ARTIFICIAL OFFSHORE ISLANDS

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1. ABSTRACT

This paper reviews the use, design and construction of artificial islands. This paper includes the use of artificial islands as hydrocarbon exploration and production platforms on the west coast of the USA and the Arctic and the use of artificial islands for surface access and ventilation for undersea coal mine operations in Japan.

The technology of artificial island construction has been used by the Dutch since the seventeenth century. Types of artificial islands include fill islands, caisson retained islands and hybrid islands. The technology is now available to build artificial islands in water 70m deep. Ocean floor based oil production structures have been designed for water depths of 300m.

The application of artificial island technology to the Sydney Coal Basin is discussed. The authors review the ventilation problems associated with submarine mines, types and cost of artificial islands that might be used for ventilation.

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2. INTRODUCTION

1. The ventilation of an undersea coal mine, from a land based structure, becomes increasingly difficult as the distance between the workings and the ventilation structure increases. The ventilating air must provide and maintain a safe working environment for the miners. As the air travels to the working face, a portion of the air leaks through worked out areas and it is not unusual to have an effective air flow at the face of 50% to 60% of the original intake air. The air velocity and quantity decreases due to resistance along the air path, and booster fans are often used to increase air velocity. An alternative to land based ventilation structures for coal mines is a ventilation shaft constructed from an artificial island. Artificial islands have been used in Japan, for ventilating coal mines, since 1951. This paper will discuss artificial island types, design and construction criteria. A preliminary assessment of the feasibility of using an artificial island to ventilate a coal mine in the Sydney Basin is presented.

2.1. THE VENTILATION PROBLEM

The Sydney Coalfield comprises of numerous coal seams which dip to the north and extend some 50 km in an east-west direction. The coal seams outcrop close to the shoreline. All existing and future underground coal mines in the Sydney coal field will extend under the ocean bottom very early in their life of operation. In order to reach the desirable limits of the coal reserve to depths of -1200 metres below sea level, the mines will have to extend some 10 km offshore. This in turn requires that the ventilating air will eventually travel 20 km to complete an air change. The resulting problems are numerous. The objective of the ventilation is to provide sufficient effective air to all working places. This air will dilute all noxious gases and dusts and render them harmless for breathing and safe winning of the coal reserves. In harmony with this main objective is the aim to ventilate the mines in a cost effective manner.

2.2. BASIC DESIGN CRITERIA

The cost of ventilating power is a function of how much air is utilized and what pressure is required to circulate the air where it is required. The total quantity of air required is based on: the gassiness of the seam; the production rates anticipated; the possibility of methane drainage or pre-drainage; the layout of the mine or the method of mining; and leakage quantities which never reach the workplace.

The optimum quantity of required air will be realized when resistance is minimized. The resulting lower pressures across ventilation doors and air crossings will minimize leakage losses at these points. Power is a function of the quantity of air cubed so it is of utmost importance that air not be wasted (Power = Resistance x $(\text{Quantity})^3$).

Resistance can be minimized in a number of ways. Resistance varies directly with the roughness of the airway surfaces and the area of the rubbing surfaces and varies inversely with the cross-sectional area cubed (Resistance = $(klo)/A^3$), where “k” is the roughness factor, “l” is the length, “o” is the perimeter, and “A” is the cross-sectional area; length “1” x the perimeter “o” gives the rubbing surface. Resistance, and therefore power cost, can be lowered by providing smooth surfaces such as lining between the web of arches, by minimizing the length of the airways in which the air must flow and most important, by maximizing the effective cross-sectional area of all roadways.

Lining roadways or minimizing sharp turns or winding roadways and increasing cross-sectional area are always possible and often feasible. The length of airways is normally beyond the planner's control in submarine mines such as in the Sydney coal field.

2.3. POSSIBLE SOLUTIONS TO THE VENTILATION PROBLEM

Increasing fan pressure on the surface will marginally increase the effective air at the face but this will also increase air leakages. This possible solution therefore requires tightening up all sources of leakages (which should be done in any case).

A more effective solution is the addition of booster fans which, while increasing total fan pressure, distributes the pressure along the circuit thereby minimizing excessive large pressure differences across ventilation doors and stopings near the surface.

In both cases, however, power costs are increased.

Controlled recirculation is one more method used to solve the problem of the long distances air must travel from the surface to the workplace and back. The concept of controlled recirculation is that a controlled portion of the air returning from the workplace is reintroduced back into the intake airways at some point underground on the return side of a booster fan. The success of this concept depends upon an acceptance of a certain level of methane in the intake air being fed to the work- place. This method is definitely cost effective and should be seriously examined as a feasible alternative among solutions to ventilation problems related to long distances from the surface. (This method will increase effective air at the workplace by about 10%, but will increase power costs by 5% to 6%.) Controlled recirculation is being used at the Wearmouth Colliery in the U.K. to re-circulate up to 30% of the inbye air. (1)

3. ARTIFICIAL ISLANDS

An artificial island in a strategic location could reduce by a third the distance the air must travel to complete an air change. This single parameter would reduce the resistance by a third and consequently the water gauge and power by a third. Normally, a minimum of three slopes are required, one designated for coal conveyance, one for man transport and one for material transport although any slope can be used interchangeably for material and/or man transport. Under normal mine layouts, two of these slopes would be intake airways and one return. There often is a fourth slope used for a return airway too. Let us consider the three slope scenario. An artificial island will allow all three slopes to be used as intake airways as far away as the vicinity of the level connecting the shaft on the island. This will increase the cross-sectional area for the total air quantity by 50% for nearly the entire distance from surface to the workplace.

Thirdly, leakages which may amount to 50% in an old mine will be reduced to zero along the length of airways totally on intake between the surface and the Island. Let us assume a conservative saving of 25% for the entire mine layout. The following table compares critical data from detailed computer outputs of a ventilation network simulation of Lingan Colliery at the end of the mine's life.

	Present Fan	Increasing Fan Pressure	Booster Fans	Controlled Re-Circulation	Artificial Island
Total W.G. (KPa)	5.387	6.750	13.398	13.741	
Operating Cost/yr ($C)	657k	921k	1,167k	1,232k	657k
Air Wall 1 (m^3/s)	24.7	27.7	33.7	36.5	35.8
Air Wall 2 (m^3/s)	27.6	30.9	37.6	40.8	39.1

A minimum of 35 m^3/s of effective air per longwall section is normally required for proper ventilation at an operation with similar conditions as Lingan Colliery.

From the table, booster fans or artificial islands are required to attain proper ventilation to the end of the life of the mine. One can readily notice the operating cost advantages of artificial islands while maintaining effective air quantities at the workplace.

3.1. HISTORY OF ARTIFICIAL ISLANDS

The Dutch have been reclaiming land from the sea since the seventeenth century (3). This reclamation work included the extension of peninsular land, enlarging existing islands and the construction of artificial islands. In the seventeenth century, Dutch engineers advised the French on artificial island construction for the Ile Saint-Louis in the Seine. Dutch Engineers also helped the Japanese build artificial islands, for industrial use in Nagasaki Bay, in the twentieth century.

Artificial islands have been used as a structure for coastal defence in Japan since the latter half of the 19th century (4). At that time six artificial islands were constructed for marine batteries, inside Tokyo Bay. Two of the six remain intact. At the end of the 19th century, three more artificial islands were built near the entrance of Tokyo Bay, where the depth of water is 30 to 40 m.

Japan is a mountainous country with very little flat land, in the order of only 20%; artificial island construction has offered a means of expanding the usable land base in the heavily industrialized areas. A great many artificial islands have been constructed for industrial purposes in Japan since World War II, beginning with the first artificial island for the Miike Mine completed in 1951 and continuing through to the 1980's. The total usable surface of the Japanese artificial islands is now greater than 1000 km^2.

Artificial islands have been used in the United States (5) principally for the exploration and production of hydrocarbons. Several islands have been constructed off of the California coast, and off the coast of Alaska. During the production stage, there is a need to locate a structure over the hydrocarbon resource; the advantage is that the same techniques and equipment that are used onshore can be used offshore.

Artificial islands have also been used as:

- a base for industrial operations, including metallurgical works;
- for airport extensions;
- for desalinization plants;
- for petroleum exploration and production platforms; and,
- as a platform for coal mine ventilation structures.

3.2. PETROLEUM PRODUCTION PLATFORMS

Rincon Island was constructed by Atlantic Richfield Company, off the California coast near Santa Barbara, between February 1957 and September 1958 (6). This island (figure 1) was built to provide a site for up to 68 (directionally drilled) oil wells. The depth of water is from 12.4 m to 14.6 m, and the tidal range is 3.0m.

The working elevation of the island is 4.87 m. The island has a total area of 0.85 ha and a usable flat area of 0.46 ha. On the ocean floor the island's area is 2.55 ha. The sediment on which the island rests is silty sand to sandy silt, with a thickness ranging from 4.3 m to 7.6 m. The bedrock is a geologically recent shale or siltstone formation with a bottom slope of 3%.

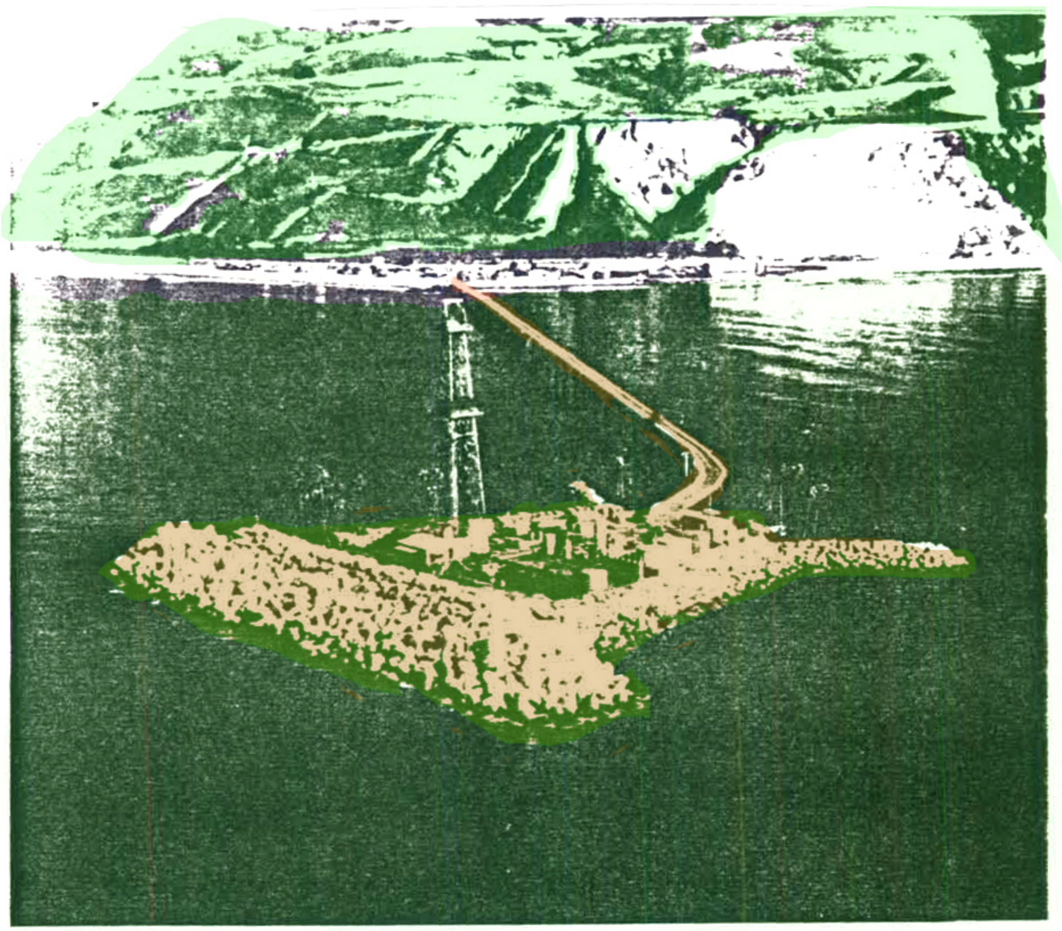

Figure 1 Atlantic Richfield Company's Rincon Island (Ref. 6)

Rincon Island was constructed by first placing rock revetments (retaining structure) on the ocean bottom, then filling the interior space with sand to the top of the revetment. The process was then repeated, with the revetment moved inward to allow for the island slope. Since the island was exposed to Pacific ocean storms, the exposed western face of the island was protected with 1130 concrete tetrapods each weighing about 30 t(4). The crest elevation of the concrete tetrapods is 12.5 m. Connecting the island to the shore is a 832 m single lane causeway.

Johnson and DeWit (6) conducted an 18 month study of the ecological effects of artificial islands (artificial reefs), using Rincon Island as a model. The findings of the study indicated that the structure acted as the focus for a rich and varied fauna and flora, substantially different from the less well endowed surrounding area.

At Long Beach, California, four manmade islands were constructed between 1965 and 1966 (5) by a consortium of five oil companies: Texaco, Humble, Union, Mobile and Shell. Water depths range from 7.6 m to 12.2 m. Each island has a useful working area of 4.0 ha, at an elevation of 4.6 m, which was designed to accommodate up to 200 oil production wells. Island construction was similar to Ricon Island, with the exception that the bottom layer is entirely quarry rock, 4.5 m thick. The first layer was followed by two lifts composed of exterior rock revetments filled with quarry rock. Armour rock was used to protect the surface. Since the islands were constructed in a metropolitan area, the aesthetics of the site were given special consideration. All oil derricks are housed in soundproof buildings that look like apartment towers. There are palm trees and shrubs on the islands, and facing the shore is a 14 m high illuminated waterfall. All utilities are underwater and access is by boat or helicopter.

Artificial islands have been built for oil exploration and oil production from the North Shore of Alaska and also in the Canadian Arctic. Water depths are 3 m to 12 m. Island construction for the exploration drilling is either with a suction dredge or with trucks traveling over the ice and dropping sand and gravel through holes in the ice. These islands are subject to large horizontal forces from ice pressures. Precautions against the ice pressures must be included if the island is to last more than a season or two.

These include:

- Armouring the island slopes;
- Maintaining an open "moat" around the island; and,
- Monitoring ice pressures so that pressure relief measures can be taken before damage occurs to the structure.

If no discovery is made, the island is abandoned and allowed to erode. If a discovery is made, the island is enlarged so that it becomes a permanent (20-30 yr.) structure.

Permanent structures are normally round or square with an underwater slope of 12:1. The structure is protected by laying filter cloth, held down by sandbags, over the sand.

The petroleum industry (7) has designed structures which can be used in water depths up to 300 m deep. The Statford B, a fixed position oil production structure in the North Sea, is positioned in 144 m of water. The Mississippi Canyon, a guy wire supported oil production structure designed for the Gulf of Mexico, was designed for 300 m of water.

3.3. THE JAPANESE MIIKE COLLIERY COMPLEX

The Miike Colliery of the Mitsui Coal Mining Co. Ltd. began producing coal from on land seams in 1889 (8). By 1940, mining under the land was almost completed and by 1945 mining had extended to a depth of 700 m and 2 km from the shore line. Ventilation problems, with heat, air quantities and the increasing mining cost led to the construction of three artificial island based ventilation systems.

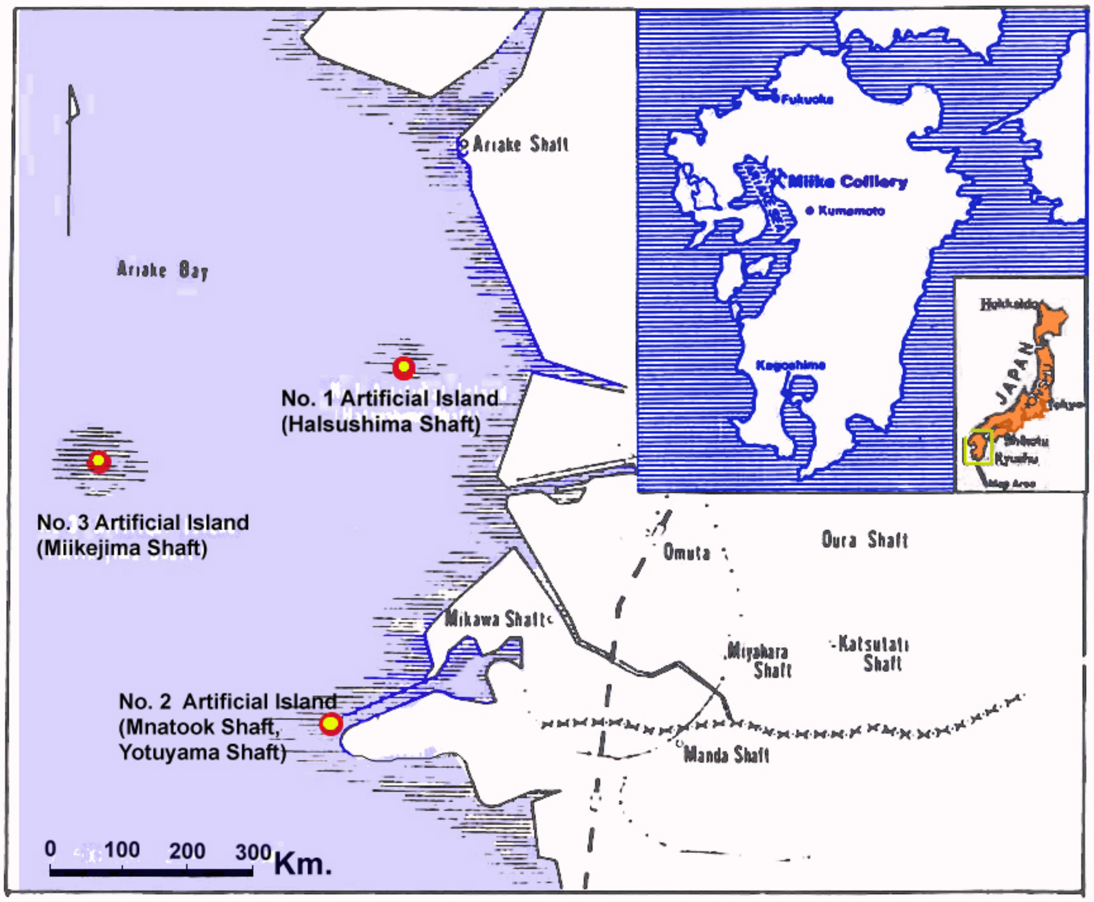

Figure 2: Location Map for the Miike Colliery (Ref. 7)

The Colliery complex is located in an area subject to Pacific Ocean typhoons, on Kyushu Island at the southern end of the Japanese archipelago (figure 2). The coal deposit, made up of three workable seams 2 m to 5 m thick, is hosted by a 700 m thick Tertiary age sedimentary sequence (figure 3). The Tertiary sequence is overlain by 100 m to 250 m impervious silt and clay of Quaternary age. The coal bearing sequence extends under the Ariake Sea, and has an areal extent of 740 km^2. The three workable coal seams dip 5° to 6° under the Ariake Sea.

The recoverable reserves at the Miike Colliery Complex are estimated to be 180,305,000 t (2).

The colliery is mined from three pits, producing a total of 17,500 t/d of clean coal, or 5,200,000 t/yr. Each pit works from three to four working faces. The seams are worked using the retreating longwall mining method; thick (greater than 4 m) portions of the coal seam are mined under shield support by the double face slicing method (figure 4) with double ranging drum shearers. When two slices are made, the upper face retreats 50 m in advance of the lower face; the lower face is mined under shield support and an artificial roof.

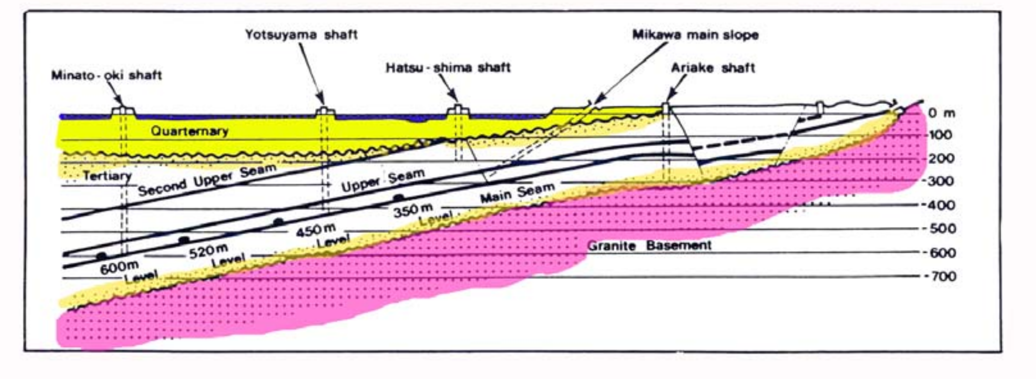

Figure 3: A Schematic Cross-Section of the Miike Colliery Showing Simplified Geology (Ref. 8)

The Colliery Complex has seven downcast shafts, supplying 65,000 m^3 /min. air. There are three upcast shafts, two onshore and one offshore. The upcast shafts have five sets of main fans with a diameter of 4 m (two fans on the artificial island and two at one onshore location). Each set of fans is driven by a 1,000 kw motor driving 13,000 m against a pressure of 350 mm water gauge (8).

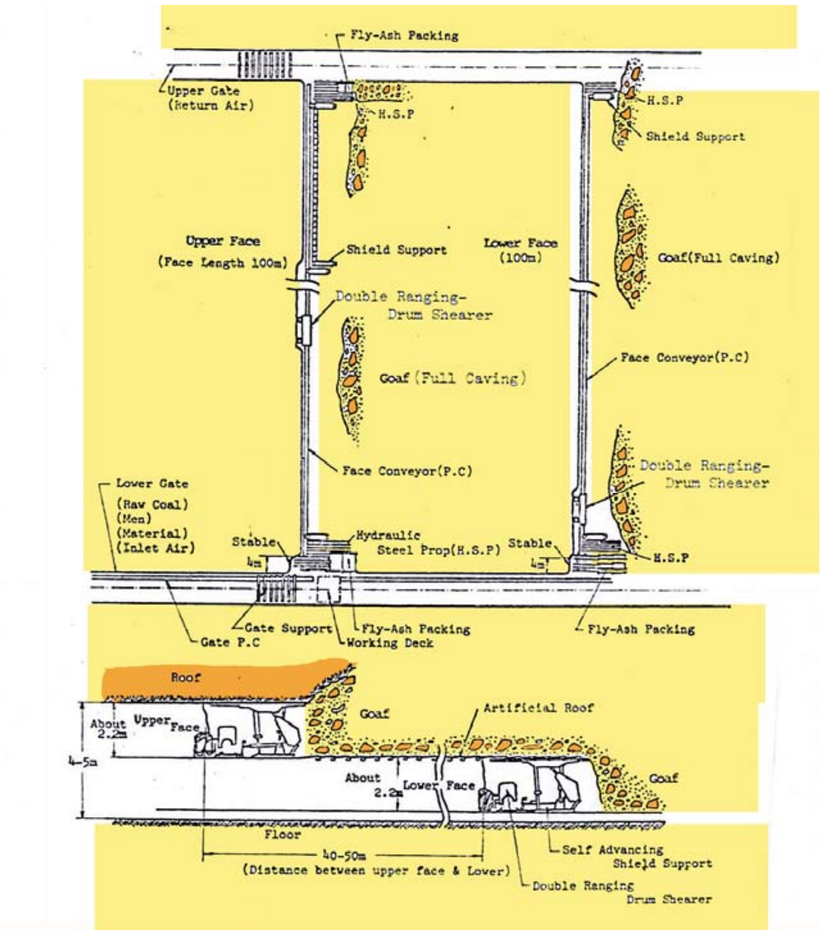

Figure 4: The Layout of the Longwall Slicing Faces at the Miike Colliery (Ref 2).

The water depth at the site of the artificial islands ranges from 3 m to 10 m deep. Number 1 artificial island is a 120 m diameter round island used as a downcast shaft, and was constructed between 1949 and 1951, 2 km from the shore. The completion of the 7 m diameter, 200 m deep vertical shaft took until 1954. The sediment on the ocean floor consists of 10 m of sandy loam overlaying hard sand and gravel. A settlement of 2 m was recorded over the first two years, followed by a settlement of 1.5 m over the next four years. The settlement is estimated to be 90% complete (4). Figure 5 shows a plan and a section view of No. 1 artificial island. Figure 6 is a photograph of the island under construction. The construction commenced with a circular revetment of rock around the perimeter of the base. Sand was then pumped into the circle. This pattern was repeated with 2.0 m lifts.

Number 2 artificial island, the site of the 6.5 m diameter, 600 m deep Minato-Oki downcast ventilation shaft, was constructed between 1952 and 1955.

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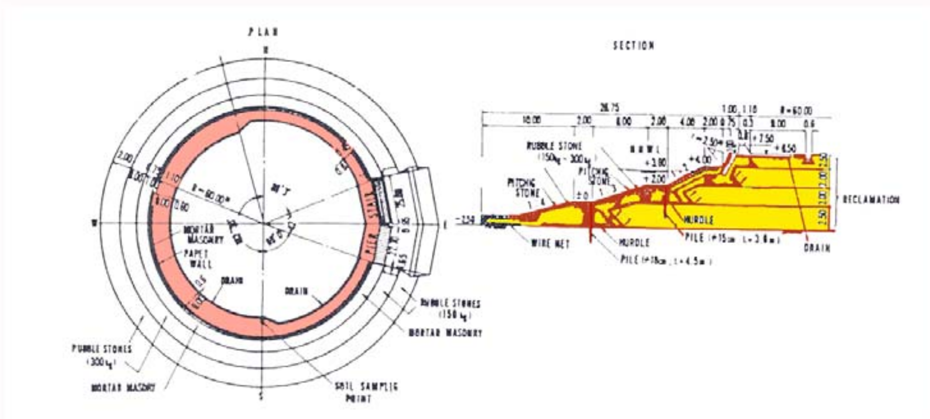

Figure 5 A Plan and Section View of No. 1 Artificial Island, Miike Colliery Complex (Ref. 4)

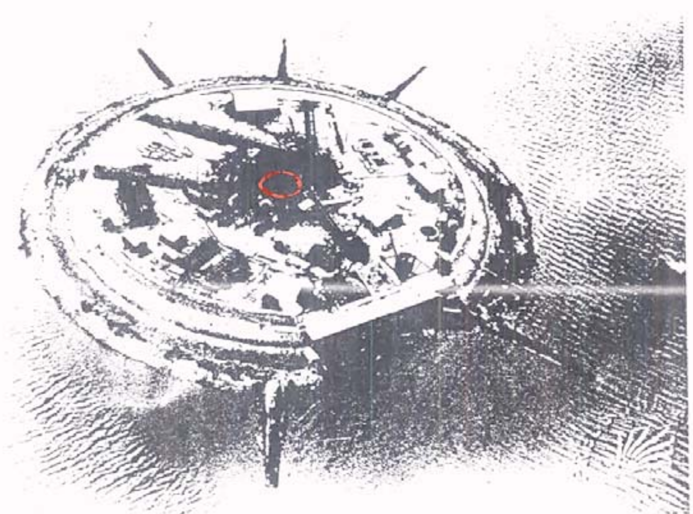

Figure 6 An Aerial View of No. 1 Artificial Island, Under Construction (Ref. 4)

The island is 80 m in diameter, and was constructed at the end of a jetty in Miike Harbour using colliery waste rock and soil reclaimed from the sea. A sea wall was constructed with coal waste to protect the structure from the seasonal typhoons; settlement amounted to 80 cm for two months, after which no further settlement was observed.

The third artificial island, 90 m in diameter, was constructed 6 km offshore in 6.5 m of water. The site has a tidal range of 6 m. The shaft has a depth of 500 m and has an inside diameter of 6.0 m. Eighteen metres of soft silt is on the ocean floor. This silt overlays a hard sand and Quaternary clay. The foundation a sea soft silt was dredged with a pump dredge and replaced with 500 000 m^3 of sand. Rather than use rock revetment, prefabricated steel frames of welded pipe truss structure was installed to protect the structure from the marine environment. Steel sheet pile was driven between the frames. Figure 7 illustrates the plan and sectional view of No. 3 artificial island and figure 8, the partially completed island. Serious corrosion problems were encountered with the steel piling 10 years after construction, and Maeda (4) states that the company is considering a reinforced concrete lining to retain the sand in the interior of the structure.

In contrast, maintenance costs for the rubble mound type of artificial island, No. 1 and No. 2. have been low; the occasional replacement of stone after a typhoon.

The excavation of the ventilation shafts used the air jet and air lift type reverse circulation method. The method employed two drills equipped with cutting heads. The drill strings were lowered through a rotary table, and then the rock was drilled out by rotating the table to drill rings of material. The spoil rock was lifted by air pressure. The Quaternary clay strata overlaying the pits were considered an impervious barrier from the intrusion of sea water, although the colliery did discharge 115 m /min. water. This water was from the Tertiary strata.

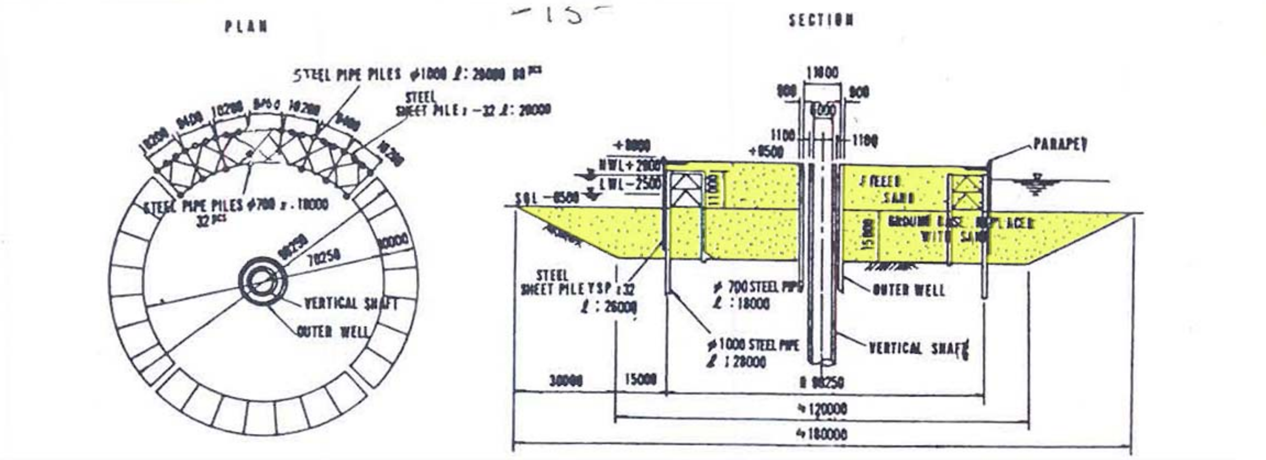

Figure 7: A Plan and Section View of No. 3 Artificial Island, Miike Colliery (Ref 4.)

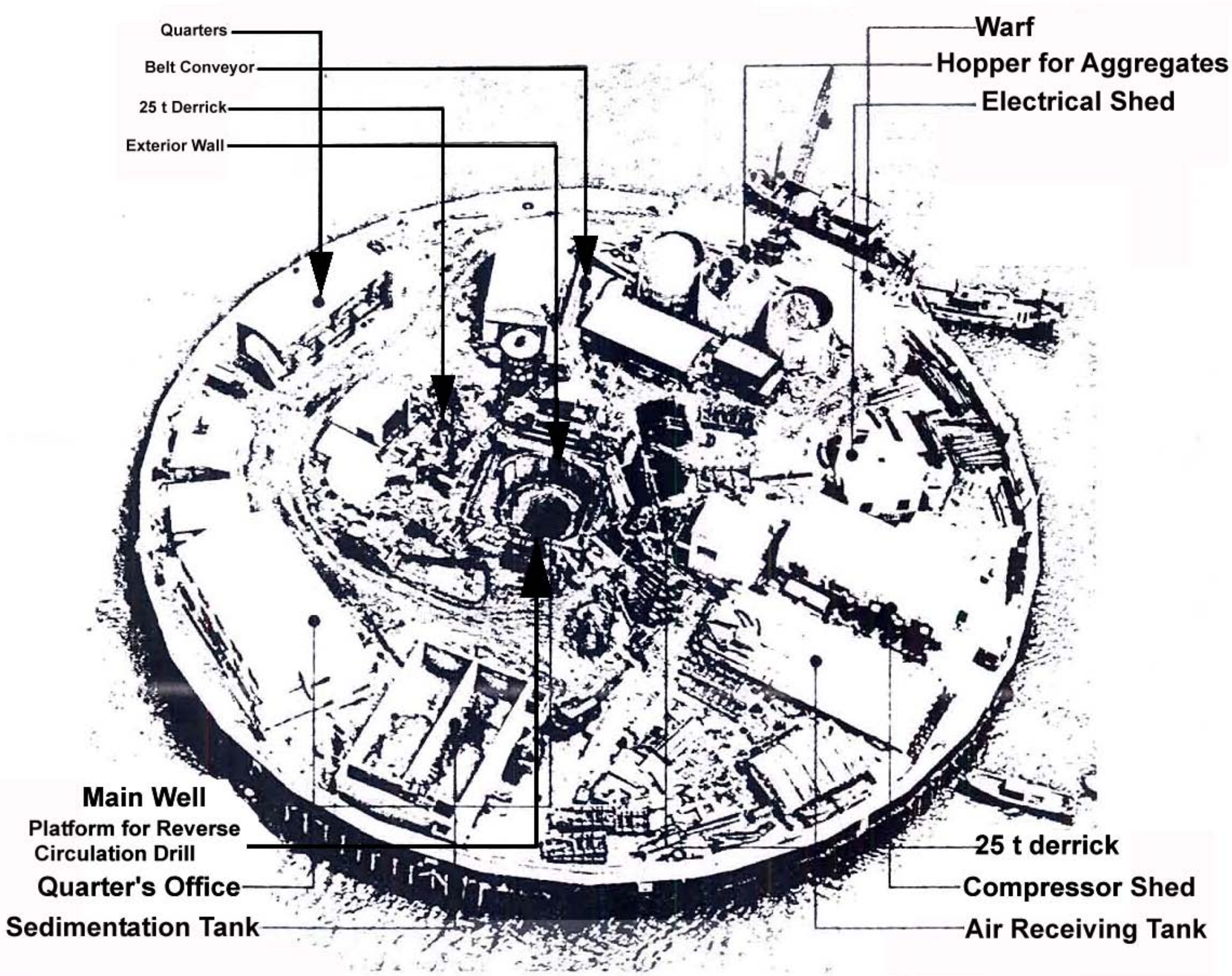

Figure 8: An Aerial View of No. 3 Artificial Island Under Construction (Ref. 4).

3.4. ARTIFICIAL ISLAND DESIGN CONSIDERATIONS

The site of the artificial island will depend to a large extent upon the proposed use of the island. Bijker (9) has documented the elements of design, construction and maintenance of islands for industrial purposes. This section of the paper is based mainly on Bijker's work.

Comprehensive investigations into the following aspects are required:

- water depth wave height range climate (50 year maximum storm);
- ice conditions;
- tidal range;
- currents;
- foundation conditions;
- earthquake risk;
- source of materials;
- shipping lanes;
- existing pipelines and cables;
- legal aspects;
- environmental considerations; and,
- fisheries considerations.

The program should be phased. The first phase is an information gathering stage to assemble all of the available data on the site, including available geology and geophysics, climatic and ecological data and environmental data. This phase is followed by a reconnaissance field program.

This preliminary field program includes a geotechnical program and an exploration program for suitable construction material. Data recording devices For tidal fluctuations, climate and current information would be distributed. Following analysis of the preliminary data, detailed investigations should be carried out on three or four sites.

The source of construction materials is one of the more critical items in the choice of island sites. Ideally, a good quality coarse grained (free draining) sand material is located within 5 to 10 km of the island site. The sand can be mined with a suction dredge and loaded into trailer barges.

The environmental impact will be less if the sand is dredged in thin layers rather than a deep pit. The barges are towed to the island site and the sand dumped directly from the trailer. When the water depth becomes too shallow, the sand is dumped at a borrow pit and pumped by a stationary dredge to the specified site.

The sand is protected by rock revetments and a layer of armour rock.

The top layer of sand can be sprayed with a bitumen emulsion and a layer of soil. Then a suitable grass is planted to reduce erosion.

The environmental impact of the island construction period is limited to disturbance of the benthic layer and turbidity during sand dredging. The overall environmental impact can be positive for the fisheries, as was documented by Johnson and deWit (6).

Prior to construction, mathematical models and scale models should be investigated. Scale model tests could be completed in the National Research Council's wave and ice tank facility at St. John's, Newfoundland.

3.5. ESTIMATED COST OF CONSTRUCTION

Dowse (11) estimates that the cost of a caisson retained artificial island specifically for an offshore ventilation shaft in 30 m of water would be in the order of $C 15 million (1986 $).

The significant variables are the depth of water at the site and the storm design wave height. In 1979, a proposal was made to the Cape Breton Development Corporation (CBDC) by Sandisle Structures to construct a prototype artificial island (10).

The island was to be constructed in about 15 m of water and was to serve as an upcast ventilation shaft platform. Sandisle Structures estimated that the cost of island construction would be $4 million ($5.8 million 1987 $) for an island in 15 m of water, and $9.8 million ($14.1 million 1987 $) for an island in 30 m of water.

Engineering studies would cost between $200,000 and $250,000. The prototype island would be designed and components fabricated over a period of one year. Construction would take place during the summer. The structure would be monitored for a year to determine the island's response to ice and wave loadings, after which the ventilation shaft would be sunk (figure 9).

In 1980, Dowse (10) proposed a hybrid island, composed of a caisson-retained shaft structure surrounded by rock fill. The reinforced concrete shaft portion of the hybrid island would be constructed onshore and floated to the island site. This method was employed in the construction of the Ekofisk storage tank in the North Sea. The Ekofisk structure was floated to location and positioned upright in 70 m of water in the summer of 1973 (figure 10).

The central core of the hybrid island proposed by Dowse would be fitted with a pilot extension of the ventilation shaft which penetrates a pre-drilled hole on the ocean floor. The shaft structure would be ballasted with sea water at the shaft site and carefully fitted into the shaft hole. The reinforced concrete structure would be stabilized with guy wires and anchoring devices on the sea floor. The shaft work could be completed using large diameter shaft drilling techniques, the air lift technique as used at the Miike Mine, or by conventional shaft sinking. The spoil rock from the shaft sinking operation would be used to enlarge the island. Additional material from the sea bed would be required to complete the island (figure 11). Dowse has also suggested the Sandisle membrane type caisson-fill island for water depths less than 60 m (figure 10).

These units are composed of a steel top fitted with a flexible membrane. Several of the Sandisle membrane units would be floated to the desired site and then positioned in place by filling the membrane with sand. The sand would be dewatered after emplacement into the membrane, and sand and rock fill placed around the perimeter of the structure to enlarge the island.

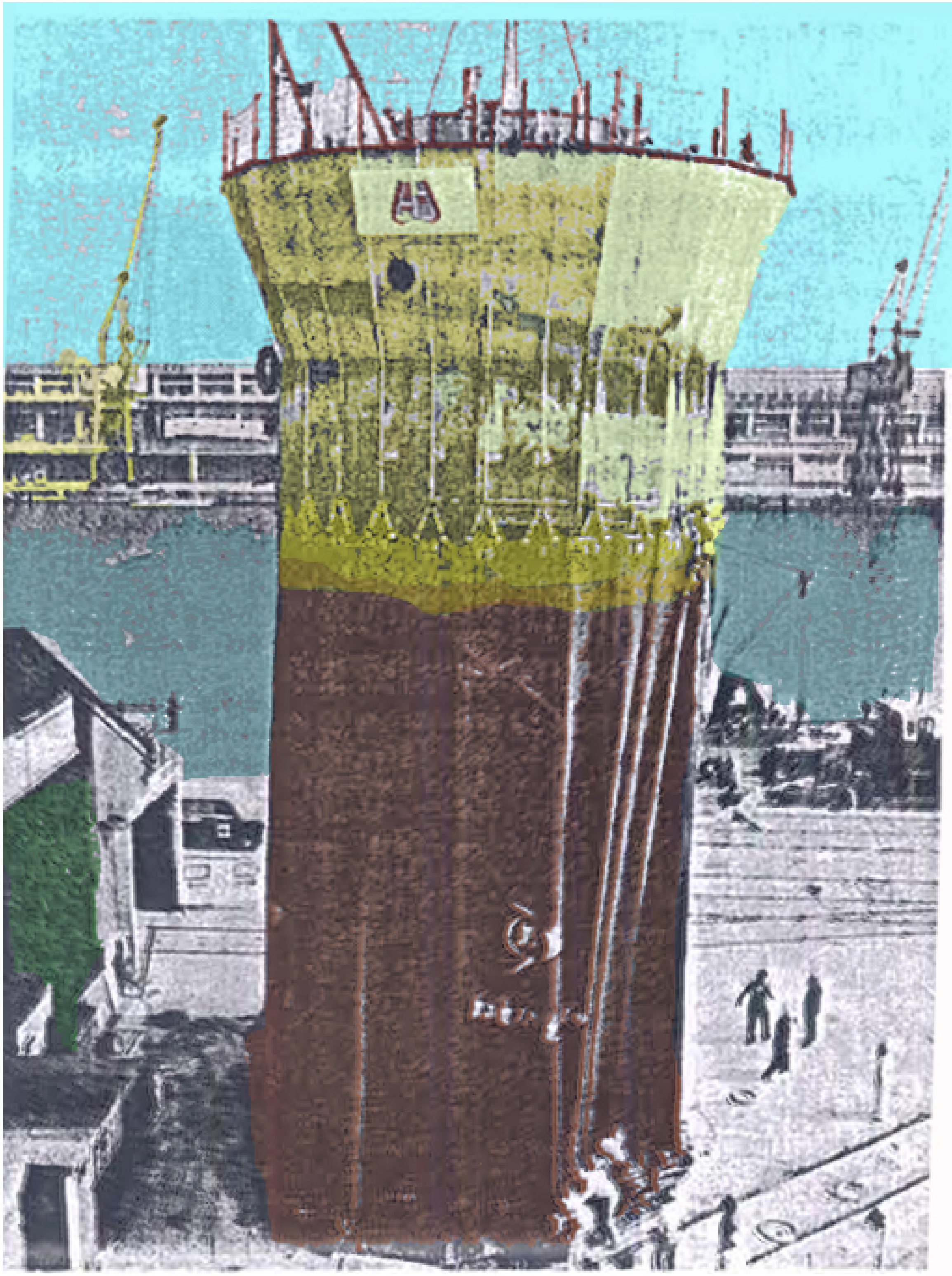

Figure 9
Sandisle Prototype During Membrane Attachment

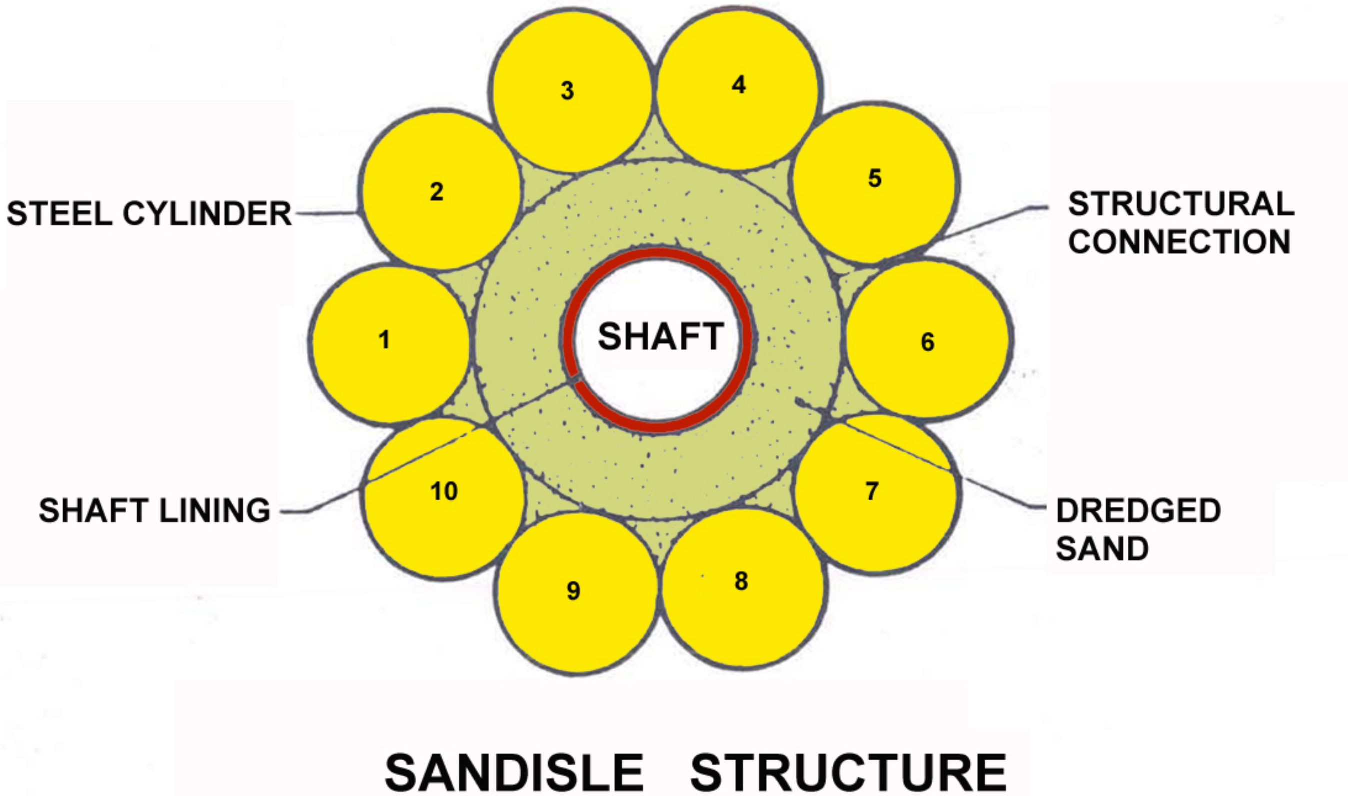

Figure 10 Ekofisk Tank-style Island (Ref. 11)

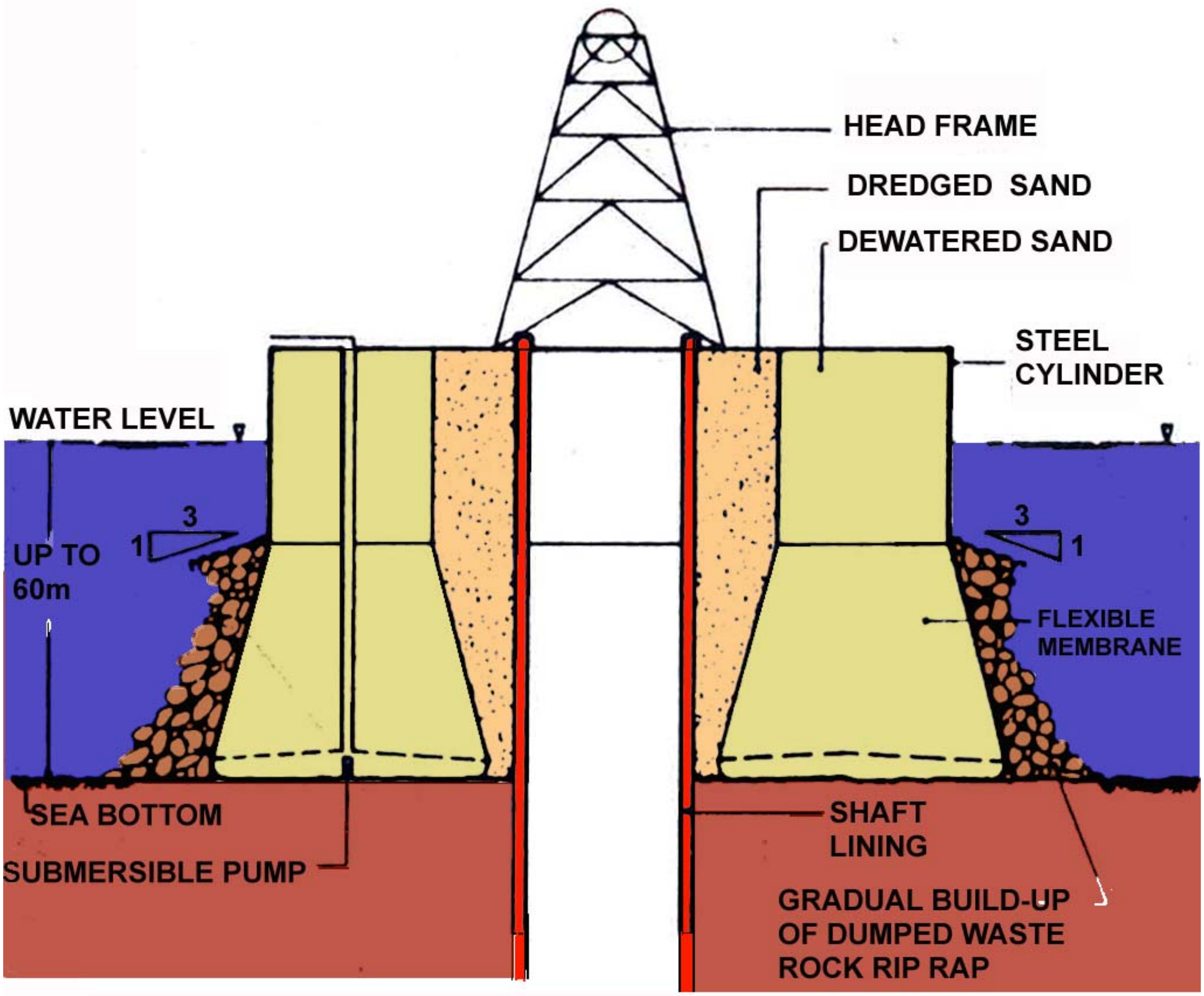

Figure 11 A Proposed Hybrid Artificial Island for the Sydney Coal Basin

4. CONCLUSIONS

1) Artificial islands have been used since the seventeenth century for coastal defence and as extensions of the land base.

2) Artificial islands are being used as oil exploration and production platforms in the Arctic and on the West Coast of the USA.

3) Japan has several artificial islands, with a total area of over 1000 km. Artificial islands are being used in Japan to provide a platform for coal mine ventilation shaft access.

4) Technology of artificial island construction is available to construct islands in water depths of 70 m.
5) An artificial island will positively contribute to the safety, effective ventilation and reserves of a coal mine in Cape Breton.

6) There could be significant operating cost savings in ventilating the mines using artificial islands.

7) Artificial islands become a focus for sea life, enhancing the marine environment.

5. ACKNOWLEDGEMENTS

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