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Options for fixed mechanical sand bypassing at river entrances

N.T. Cowper¹, L. Nankervis² and A.D. Thomas³

Slurry Systems Pty Limited, Sydney, Australia

1, manager@slurrysystems.com.au

2, lex@ssm.com.au

3 allan@allanthomas.com.au

ABSTRACT

Littoral drift of sand along coastlines can result in sand bars forming off ocean entrances causing navigational problems. Conventional management of these sand bars involves regular dredging. Two alternative fixed sand bypassing technologies are considered. The world's first large scale fixed bypass system at Nerang, Queensland, Australia, is described. Since 1986 it has bypassed around 17 million m³ of sand. The system consists of 10 jet pumps mounted along an offshore jetty. An alternative option, not requiring a jetty, is to use a Submarine Sand Shifter (SSS) buried beneath the sand. The development, pilot plant testing, and operational experience of the Sand Shifter is described.

1. INTRODUCTION

Littoral drift is a natural process due to sand being suspended by the energy dissipated in breaking waves. The resulting sand movement is predominantly towards the beach shore. However, when waves strike the beach at an oblique angle there is a shore parallel component of sand movement, or littoral drift. The quantity of littoral drift sand varies depending on wave climate.

Depending on the prevailing wave direction, sand bars may build up across river entrances, inhibiting navigation. The conventional solution involves regular dredging of the entrance. A fixed sand bypassing system can provide a more economical alternative. Fixed sand bypassing involves a system to intercept the littoral drift sand before it reaches the entrance and pump it ashore to an on-shore pump station. The on-shore pump station collects the sand and pumps it via a submarine pipeline under the entrance to be deposited

on the beach on the down drift side of the entrance. Once on the beach the littoral drift action continues moving the sand along the beach away from the entrance.

In the case of the Nerang Sands Bypass system in Queensland, ten jet pumps are located along an off-shore jetty to intercept and collect the littoral drift sand. The jet pumps transfer the sand via an elevated sloping flume along the jetty to the on-shore pump station. The Submarine Sand Shifter alternative collection system does not require a jetty, with the unit being buried unobtrusively beneath the sand. The SSS transfers the sand to a jet pump at the end of the SSS which then transfers the sand to the on-shore pump station. Both the Nerang type system and the SSS system are usually installed in conjunction with rock groynes built out from shore on both sides of the entrance. The groynes catch and store sand, helping to prevent sand leaking into the entrance.

2. THE NERANG SAND BYPASSING SYSTEM

2.1 Background

The Nerang Sands Bypass System in Queensland is located immediately south of the Gold Coast Waterway entrance. The system was designed by Slurry Systems Pty Limited and constructed by McConnell Dowell Constructors Ltd. The system began operation in 1986 and was world's first technology then, and still remains very much at the leading edge of sands bypassing technology. Because of the prevailing wave direction there is a littoral drift of sand northwards along the coast in this area averaging about 500,000 m³ per year. The basis for the design was for 100,000 m³ in 5 days during storm periods. Without any intervention, the sand would have built up against the southern groyne until eventually flowing around the tip and forming sand bars in and offshore the entrance to the newly created Gold Coast Seaway. The conventional solution at that time would have been to conduct periodic dredging of the entrance, but this method could not be guaranteed to keep the entrance navigable at all times. The Nerang Sands Bypass System was the world's first fixed sands bypass system capable of operating in all weather conditions. During its 28 years of operation the system has been extremely successful and has transported more than 15 million cubic metres of sand. It has proved capable of continuous operation during the severest storms.

The design sought to exclude any mechanical device that would be difficult to maintain in a sand laden offshore environment. Hence the decision to install jet pumps which have no moving parts. The selected jet pumps were Genflo designed by Wakefield, U.K. and proven in dredge pump suction assistance applications.

Slurry Systems was aware of unique technology developed by the University of NSW involving hydraulic hoisting of coal in the coal mining industry and so was confident operation in a vertical configuration was acceptable. The hydraulic hoisting system was based on the "hydrohoist" principle which was similar to a jet pump. An essential element in hydraulic hoisting was a vertical configuration and an upward directed jet to both induct the surrounding solids and provide the pumping energy to lift the solids/water mix.

One technical issue was how to safely direct the delivery slurry flow from the discharge of each jet pump into a single transfer pipeline from the jetty to a feed sump at the main transfer pump station. A single pressurised transfer pipe would be subject to potential blockage, hence, the concept of an elevated flume. A sloped flume offers a wide range of flows whilst still maintaining a flow velocity above deposition velocity. Each jet pump has limited head capacity and hence limited capacity to provide both static lift and friction head loss. The outer jets discharged through individual pipes to discharge into the outer end of the elevated flume. Figure 1 shows a photo of the jetty with the sloping flume.

Towards the end of the jetty can be seen the vertical discharge pipes from each jet pump directed up and over into the top of the flume.



Figure 1 Photo of Nerang jetty

Another technical issue concerned the possibility of blockage of the submarine pipeline under the entrance. The submarine transfer pipeline profile included steep slopes both into and out of the Nerang entrance. There were concerns about the possible effects of shutdown and restart of the pipeline whilst operating with sand in the pipeline. Would the pipeline plug and how difficult would it be to restart the pipeline after shutdown? These concerns required pilot plant testing prior to final design. Pilot scale tests were undertaken to confirm the basis for the flume diameter and slope as well as investigate the possibility of blockage in the submarine pipeline.

Figure 2 shows a jet pump being installed, and indicates the scale of the pump and identifies the main components.

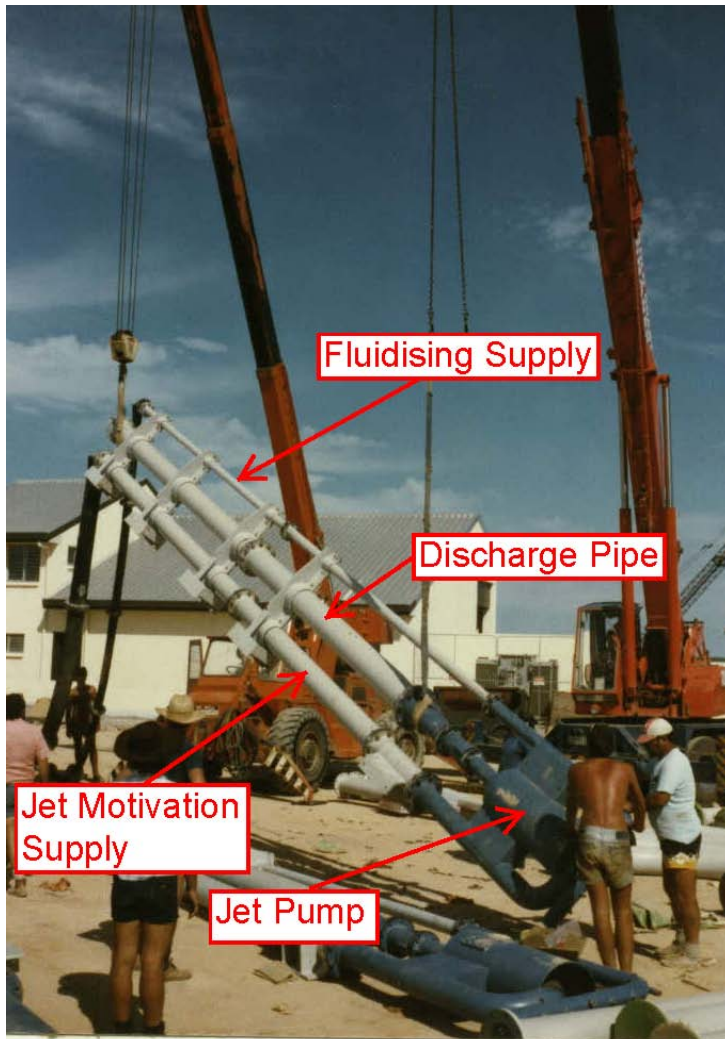


Figure 2 Installing a jet pump

2.2 Design Basis

Details of the Nerang design were recently outlined by Thomas (1) and design aspects are only briefly considered here. The basis of the Nerang system design is summarised in Table 1. The maximum quantity of littoral drift sand is $100,000\text{m}^3$ over 5 days, whereas the yearly average is $500,000\text{m}^3$. Consequently, the fixed sands bypass system is conservative from an availability sense.

The in-situ sand volumes refer to the in-situ volume of settled sand at an approximate volume concentration of 60%. One cubic metre of in-situ sand is equivalent to about 1.6 tonnes of dry sand. Under normal operating conditions the system is designed to operate at approximately 60% of the design capacity, but is capable of operating below 60% at a reduced efficiency.

Table 1
Design Basis of Nerang System

<u>Sand Properties</u>		<u>Design Sand Transfer Volumes (in-situ)</u>	
Specific Gravity	2.67	Annual average volume	500,000 m ³
Particle Size	d90=0.45 mm	Peak monthly volume	200,000 m ³
	d50=0.23 mm	Peak 5 day volume	100,000 m ³
	d10=0.17 mm		
<u>Design Criteria</u>			
Sand throughput (in-situ)		Maximum 585 m ³ /h, Normal 335 m ³ /h	
Design sand slurry concentration		Maximum 40%, Normal 31%	
Transfer pipeline flow		Maximum 1,760 m ³ /h, Normal 1,420 m ³ /h	
Weekly operation		Normal 30 hours	
Weekly sand throughput (in-situ)		Normal 10,000 m ³	

2.3 General Description

The sands bypass system consists of a jet pump recovery system, a flume transfer pipe, a remote sea water supply pump station, a transfer pump station and a sand transfer pipeline. A jet pump operates by providing a high velocity upwards flowing jet of water which entrains sand. Because of the high water velocity in the jet it is essential that the supply water be free of sand. Two 150 kW low pressure vertical axial flow sea water supply pumps, installed in a remote pump station adjacent to the Broadwater, supply water to the suction of two 560 kW high pressure jet water supply pumps located in the main transfer pump station. Ten Genflo "Sandbug" jet pumps are installed at 20 m intervals along a shore-perpendicular, 500 m long off-shore jetty, to serve the full length of the sand trap with any four or any seven operating at any one time. Under normal operation one low pressure sea water pump and one high pressure jet water supply pump supply four jet pumps to transfer the average sand volume. When peak sand transfer rates are required during periods of maximum littoral drift the second sea water supply and jet water supply pump and the remaining three of the seven jet pumps are operated. Any combination of seven of the ten jet pumps covering the sand trap can be operated. Each of the ten jet pumps discharge into an elevated pipe flume transferring sand slurry to the transfer pump station.

The Genflo jet pumps are designed specifically for sand dredging operations and to be non-clogging under fully buried conditions. Each pump includes integral fluidising jets which expand and fluidise the sand bed, enabling sand to be freely entrained by the jet pump at a controlled concentration. As sand is excavated from the region around the pump, the sand bed collapses to maintain a fluid bed adjacent to the pump. The trap continues to expand until the walls stabilise at the prevailing angle of repose.

A drawing of a jet pump is shown in Figure 3.

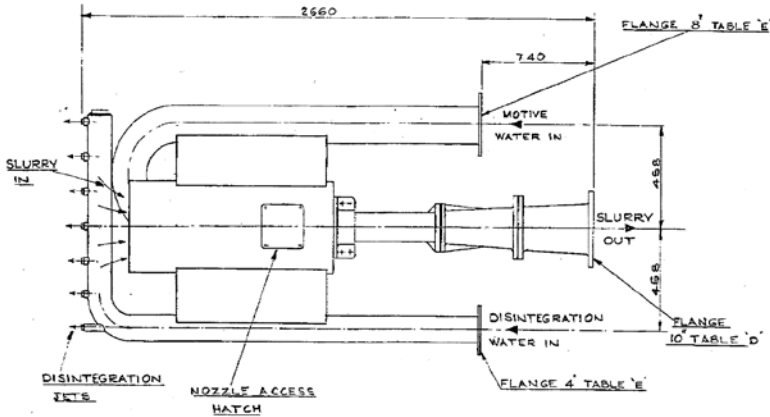


Figure 3 Drawing of typical jet pump

The 370 m long pipe flume at a slope of 2.5%, provides a non-blocking transfer system which has the capacity to handle a wide range of flow rates and solids concentrations. With each jet pump discharging separately into the flume, individual jet pump performance is not affected by the discharge pressure of other jet pumps, enabling the jet pump units to be properly balanced for equal performance. The jet pump discharge piping and pipe flume are lined with polyurethane for extended life.

The pipe flume discharges into a cone bottom sump which supplies the 710 kW Warman 14/12 G-AH centrifugal slurry transfer pump. During peak flow operation, excess water overflows the pipeline feed sump and the sand concentration automatically increases to the maximum design value in the transfer pipeline. The maximum flow rate is 1764 m³/h at 40% concentration and the normal flow rate 1420 m³/h at 31% concentration. A single DN400 steel pipeline, lined with polyurethane, transfers the sand slurry under the entrance for discharge north of the northern groyne. Total length of the transfer pipeline is 1430 m.

3. LIMITATIONS OF THE NERANG SYSTEM

From a process and mechanical criteria set by minerals industry standards, the Nerang system could transfer up to 5.5M m³ (in-situ sand) per year. So, at 500,000m³ (in-situ sand) per year the equipment is significantly under-utilised. Also, although the Nerang system was highly successful in maintaining a clear ocean entrance, the offshore jetty was expensive and would limit the application of the technology to commercially significant ocean entrances.

4. SANDSHIFTER DEVELOPMENT

4.1 Introduction

Slurry Systems recognised the financial and application limitations of the Nerang technology and changed the focus of fixed sands bypass technology to developing a cheaper alternative to apply, especially, to less significant ocean entrances. The development also recognised a need to provide a fixed system that was cheaper than the cost of trailer suction dredge methods of maintaining open entrances. The development, extending over a number of years, beginning with laboratory scale testing of a 1m long x 20mm wide sand shifter followed by pilot plant scale testing of a 13 m long x 50 mm wide shifter.

Concurrent to the development of the sand shifter, Slurry Systems, in conjunction with the Department of Marine and Harbours, Western Australia, initiated and investigated the preferred options for the location of a sand trap. This work, including model testing, concluded that a shore parallel trap is preferred over the shore normal trap as used at Nerang (Foster *et al* (2)). This work was orientated to a sand trap for direct jet pump recovery but the shore parallel trap is similarly optimum for a Sand Shifter. Sand shifters in a parallel trap location utilise the onshore/offshore movement of sand from breaking waves to feed sand to the recovery system.

One advantage of a Sand Shifter over a Nerang type system is evident from the geometry differences as illustrated in Figure 4. A single jet pump buried to RL-11 m as per Nerang, provides sub-seabed storage of only 1300 m³. By using a Sandshifter, it is possible to significantly increase the storage capacity. Cowper and Cowper (3), in general, discussed the various advantages of the sand shifter.

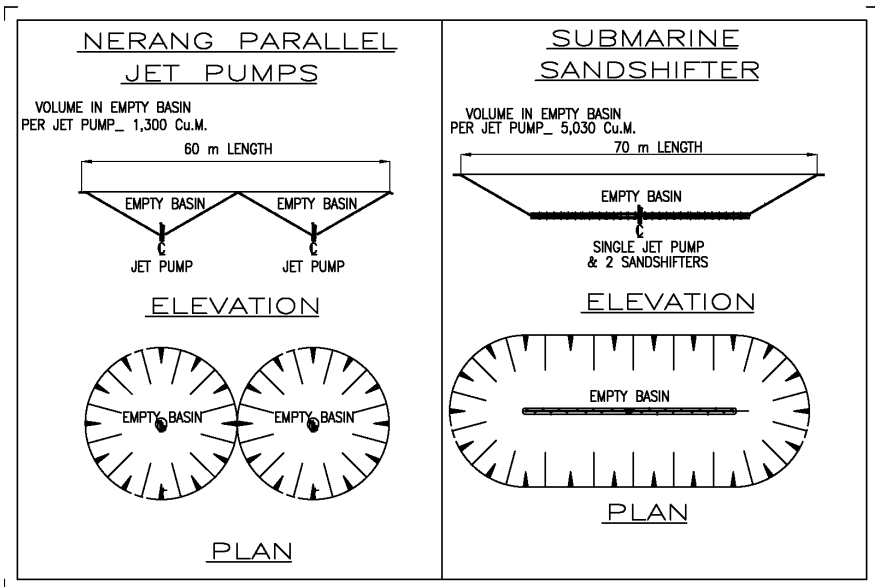


Figure 4 Sandshifter increases storage capacity

4.2 Sandshifter - Flow Mechanism

The major components of a Sand Shifter are indicated in Figure 5. They are: a header pipe/support frame providing pressurised water, an inverted U shaped flume formed by vertical skirts below the header pipe and sealed at one end, and a fluidising pipe with downwards facing nozzles situated below the inverted U.

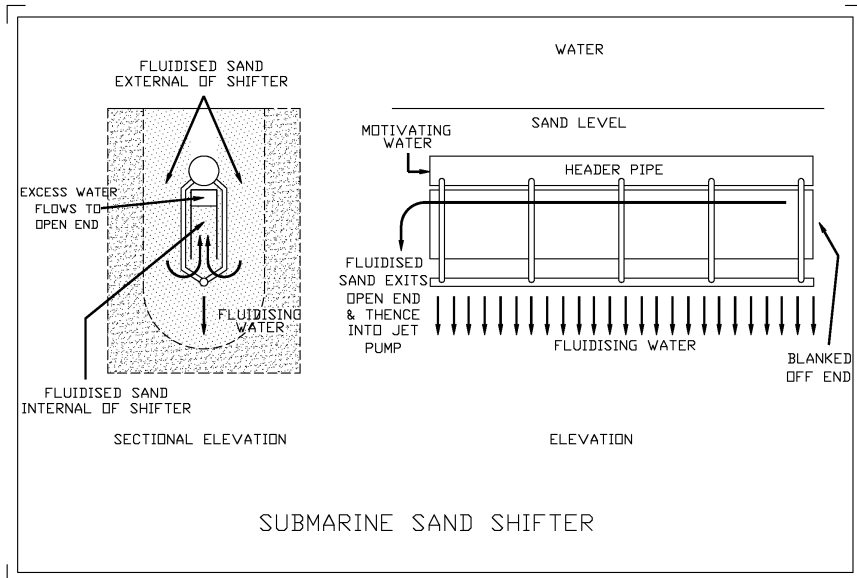


Figure 5 Schematic drawing of sand shifter

In operation, the shifter is buried beneath the sand. Pressurised motivating water flows through the horizontal header pipe then down via the vertical connecting pipes to the horizontal fluidising pipe below the inverted U. The fluidising water fluidises the sand within and immediately surrounding the shifter, causing the sand to become capable of flow. The difference in levels and mixture density of fluidised sand inside and outside of the shifter, force fluidised sand into the shifter where a resulting pressure differential and slight pressure gradient motivate the fluidised sand to flow horizontally within the shifter. If a sand cavity exists at one end of the shifter, the fluidised sand will flow horizontally within the shifter into the end cavity. In practical operation the cavity is formed by a jet pump located at one end. The jet pump at the open end of the flume collects the sand and pumps it ashore to a transfer station.

4.3 Laboratory Scale Tests

The initial laboratory scale tests were conducted in a 1 m long, 20 mm wide shifter. The rig consisted of a vertical sheet of plywood mounted 20 mm from the clear acrylic plastic side of a 1000 mm x 500 mm x 100 mm flume. A 20 mm wide wooden spacer formed the top of the simulated inverted U flume. The depth of the plywood skirt was varied between 50 mm and 200 mm below the under-side of the wooden spacer. Located 50 mm below the skirt was a fluidising pipe having 3.5 mm holes spaced at 50 mm intervals directed vertically downwards. The rectangular space between the skirt and the acrylic plastic wall formed the shifter. At one end an exit orifice allowed the fluidised sand within the simulated inverted U flume to flow into a collection sump from which the sand was removed and measured. The size of the exit orifice was varied from 200x20 mm to 20x20

mm. Pressure tapings at five locations horizontally along the shifter, just below the top, were connected to manometer tubes enabling the axial pressure gradient to be measured.

During a test, sand ($d_{50} = 0.27$ mm) was placed in the flume until it covered the top of the shifter by typically about 150 mm. The water level was typically 20 or 30 mm above the sand. Since the shifter was connected to the collection sump via the orifice, the water level was the same both in the sump and on the shifter side. When fluidising water flow commenced, the sand in the shifter became fluidised and it would start to flow out the exit orifice into the collection sump. It was continuously removed at a controlled rate such that the water levels in both the shifter portion and the sump were kept equal.

The laboratory scale test results revealed that the vertical flow velocities were very low, with the maximum during the tests being only 0.028 m/s. Thus the vertical flow down and up into the shifter is laminar. The horizontal flow inside the shifter is also generally laminar as confirmed by the low measured axial pressure gradient, typically about 100 Pa/m. The low pressure gradient is consistent with laminar flow of such a sand mixture.

A theoretical model was developed to predict sand flow rate as a function of fluidising flow rate, height of sand and width and length of shifter. The model allowed for the horizontal flow to become turbulent at high flow rates. The effect of shifter length can be envisaged as follows: The horizontal flow and concentration in the first 1 m length at the far end of the shifter will be similar to that in the laboratory scale tests. In the second metre length the concentration of solids moving up into the shifter will be similar to that in the first metre length. However it will also have the mixture from the previous metre length entering horizontally. Thus the horizontal velocity in this section will be approximately double that of the first metre and the discharge concentration will be less due to the diluting effect of the fluidising water. In this manner the velocity increases towards the exit and the concentration decreases.

4.4 Pilot Scale Testing

Pilot scale tests were conducted in association with the West Australian, Department of Marine and Harbours using a 13 m long x 50 mm wide shifter. The test unit was constructed using a 200 mm deep x 50 mm wide aluminium channel. The unit was installed in a 25 m long x 4.5 m wide x 1 m deep concrete basin. The exit end of the shifter passed through a 230 mm wide brick weir and extended 100 mm into a 4.5 m wide x 1.2 m long collection pit. The collection pit was 750 mm deeper than the test basin allowing sand to freely exit the shifter and collect in the bottom of the pit. Figure 6 shows the shifter installed inside the basin part way during the process of covering it with sand.

These pilot scale tests confirmed and demonstrated the suitability of SSS technology for sands bypassing. They also demonstrated that the presence of sea grass over the unit does not result in blockage. The sand is transferred under the accumulated sea grass. The tests also confirmed the suitability of the prediction model.



Figure 6 Photo of pilot scale shifter in test basin partly covered with sand

4.5 Predicted Behaviour in Full Size Shifter

The developed theoretical model was used to predict the behaviour in any size shifter. The concentration increases from 40% to 50% as the shifter width is increased from 20 to 100mm. The reduced frictional resistance as the width increases allows sand to flow more easily into the shifter. The concentration of sand entering the shifter is greater near the exit because of the greater net head available there.

Predictions were made for a 200 mm wide shifter having 1000 mm long skirts. Figure 7 shows the predicted solids delivery rate versus fluidising water flow rate for a length of 40 m, and a sand height level with the top of the shifter. The solids delivery rate initially increases rapidly but the rate of increase decreases at higher fluidising rates because the increased dilution with its attendant high velocities and pressure drop, reduces the solids delivered.

However, this does not mean the shifter cannot transport sand over longer distances than 40 metres. In practice, the sand in the first 40 m would be removed until the sand level drops to the bottom of the skirts. Sand transport would then cease. At this stage the sump has effectively been moved 40 m out to sea so sand will begin to be shifted from the next 40m and so on. In reality, it would be a more continuous process with a constant decrease in the height of sand above the shifter from the far end to the sump. However the practical limitation of mechanically handling and installing shifters over 20 m in length is a factor.

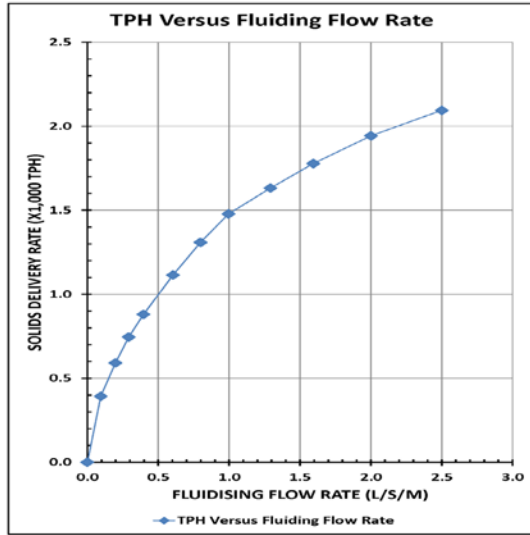


Figure 7 Sand shifter - typical production prediction

Figure 8 shows a full scale prototype about to be tested.



Figure 8 Prototype Sandshifter

5. PORT OF PORTLAND, VICTORIA AUSTRALIA

5.1 Fixed Sandshifters Installed at Portland

The first fixed sand bypass system using sand shifters was installed at the Port of Portland in Victoria, Australia. Full details of this project were given by Cowper and Nankervis (4). The Portland project required not only a fixed sand bypass system, but also a mobile sand

shifter unit mounted on a dumb barge to dredge offshore littoral sand accumulated over a period of years and ingressing into the harbour. The long term fixed shifter was installed in 4m of water on the ocean side of the western harbour groyne. In retrospect, locating the sand shifter off the tip of the groyne was not the ideal position to interface with the littoral sand processes. A better location would have been back near the start of the groyne.

The total Portland system is shown in Figure 9. The Portland units consist of two 18m sand shifters each coupled to a jet pump. If required, the coverage area of each unit can be readily increased by the addition of further 18m sand shifter units feeding to the jet pumps servicing the original units. The units are 60m offshore and 120m apart, they are self buried in the up drift sand accumulations east of the main breakwater.

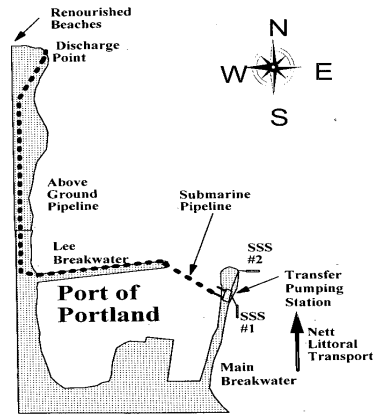


Figure 9 Port of Portland fixed sand bypass system facilities

The sand shifters create sand traps which are filled by littoral drift sand migrating along the eastern side of the main breakwater. The units are operated on an as required basis dictated by the weather-dependent littoral sand movement. The sand collected is pumped beneath the harbour and along the coast a distance of 3km where it recommences its interrupted littoral drift process and nourishes the down drift beaches, assisting in the protection of a shoreline which was previously undergoing severe erosion.

5.2 Mobile Sand Shifter Unit

The Port of Portland sand bypass installation contract also called for the initial dredging of accumulated sand and a buffer zone in and around the harbour entrance. To accomplish this, a 12m sand shifter coupled to a jet pump was mounted on a dumb barge along with the combined jet motive and fluidising water supply pump and a slurry pump. Recovered sand was pumped ashore via floating pipeline to the transfer station whereupon it was transferred along the coast via the bypass system.

The sand shifter was raised from, and lowered to, the sea floor by supporting winch wires and two A-frames. This arrangement negated the use of a dredging ladder hence motion of the barge was not transferred to the sand recovery unit. As a result, dredging was able to be conducted in seas that would preclude the use of most conventional dredges. Connecting extra lengths of supply water and slurry return hose to the sand shifter allows sand recovery in water depths restricted only by the installed pumping power. The mobile sand shifter can be readily adapted to operate from any floating platform thus negating the requirement for a specialised dredging platform. The mobile sand shifter system could be

utilised for sands recovery for beach nourishment from water depths that preclude most conventional dredges.

6. NOOSA SAND BACK PASS SYSTEM

A sands back pass system collects littoral drift sand and pumps it back along the beach to where it came from rather than pumping it under an entrance to continue its normal movement along the beach as at Nerang. In 2004, Slurry Systems Marine Pty Ltd undertook the trialling of a sands back pass system at Noosa Beach in Queensland, Australia. Noosa Beach suffered from regular erosion due to littoral drift. The trial was successful and a permanent, electrically driven system has been installed. Full details of the permanent system were provided by Nankervis (5).

The sand shifter system for sand recycling has proven itself to be an effective alternative to traditional methods of beach nourishment. The sand shifter system offers the following advantages over traditional intermittent dredging methods:

- Low cost solution for beach nourishment
- Low visual impact
- System is permanently installed there are no lead times or mobilisation periods before operation
- Unobtrusive installation without interfering with beach use
- Proven, low risk system
- Well suited to short term trial before commitment.

Additionally, the recycling system offers significant environmental advantages over the previous dredging activities:

- Sand is bypassed at a rate equal to the net longshore drift. Regular volumes of sand recycled do not inundate marine habitats.
- The sand is clean and well sorted, silt plumes are not generated.
- The estuary is not affected by the system and no sand is taken from it.
- The sand shifter system strives to imitate as close as possible, those processes that occur naturally

7. THE TWEED RIVER ENTRANCE FIXED SANDS BYPASS SYSTEM

7.1 Background

In late 1996, the NSW Department of Land and Water Conservation and the Queensland Department of the Environment, requested submissions for a permanent sand bypassing system for the Tweed River Entrance. Slurry Systems proposed a system based on the successful sand shifter technology which had been commercially proven at Port of Portland. The proposed system offered potential cost savings of 43% of the Nerang type technology. Unfortunately, the project team decided to accept a system based on the Nerang approach. In fact, the Tweed system was a carbon copy of the Nerang system, complete with offshore jetty and 10 jet pumps installed shore perpendicular, located to intercept the nett littoral drift.

7.2 Operation of the Tweed Fixed Sand Bypass System

Published data of sand bypassing and associated offshore dredging of the Tweed River entrance indicate some serious and costly failures of the Tweed Fixed Bypass System. The

Tweed system commenced operation in March 2001 and for the first six and a half years to September 2007 there was a requirement to dredge the Entrance. The indicated sand leakage for the Tweed sand bypass system over the period amounted to a dredging requirement of 1.5 million m³ of sand. Based on commercial dredging rates the leakage cost in the order of \$15 Million Australian. Why did the Tweed system leak when the Nerang system did not? The problem is readily apparent by comparing the available Google Earth images in Figure 10. The major reason is because the groyne associated with the Tweed system is much shorter than the Nerang groyne. This meant there was insufficient storage against the groyne to trap any sand which leaked past the jet pumps. The longer groyne at Nerang provides sufficient storage for the leaked sand to be subsequently moved back south into the jet pump storage basin as the crescent shape of the accumulated sand volume automatically changes the relative incidence of the waves relative to the trapped sand.

Pilot plant testing of sand bypassing using a shore parallel trap (Foster *et al*, (2)) concluded that a shore parallel sand trap was more efficient in trapping sand than the shore perpendicular system copied from Nerang and installed on the Tweed River Entrance. The adoption of sand shifter technology with a shore parallel configuration would have minimised sand leakage past the trap and into the Tweed River Entrance

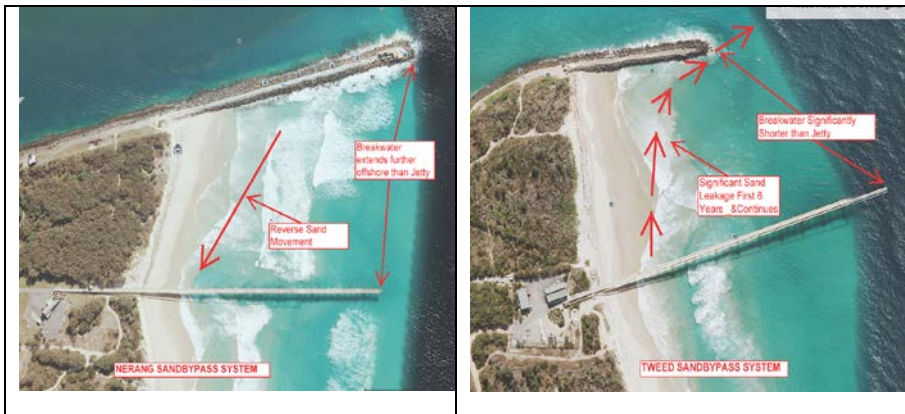


Figure 10 Comparisons - Nerang and Tweed sands bypass systems

8. CONCLUSIONS

The Nerang Sands Bypassing System has been a resounding technical success. It was the world's first fixed sands bypass system capable of operating in all weather conditions and after 27 years operation it has transferred 15 million cubic metres of in-situ sand. The Nerang Sands Bypass system requires a jetty structure. More recently Slurry Systems embarked on the development of a significantly cheaper sand bypass concept not requiring a jetty. This concept can be applied more universally to the majority of ocean entrances.

The development resulted in the invention of a fixed submarine sand recovery system, the Slurry Systems Sand Shifter Unit (SSUnitTM). SSUnits were initially commercialised at the Port of Portland, Victoria, Australia. The SSUnit development was extended to application at Noosa, Queensland, Australia. The Noosa system recovers littoral sand which accumulates at the western end of Noosa beach and recycles the sand for beach nourishment at the eastern of Noosa beach. The trialled system was successful and the

permanent system was installed a few years ago. The technology has been commercially proved and is available for installation for future fixed bypassing of ocean entrances.

The sand shifter technology provides a viable alternative to economically maintain navigable ocean entrance by fixed sands bypassing. Both the Portland and the Noosa systems proved the technology commercially, and demonstrated cost effective, environmentally friendly, sand bypassing to maintain safe navigable ocean entrances and nourish down drift beaches and shorelines.

The sand shifter technology is readily adapted to transform floating plant into sand recovery vessels capable of operating in deep water and sea conditions that exclude many conventional dredges. In another application, the low visual impact and ability of the sand shifter to be buried within the shipping channel itself, allows unobtrusive installation without interfering with safe navigation. The low cost installation and operation of sand bypass systems is now a reality and offers a technically viable alternative to conventional dredging.

9. REFERENCES

- 1) Thomas, A.D. (2013) Technical Innovations in the Nerang Sands Bypass System, *IRR 3rd Annual Slurry Pipelines Conference, Perth, Western Australia, Nov 13-14.*
- 2) Foster, D., Brindley, R., Thomas, A. and Blake, K. (1990), Sand Bypassing using the Shore Parallel Trap, *I.E.Aust. Ports and Harbour Conference, Melbourne, 28-30 August., IE Aust. Publication No. 90/7, pp 106-109.*
- 3) Cowper, N and Cowper, N., (1990). 'The Submarine Sand Shifter – A Unique Development to Economically Maintain Navigable Entrances', *IE Australia, Ports and Harbours Conference, Melbourne 28-30 Aug, IE Aust. Publication No. 90/7, pp 110-115.*
- 4) Cowper N.T., and Nankervis, L., (1997) 'Innovative Sand Shifter Technology for Maintaining Clear Ocean Entrances Year Round. Fixed Sands Bypassing at the Port of Portland, Victoria'. *13th Australasian Coastal and Ocean Engineering Conference and 6th Australasian Port and Harbour Conference, 7-11 Sept., Christchurch NZ, pp 871-875.*
- 5) Nankervis, L. (2005) 'Beach Nourishment with the Submarine Sandshifter', *Coasts and Ports 2005: Coastal Living – Living Coast, Australasian Conference. Adelaide, South Australia 20-23 Sept.*