guarantees	Proponents who submit warranties or performance guarantees to deliver the areas within the residual settlement criteria nominated under the nominated loadings and design criteria will be highly ranked.
QA, Environmental, and Loss Control systems	PBC is strongly committed to ensuring all its activities are carried out to the highest possible standards, including those relating to health, safety and the environment. Proponents who can demonstrate a similarly high commitment to these standards shall be ranked highly under this criterion.



Figure 3. The Boskalis/Cofra rig installing wick drains in the Terminal 11 Trial area. Rig is an 80t machine with 45 metre mast. The dredge pipe is in the foreground. A Car Carrier vessel departing the Brisbane River is visible in the background.

Figure 4. Close up of the Boskalis/Cofra rig during installation of BeauDrain-S.





Figure 5. Van Oord is also a trialist in the Terminal 11 Area. Stitching Rig is being filled with new reel of wick drain. Note wick anchor plates used to mark location of each wick prior to installation.

### Field trials progress

As at June 2007, Boskalis Australia had completed installation of all wick drains and the BeauDrain-S system (Figures 3 and 4). Van Oord had also completed all PVD installation works (Figure 5). After rather extensive preparatory works, including constructing the 15 metre deep perimeter vacuum cutoff wall, Austress Menard completed wick drain installation to all trial areas in May. The vacuum consolidation system installation including membrane, pipework and pumps was completed and the system commissioned in June 2007 (Figure 6).

The aerial photo (Figure 7) taken in June 2007 shows the Austress Menard site located in the S3A Trial area adjacent the Port's Bird Roost with the Moreton Bay Marine Park in the foreground, and the Port in the background. The black **L** is the vacuum trial area with (black) membrane, pipework and pumps installed. Behind this is the white sand drainage layer placed over the wick drain trial areas which extend up to the future road alignment. Surcharge placement across both the wick drain and vacuum trial areas is currently underway. The 15 m deep cutoff wall was installed around the perimeter of the **L**.

Given the expanded area of the trials and increased loading parameters, some 1.5 million cubic metres of surcharge is required to be placed following the contractors' installation works. Installation of an extensive number and type of monitoring instruments including piezometers, extensometers, deep settlement plates, load cells and inclinometers is now complete. Surface settlement markers on a 25 m grid are also in place.

The common view of the trialists is that meaningful interpretations of the measured performances of each trial area will be able to be made 6 months after the surcharge is



Figure 6. The 80t excavator from Austress Menard excavating the cutoff wall with the PVD installation rig working in the background.

placed to full load. PBC plans to have the results reviewed by CG experts, including Prof Harry Poulos, and externally by an appropriate expert. PBC is currently sourcing a suitable data capture and presentation software system for use during the Trials.

Trialists have submitted samples of all PVD types being used in the Trials to enable relevant laboratory testing of the PVDs to be undertaken, including horizontal and vertical flow capacities in unkinked and kinked states. Kinking of PVDs is a possible outcome with certain PVD cores subjected to large settlements.

### Anticipated outcomes

PBC and CG expect to achieve the following outcomes from the trials:

1. Identify the effectiveness of PVDs for local site conditions, including thickness and depth of dredged mud and soft clays plus natural drainage conditions
2. Identify the performance of PVDs for different spacings in relation to local conditions
3. Identify differences in PVD performance and cost implications
4. Verify consolidation times, and required surcharge loadings using PVDs and using vacuum consolidation
5. Identify performance of Contractors in relation to design and construction.

As regards comparison of design and construction capabilities of three world-class contractors, as the size of the trials has expanded, the 6 months results are not expected to be available before the middle of 2008.

### CONCLUSIONS

PBC identified that no single optimum solution existed to accelerate the consolidation of soils and dredged sediment to develop land within the future Port reclamation areas. Indeed several techniques are available and all have their advantages and disadvantages in relation to time, cost and performance. By calling and receiving expressions of interest from specialist contractors both



Figure 7. An aerial photo taken in June 2007 shows the Austress Menard site located in the S3A Trial area adjacent to the Port's Bird Roost with the Moreton Bay Marine Park in the foreground, and the Port in the background.

locally and overseas and subsequently engaging three world-class contractors to undertake an extensive suite of trials, PBC believes it will arrive at an optimum solution or series of working solutions. These solutions will be able to be utilized to develop large tracks of reclaimed land suitable for Port industries and meet a range of future time demands.

Whilst undertaking trials over an area of 11.5 ha looks excessive, it needs to be realized that this only equates to less than 4% of the land areas to be developed (see Figure 1). It is considered that the additional costs associated in undertaking the trials, such as extra field and laboratory testing and intense performance monitoring, will be recovered in the first couple of years of optimized broad scale treatment rollout. Further, it will provide for a significant degree of confidence in land availability timelines going forward that can be taken with confidence to the market place. Implementing results of the Trials will allow quality land parcelling for development that can be released in a staged, timely manner.

PBC is aware and currently addressing the logistical issues in instrumenting numerous large trial sites, data capture, processing and presentation and the placement of 1.5 million cubic metres of surcharge in an obstacle intense area.

The Trials have already generated significant interest from industry, both Client and Contractor.

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