AUSTRALIAN CONSTRUCTION ACHIEVEMENT AWARD 2012

TECHNICAL PAPER

PORT BOTANY EXPANSION PROJECT

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ABSTRACT

The $515m Port Botany Expansion Project was delivered for Sydney Ports Corporation by a Baulderstone - Jan de Nul Joint Venture. The scheme involved the reclamation of 60 hectares of land with 1.85km of shipping wharves, together with substantial community and environmental enhancements.

This project was technically complex and logistically challenging, and through the use of unique and innovative solutions was successfully delivered with the following key features:

- ***Engineering Innovation*** - development of pragmatic solutions to construction challenges, including the patenting of a new formwork tie bar system;
- ***Ground-breaking Design*** – development of cutting edge solutions in reclamation compaction, seismic engineering and continuously reinforced marine structures;
- ***Radical Construction*** – implementation of new construction methodologies, including production and transportation of the 640tonne concrete counterforts;
- ***Establishing New Benchmarks*** – setting the standards in design and construction for future infrastructure projects;
- ***Providing a Lasting Legacy*** – sustainable environmental delivery with significant local environment and community enhancements.

KEY WORDS

Port Botany, Port Botany Expansion, Baulderstone, Jan de Nul, Sydney Ports Corporation, counterfort unit, shear leg barge, port expansion, marine project, deep water wharf, screed frame, dredging operations, dynamic compaction, vibro-compaction

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1.0 The Port Botany Expansion Project

1.1 Introduction

Port Botany was developed in the 1970's to provide for the long-term trade requirements of Sydney and New South Wales. Over the last forty years demand at the port facility has increased steadily, with particularly strong growth over the last decade. This growth, as shown in Figure 1 below, has seen an increase in container throughput over the years from 175,000 TEUs* in 1970 to 1.98m TEU's in 2010.

During this period the port facility has been able to meet the increasing demand and growth of our economy by investing in evolving technology and through significant improvements in productivity. Whilst productivity and technology will continue to improve, it is unlikely they will be able to keep pace with the rapid global growth in container trade. Without action, the capacity of the existing terminals would be constrained by the limited number of berths and stacking area available to service the container ships. As such Sydney Ports Corporation is undertaking a massive port expansion project to ensure that Port Botany is capable of handling the projected demand of over 3 million TEUs by 2020.

The current expansion of Port Botany by Sydney Ports is the largest port project undertaken in Australia during the last 30 years, with a total project value of $1 billion dollars. The Port Botany Expansion Project represents the first stage of this port expansion works, with a value of $515m. This stage of the works will provide the reclaimed container handling yard and new shipping wharves. On completion of the project, this raw infrastructure will then be further developed by Sydney Port's selected stevedore, to provide a new, fully operational port facility by the end of 2012.

**TEU = Twenty foot (container) equivalent unit*

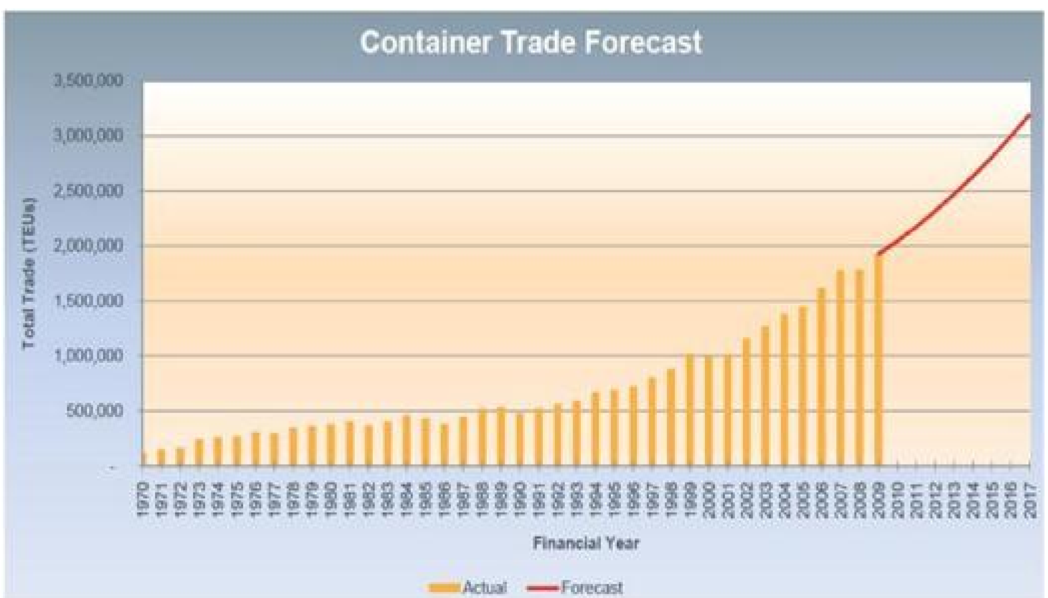

Figure 1 – Port Botany Container Trade Growth

1.2 Economic Benefits

Port Botany is currently the second largest container port in Australia (by volume), handling over $61bn worth of annual trade and generating more than $2.5 billion a year in economic activity. The expansion of the port will have significant economic benefits for New South Wales by improving efficiency of cargo handling and making exports more competitive. In addition to the 2,000 direct and indirect jobs that will be created during the construction phase of the works, the expanded port terminal is forecast to generate 9,000 direct and indirect jobs by 2025.

In conjunction with the project's important role in supporting the future economic growth of Sydney and New South Wales, the port will also provide a critical role for the State in post disaster relief. To meet this requirement, the terminal has been designed and constructed to ensure it will remain operational following a one in a 1000 year earthquake event.

1.3 Parties Involved

The Port Botany Expansion project was a Design and Construct contract, delivered for Sydney Ports by a consortium of Baulderstone and Belgium dredging experts Jan de Nul. The contract for the works was awarded in December 2007, and works commenced on site in mid-2008.

Parsons Brinckerhoff was engaged as the Independent Project Verifier for the project, with responsibility for verification of both the design and construction elements of the works. Design works were carried out by Hyder Consulting, with support from Scott Wilson (marine) and Golder Associates (geotechnical). A number of other design and durability consultants also played a key role in the design of the works.

1.4 Scope of Works

The Port Botany Expansion project involved the development of 60 hectares of reclaimed land with provision for five new shipping berths and over 1,850 metres of new wharves. In addition, substantial community and enhancement works were delivered along the Foreshore Road promenade. All works were constructed in close proximity to Sydney Airport's third runway and existing live port operations, as shown below in Figure 2.

The first stage of the terminal construction involved the dredging of foundation trenches to support the new wharf structures. These trenches were excavated to a depth of 30m underwater to remove clay and other unsuitable materials. The trench was then filled using clean sand sourced from site and compacted using marine vibro-compaction techniques.

Figure 2 – Extent of Port Botany Expansion Project Development

In addition to the foundation trench works, a variety of dredgers were also used to excavate the deep berthing basin and navigation channels required to provide access for future post-panamax sized container vessels. In total over eleven million cubic metres of material was dredged, with all operations controlled to meet strict turbidity compliance requirements.

The wharves themselves were constructed using reinforced concrete counterfort units. This replicated the design of the existing Port Botany wharves, and was the preferred option by Sydney Ports due to the lower maintenance and whole of life costs associated with a concrete solution. Each counterfort measured 20m high by 9m, wide and weighed 640 tonnes.

The counterfort units were precast on site and then moved to an adjacent storage area. Once cured, the units were transported 1.5km across the project site to a purpose built load out wharf. The counterforts were picked up from this temporary wharf using a 700t capacity shear leg barge, and manoeuvred into location over the new foundation trench. Once in position, the units were lowered onto a screeded foundation bed which had been prepared using a purpose built underwater screeding frame.

Following installation of the counterfort retaining wall structure the area behind the units was reclaimed. Reclamation material was collected at seabed level by a cutter suction dredger and pumped in slurry form through a floating line for either underwater or surface discharge. In total over eight million cubic metres of dredged material was placed in the reclamation area.

Material within the reclamation was compacted using both dynamic and vibro-compaction techniques. The counterfort units themselves were also treated with a combination of kentledge and surcharge loading to ensure that long term settlement performance was in line with stringent design criteria.

On completion of the compaction works, a continuous reinforced concrete cope beam was constructed along the full length of the new wharves. A full length rear crane rail beam was also constructed on a piled foundation to provide support for the rear leg of the future stevedore gantry cranes.

Other key works included the construction of 5km of rock revetment, a 200m tug berth, a new terminal access bridge and inter terminal rail access corridor, a three hectare public boat ramp facility and extensive community and environmental enhancement works.

Initial dredging and reclamation works commenced on the project in August 2008, and the new terminal was completed ready for handover to the subsequent stevedore in May 2011.

1.5 Challenges and Constraints

The project contained an inherently high level of challenges and constraints in both the design and construction phase of the works. These key challenges and constraints included:

- working adjacent to live port and shipping channels, whilst ensuring no disruption to ongoing operations;
- working within strict height limitations imposed by Sydney Airport's 'Obstacle Limitation Surface (OLS)' due to the close proximity of the works to the third runway;
- management of a substantial recreational boating community around continually changing marine worksites;
- dredging, placing and compacting eight million cubic metres of reclaimed material with no impact on the environment;
- design and delivery of the works to ensure compliance with the stringent long term performance objectives and 100 year design life criteria;
- management of program delivery where every sequential construction activity was effectively on the critical path.

All of the above issues were successfully managed by the project team both through the implementation of innovative design and construction solutions, and through strong leadership, planning and delivery of the works.

1.6 Key Design Features and Innovations

From a design perspective, Port Botany Expansion was a complicated, technically challenging infrastructure project. The stringent design criteria, specified operational loadings and complex geotechnical conditions demanded a high level of innovative design and modelling. To meet the challenges faced, a significant multidisciplinary team was assembled involving over 100 national and international design engineers and specialist consultants.

A number of cutting edge design solutions were developed during the design phase of the project to provide a robust, durable and economic product. These key design solutions, as detailed below, were integral to the overall success of the project.

Improved Counterfort Design

The design of the counterfort unit itself was developed from a traditional 6m wide unit with a single centrally located buttress wall, to a 9m wide unit with a second buttress wall. Whilst this substantially increased the weight of each individual unit, the solution provided a more efficient design by minimising the overall unit weight of wall structure. In addition, considerable program benefits were also achieved through the reduction in the number of units that needed to be cast and placed into position.

The 9m wide design also provided additional durability benefits as the majority of the front face of the counterfort remained in compression throughout all design load cases. The presence of this compressive stress across the front of the counterfort wall ensured that concrete would not crack, which meant the rate of chloride ingress was controlled and the amount of reinforcement required could be economised.

Iterative soil-structure Design

In light of the number and size of the counterfort units, considerable focus was paid during the design phase to optimise the design of the standard unit. Rather than designing for simplified earth pressure envelopes, the soil-concrete structure interaction was analysed and found to be complex and construction stage dependent. As such the structural wall design was tailored for site specific earth pressure envelopes which provided a significant economisation on materials and costs. This process also demonstrated a high level of correlation between the geotechnical and structural design models which provided an increased level of confidence in the robustness of the resulting design.

Vibro-compaction Methodology

An area that was thoroughly researched during the design phase was the potential impact of vibro-compaction on retaining structures. A review of published papers and other technical information did not identify any guidance on the use of this compaction method in close proximity to retaining wall structures, or any methods to estimate compaction induced pressures as a result of these works.

In order to understand this issue and reduce the risk of over-stressing the counterfort structure, practical research was completed on site in the form of compaction trials to assess and quantify the influence of vibro-compaction. This research enabled the team to develop customised compaction methodologies that reduced the risk of locking-in high earth pressure and wall stresses which could potentially have led to cracking of concrete wall panels.

Continuous Cope Beam Design

The use of a continuously reinforced cope beam tying in the top of the counterfort units, in lieu of the more traditional jointed cope beam structure, was another unique solution developed on the project. The design of this continuous cope beam was based on recent works carried out by Hyder on watertight building basements in

Dubai. By implementing this solution on the project considerable benefits were gained through a more efficient construction process because it enabled the extensive use of a standard counterfort and precast cope beam section.

By removing the joints and restricting potential movements, this design also provided greater assurance that the design criteria relating to the long term differential movement between the cope beam and rear crane beam would be achieved. This solution not only provided a more economic and durable product, but also exceeded the Client's expectations in permissible long term differential movements in this area.

Seismic Design Solution

As part of its role as a key piece of infrastructure, the new port was required to remain operational following an earthquake event. In order to ensure that the required operational characteristics were met during such an event, a shift was made away from conventional seismic bearing capacity safety factors towards a dynamic, displacement based seismic design.

This was a major shift away from established seismic design philosophy, but importantly enabled the client to make more informed, quantitative assessments of quay wall performance during a 1 in 1000 year earthquake. This more pragmatic design approach had not previously been used in marine situations, but provided additional assurance that Sydney Port's operational requirements and design intent were achieved.

Design and Construction Monitoring

To improve confidence that the new terminal would be fit for purpose, the designs were benchmarked against historical movements at Brotherson Dock, the existing port terminal. This allowed lessons to be learned from performance of original port structures and reclamation. Back analysis of movements of the original structures was used to help derive design parameters for the new port, in combination with site geotechnical sampling and testing.

In order to provide additional confidence to the Client that the performance of the berth structures and the reclamation were in accordance with the design predictions, an extensive monitoring program was also implemented during the construction phase of the project. Monitoring results were incorporated into an observational process involving check-analyses at any non-compliant areas. These 'as-built' models allowed the team to refine design assumptions, check reclamation / structural behaviour and optimise construction designs. This process improved certainty in the design and helped achieve considerable material savings.

1.7 Key Construction Features and Innovations

A number of unique, pragmatic solutions and methodologies were implemented during the construction phase of the works. These were all based on proven, sound engineering principles and executed using reliable and available technologies, albeit on a very large scale. The development of these solutions, as detailed below, was encouraged through a culture of innovation, and through the establishment of close, productive relationships between the construction team and designers.

Radial Precast Yard Methodology

The construction of the 216no concrete counterfort units was carried out on site. To achieve this, a radial precast yard was established, centred around a 460t capacity ringer crane. The yard consisted of three rings: an outer ring for storage and materials handling, a median ring for reinforcing cage prefabrication and an inner ring for concrete forming and pouring. At its peak the precast operation utilised 220 men, tying 50t of reinforcement, pouring 300m^3 of concrete and undertaking 2,000t of lifting operations per day.

The counterfort units themselves were constructed in three sections, each of roughly equal weight. The base and wall sections were constructed in moulds set up around the central crane. Once these elements had been cast, the base was lifted out of the mould by the ringer crane and placed in an adjacent assembly area. The wall section, which was cast lying down, was rotated out of its mould and positioned on top of the completed base unit. The base and wall were then stitched together by the two buttress walls, to form the completed counterfort unit.

This radial precast yard was developed in lieu of a more traditional linear yard, to allow for a rapid site establishment utilising land available early in the construction cycle. From a program perspective, the efficiencies achieved from the radial yard set up enabled the team to substantially exceed programme requirements, producing seven 640t units per six day cycle.

Patented Tie Bar System

The sheer scale and size of the counterfort operation dictated that a number of standard construction techniques needed to be modified to meet the stringent durability requirements. One area of focus was the development of a new system for the treatment of formwork tie bar holes, in order to eliminate the requirement to carry out extensive concrete patching works. The use of traditional tie bar patches was considered a potential durability weak spot in the completed counterfort structure, due to reliance on the integrity of a concrete repair solution.

As part of this durability review, the buttress formwork was designed to accommodate full hydrostatic head over the 20m high wall pour. This was required to enable the pours to be carried out within a target two hour period, and also to ensure that compaction loading applied by the external form vibration system did not damage concrete that had already undergone an initial set. To accommodate the pressures involved, a purpose built stress bar system was developed which incorporated an ingenious plastic tie bar tube. This tube not only performed the standard spacer tube functions, but provided a durable solution whereby the cast in tie bar could remain in the works without any requirement to remove and patch the section of tube contained within the cover zone.

To provide this superior durability performance, the tie bar tube had several key features, including:

- roughened surface for superior concrete / plastic adherence;
- use of ridges and flanges to increase the travel path for water travelling along the concrete / tube interface;
- inclusion of a factory applied polyurethane water-swelling sealant to provide a failsafe water tight seal against tracking water.

Several working prototypes were developed and subjected to vigorous performance testing by an independent laboratory to prove the integrity of the product. As a result of this testing the product was approved for use on the project and was subsequently patented by Baulderstone as a new invention. The use of this tube had significant advantages for the project, both in long term durability through the removal of over 100,000 concrete repair patches, and through the improved safety of the workforce by removing substantial works carried out at heights.

Concrete Mix Design

In order to provide the 100 year design life in a marine environment specialist concrete mixes were required to be designed and proven using complex chloride diffusion modelling. Producing a compliant concrete mix design was essential to the long term durability of the port facility as crack control in the structure was highlighted as the most critical element in achieving the specified design life.

The production of a compliant mix design was a challenging process due to the conflicting requirements of durability and constructability. A traditional durable concrete mix uses a high portion of supplementary cementitious materials such as fly ash and slag. This provides a very durable concrete, but with a slow strength gain unsuitable for precast operations. Conversely, a traditional Portland cement concrete provides the early strength gain required for precast operations, but has a lower durability performance.

To overcome this conflict, a series of mixes were developed which included sufficient supplementary cementitious materials to satisfy the durability characteristics, but also enough Portland cement to react with a complex brew of the latest polycarboxylate water reducers and other admixtures to provide accelerated early age strength.

In total, the overall mix design development work took 12 months and required substantial industry consultation, trial mix testing and site constructability trials. This ensured that the final mixes selected for the project not only provided the required 100 year durability, but were also placeable in the complex formwork systems and provided the high early strength necessary to operate an efficient precast yard. These mixes not only satisfied all specification and construction requirements, but also provided a superior durability performance well above Client expectations.

Integration of Temporary Works Designs

Another critical element of the works was the interface between temporary works designs and construction methodologies. The final design influenced the formwork, rock screeding and shear leg barge designs, whilst the precast handling methodologies, crane capacities and shear leg barge capabilities all affected the permanent design. This required an iterative approach to the design process to ensure that the permanent and temporary design requirements were considered and compatible.

To put this in perspective, the formwork systems and lifting equipment used in the precast yard alone required over 2,000 tonne of steelwork, detailed on over 1,500 temporary works drawings. All of these temporary work designs and construction methodologies had to be integrated into the permanent design to ensure that the structure was capable of accommodating all imposed temporary loadings. This all had to be completed in a timely manner to enable construction methodologies to be finalised and plant procured.

Counterfort Movement

A series of Self Propelled Modular Transporter units, fitted with a purpose built support frame, were utilised to transport the counterfort units on site. These units had integrated hydraulic rams enabling them to lift heavy loads, as well as a computer controlled 360^{o} steering system. This steering provided exceptional manoeuvrability, which was critical when moving the units within the tight constraints of the precast yard and storage areas.

A unique feature of this operation was the use of state of the art, high capacity kevlar slings to lift the counterfort unit. These slings were originally developed by the American military for their superior flexibility and low self weight, and had not previously been used to lift loads of this size. The slings provided excellent benefits to the project by not only eliminating damage to the concrete units that would have been caused by using steel lifting equipment, but through a substantial reduction in manual handling operations.

Design of Specialist Plant

The size and weight of the counterfort units meant that there was no existing equipment available globally that was suitable for the marine operations. As such the project team designed and built two key pieces of plant for the counterfort placement operation.

Firstly, an underwater screed frame was developed to provide a structural, level bedding surface for the counterfort units to sit on. This equipment firstly dredged the top metre of loose, uncompacted material from the foundation bed, and then replaced this with a screeded basalt bedding layer. By using a series of sensors and a fully computerised control system, the screed beds were constructed 18m underwater within a level tolerance of 30mm. This high level of accuracy provided an excellent platform for the subsequent accurate placement of the counterfort units.

To place the counterfort units a 700t capacity, fully ballastable, shear leg barge was designed and constructed to stringent Australian Bureau of shipping standards. This barge was used to pick the units up from the load out wharf, transport them on the water and then lower them into position on the screeded bed. By utilising a state of the art six point mooring system the manoeuvrability of this barge was so controllable that the units were placed within a 50mm positional tolerance.

1.8 Program Management and Project Delivery

The sequential, lineal nature of the construction works placed substantial demands on the efficient control and management of the construction program. This was because a delay to any activity could ultimately delay all subsequent deliveries. In addition, all works also had to be managed and programmed to interface with existing port operations, Sydney Airport constraints, recreational boaters and the general community. As part of this process, all dredge and crane operations were required to be coordinated with Sydney Airport Corporation Limited (SACL) and the Harbour Master. This included providing SACL Air Traffic Control with continual, real time dredge positioning information.

A number of strategies were employed to manage the delivery of the works and ensure that the program objectives were achieved. On a global scale, this included maintaining as much contingency as possible on each individual operation whilst still allowing flexibility to accommodate problems and unforeseen delays. This level of integration required high levels of detailed programming and field collaboration to ensure timely, dispute free completion.

On an individual activity scale, the precast yard operation provides some excellent examples of the level of planning that was carried out on all repetitive operations to ensure a high level of production was achieved.

Firstly, the 10,000t of reinforcement used in the counterfort structures was produced overseas and delivered to site in shipping containers. As part of this operation a considerable portion of the counterfort base and wall reinforcing steel was supplied as prefabricated, welded 'slices'. This not only provided greater efficiencies in production on site through a reduction in steel fixing, but also provided substantial consequential benefits through reduced manual handling and improved quality control.

Secondly, productivity benefits were also delivered through the use of a concrete maturity model to measure concrete compressive strength, in lieu of traditional destructive cylinder testing. This is an established process whereby the strength of a specific concrete mix is determined by measuring the actual concrete temperature of an element during the curing process, and comparing this to a mix specific maturity model previously established by laboratory testing.

Whilst the technology required for this process is not new, an innovative automated monitoring and reporting process was established through the use of wireless technology. To achieve this, two wireless temperature probes were cast into every concrete pour. These probes emitted a continuous temperature reading to a central base station, which would continuously analyse the data and calculate the theoretical strength of the concrete at any point in time. This system was implemented with great success in the precast yard, and included an automatically generated email notification when the concrete strength reached nominated target limits. The overall process provided unrivalled efficiencies in the execution of the works because daily operations could be accurately planned, and elements could be removed from the moulds within minutes of reaching the nominated compressive strength.

In conjunction with the pursuit of continual improvements and construction efficiencies, the site team were also very focused on ensuring that the safety of the work force was ingrained into every activity. This was particularly evident in the management of high risk activities on site, such as the heavy lift operations. In total, over 1,000,000 tonnes of heavy lifts were executed without incident. This was as a result of stringent planning, focused delivery and the establishment of strict plant maintenance procedures which included all site cranes undergoing a full, independent mechanical inspection every three months.

1.9 Benefits to the Community

On large infrastructure projects, the local community can often be adversely impacted as a result of the construction and future operation of a new facility. As part of the Port Botany Expansion project, Sydney Ports was committed to delivering this key piece of infrastructure whilst simultaneously minimising the impact on local communities.

In order to achieve this goal, the project included a $30m investment in the local community and environmental, including:

- construction of a four lane boat ramp and associated facilities;
- restoration and enhancement of Foreshore Road promenade including footpaths, cycle paths and extensive native vegetation plantings;
- provision of a pedestrian bridge across Foreshore Road linking the local community direct with Foreshore Beach;
- significant enhancement of the degraded Penrhyn Estuary including creation of bird roosting islands, and expansion and regeneration of existing saltmarsh habitat, mudflats and sea grass habitat areas.

These facilities were designed and developed in consultation with the local community and as such have been embraced and well used by all parties. In addition, areas of regenerated habitat have already led to an increase in native wildlife. The successful delivery of this part of the project has provided tangible benefits to the local community and will be a lasting legacy of the Port Botany Expansion project.

In addition to the above, a new terminal access bridge was also constructed to provide a third road access point in the port precinct, together with capacity increases to the existing rail infrastructure which will enable 40% of all container movements in the future to be facilitated by rail. These upgrades were important to provide increased freight capacity for the local network to enable the new terminal to operate with minimal impact on the existing local road network.

Ongoing community consultation was also conducted throughout the project through the establishment of functional Consultative Community Committees. These groups met on a monthly basis throughout the duration of the works, and were invaluable in ensuring the project was delivered with the least possible impact to all stakeholders.

From a wider community perspective, the project team also proactively encouraged opportunities to showcase the project, and to promote engineering and the construction industry. This included conducting numerous site visits and presentations for a range of organisations including schools, universities, professional bodies, engineering conference tours, and international industry visitors.

1.10 Environmental Sustainability

Port Botany Expansion provides a clear example of how the principals of sustainability can be successfully applied on a large infrastructure project, including:

Intergeneration Equity – successful regeneration and enhancement of Foreshore Beach and promenade areas as a habitat for native fauna and wildlife;

Precautionary Principle – early identification and incorporation as reclamation fill material of all Potential Acid Sulphate Soil (PASS) dredged material;

Biodiversity – saltmarsh propagation and replanting using local cuttings together with creation of new seagrass habitat beds;

Economy in the use of resources – recycling of waste water from site concrete batch plant and precast yard for use in dust suppression activities;

Mitigation of environmental impacts – continuous turbidity monitoring and reporting using solar powered monitoring buoys and real time SMS alert notifications;

Remediation of environmental damage - successful enhancement and regeneration of the degraded Penrhyn Estuary area as a habitat for aquatic life and migratory roosting birds.

The control and management of all environmental issues was based around a site specific Construction Environmental Management Plan. This plan included 22 environmental sub-plans which addressed all significant environmental activities. To assist in the execution and monitoring of these plans, a number of specialists were utilised on the project including saltmarsh and sea grass ecologists, marine scientists, soil conservationists, avian ecologists, and air quality, noise and vibration consultants.

The implementation of the environmental controls and plans was reviewed on an annual basis through five day audits conducted by the Department of Planning. The high level of environmental delivery and management was commended by DOP during the final project audit, and is clearly demonstrated by the fact that no non conforming items were identified by the auditors during any of the three annual audits.

1.11 Significance of Project works

Port Botany Expansion delivered a number of design and construction solutions that not only benchmarked the project at the forefront of Australian Engineering, but also represented world best practice in marine infrastructure construction. The project's lasting legacies include:

- rejuvenation of national and international interest in the use of reinforced concrete marine structures, through the proven delivery of a 100 year design life project;
- design of a world first 9m wide counterfort unit in lieu of the traditional 6m wide structure;
- implementation of a new radial precast construction methodology;

- § development of a patented formwork tie bar system;
- § development of an wireless temperature recording system to instantly assess concrete strength, which is already being utilised on other national precast projects;
- § development of world leading construction techniques for the compaction of underwater fill material behind sensitive retaining wall structures;
- § design of a 2km continuous reinforced concrete cope beam, a world first in port construction, which is already under consideration for use on future national and international marine projects;
- § recognition of the technical excellence delivered on the project through the publication of research papers in leading national and international industry journals and conference forums.

2.0 Managing Project Compliance

2.1 Control Systems

An essential element on large, complex projects such as Port Botany Expansion is that adequate control systems are established to ensure that the works are designed and delivered against the agreed specifications and objectives. As such, a comprehensive project management system was established on this project to control all major work activities. This system not only outlined the procedures necessary to control the works, but also detailed the ongoing monitoring required to ensure that the project objectives were being achieved.

In addition to the management systems, the project also operated a comprehensive review system on all design, temporary works and construction activities. This review process was carried out both internally by the joint venture team and externally by the Project Verifier. An important part of this system was to ensure that continual improvements were made through the project and that all lessons learned were captured and appropriate actions implemented for outstanding works.

2.2 Quality Assurance

The delivery of a high standard, consistent product was a strong focus of the project team at all times. This was particularly important on this project due to the aggressive marine environment and the stringent standards required to meet the specified design life. In addition to the implementation of a comprehensive Quality Management system (ISO9001), supported by a web based document management system, a range of specific quality control actions were implemented to ensure that the product delivered met all specified requirements. Examples of these actions include:

- steel reinforcement mill and processing facility in Thailand was inspected, audited and fully accredited by the Australian Certification Authority for Reinforcing Steel (ACRS);
- extensive concrete testing was undertaken, including ultrasonic and x-ray test procedures, to confirm that concrete placement and compaction met all design and durability objectives;

- extensive overseas surveillance conducted, supported by local compliance testing of delivered products;
- use of underwater cameras (remote operating vehicle (ROV) and diver helmet cams) to provide live feedback and surveillance of underwater operations.

Substantial design controls were also established to monitor and control the delivery of the works. This included the establishment of a 3d dredge model, based on extensive geotechnical investigations, which indentified areas of clay layering and high fines content material that were unsuitable for incorporation within the reclamation area. This model was used to guide the dredges and control the quality of sand that was placed in the reclamation. This process ensured the specified long term settlement criteria was not compromised through the inclusion of unsuitable reclamation material.

2.3 Adherence to Time and Budget

The implemented Project Management systems also established control processes to ensure that the project was delivered within the agreed commercial and program requirements. The timely delivery of this project was especially important to Sydney Ports because the completed infrastructure had to be transferred to the stevedore on a fixed date for the next stage of construction works to be carried out.

From a commercial perspective, this system included a comprehensive cost control and forecasting system, as well as an ongoing review process for identifying risks and opportunities during the delivery of the works. A series of Value Engineering workshops were also conducted at various stages throughout the project. The overriding objective of the established system was to ensure that potential problems, risks and opportunities were identified early enough so that any required actions could be undertaken. These systems worked well on this project and resulted in the development of a streamlined design which was efficiently delivered through economic international procurement and productive construction methodologies.

From a program perspective, a similar risk based control system was implemented to identify and action potential problems and opportunities. This involved the continual monitoring and alteration of construction activities to maintain as much contingency and flexibility in the program as possible, without compromising the overall delivery objectives. These processes assisted the project team in completing the new boat ramp facility and associated works nine months ahead of the contract program. This enabled the Foreshore Road promenade to be handed over to the public in mid 2010, providing considerable benefit to both the local community and other project stakeholders.

From an operational perspective, the success of the program management procedures was evidenced in the precast yard operation where the average production rate for a counterfort unit was 34% better than the original target program. This outstanding program benefit was delivered not only through the use of innovative construction methodologies, but through the implementation of ‘Lean Construction Management’ practices to encourage continual improvements throughout the construction period. This included the engagement of external consultants to train all personnel in Lean Construction procedures and principles, which resulted in tangible improvements in both safety and productivity.

3.0 Conclusion

The Award winning[(*)] Port Botany Expansion Project was a technically complex and logistically challenging project. The works were delivered safely, on time and within budget, through the use of innovative design solutions and construction methodologies.

The project provided important enhancements to the local community and environment, as well as major economical benefits and value for money to the wider community. In addition to setting a number of benchmarks for future infrastructure projects, both within Australia and the wider International industry, the project will continue to provide substantial tangible benefits for future generations to come.

[(*)] The Project Team are honoured to have been recognised through the following awards:

- Infrastructure Partnerships Australia National Infrastructure Awards 2012- *Contractor Excellence Award*
- Concrete Institute of Australia Awards 2011 - *Engineering Project Award for Excellence*
- Australian Construction Achievement Award 2012 - *Finalist*
- International Ground Engineering Awards 2011 – International Project of the Year – *Highly Commended*
- Engineers Australia Engineering Excellence Award 2011 – Infrastructure (Sydney Division) *- Highly Commended*
- Engineers Australia Engineering Excellence Award 2011 – Environment and Heritage (Sydney Division) *- Highly Commended*
- World Environmental Day Awards 2011 - Excellence in Marine and Coastal Management Award – *Highly Commended*
- Australian Marine Environment Protection Association's Environmental Award 2011 – *Highly Commended*