Beneficial use of mudcrete in reclamations

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Abstract

Redevelopment of the eastern section of the Viaduct Basin in downtown Auckland, New Zealand, provided the stopover base for the 1993/1994 Whitbread Race. This required the construction of a new quay structure, dredging and a reclamation. An intregal part of the whole project was the use dredged marine mud for the reclamation. To gain strength and to minimise leaching of the contaminants, the marine mud was stabilised with ordinary Portland cement to become known as mudcrete. This paper discusses the design methodology for the sizing of the structural elements in the quay wall and outlines the benefits of using mudcrete. The paper also outlines investigations undertaken to assess the effects of leachate released from the reclamation to the natural environment. Finally, the paper compares measured strengths and water quality parameters with those values assessed during the design phase of the project.

1 Introduction

The 1993/1994 Whitbread Round the World Race provided the opportunity to redevelop part of the Viaduct Basin in downtown Auckland. The project comprised the construction of about 200 metres of quay structure, the stabilisation of some 10,000 m^3 of dredging and a 3,000 m^2 reclamation.

This project also met the requirements of Auckland City Council who were promoting the development and rejuvenation of Auckland's harbour edge. In the long term this facility will provide improved public access to the harbour area and meet future requirements for the fishing industry.

2 Options

Early investigations into the seabed sediment chemistry indicated that the high levels of DDT, lead and zinc would preclude the dredged material from unconfined marine disposal. In the process of developing the conceptual design of the project a number of options were evaluated. These options ranged from a sealed reclamation with a heavy quay structure supporting untreated dredged material placed behind the wall, to complete removal of the dredged material from site and the construction of a timber piled wharf. The preferred option was to stabilise the dredged sediment to form mudcrete and place the mudcrete within an unsealed reclamation, enabling a lighter quay structure to be utilised. This option was selected because it was:

Environmentally Sound
The addition of cement effectively immobilised many contaminants including heavy metals and some organics. The dredgings could be disposed of in an environmentally sound fashion reducing the load on existing landfill facilities.

Cost effective
The quay wall could be a light structure as the mudcrete would form a solid mass and exert little or no load on the wall, and all dredgings could be utilised on site precluding removal and disposal. The lining of the reclamation with an impermeable liner was not required.

Functional
A useable surface would be provided in a short period of time, a vital requirement for the hosting of the Whitbread fleet.

Tied back soldier piles with precast panels was adopted as the most effective form of quay wall. It utilised limited space within the reclamation and was cost effective. A typical section of the preferred option is shown in Figure 1.

3 Design of the Scheme

3.1 Geotechnical Investigations
Site investigations were carried out to determine the geotechnical characteristics of the subsoils. In general terms about 2 metres of unconsolidated mud overlay one metre of stiff residual clay and weathered sandstone/mudstone rock of the Waitemata Group (Miocene age).

The shear strength of the mud was 5 kPa on average which improved slightly with depth. The clay was relatively stiff with an average shear strength of 50 kPa. The rock had an SPT-N value significantly higher than 50.

3.2 Mudcrete Investigations
Extensive laboratory trials were conducted to ascertain the additive that would best improve strength and contaminant binding properties when mixed with marine mud. The additives trialled were ordinary Portland cement, lime, flyash and a proprietary product.

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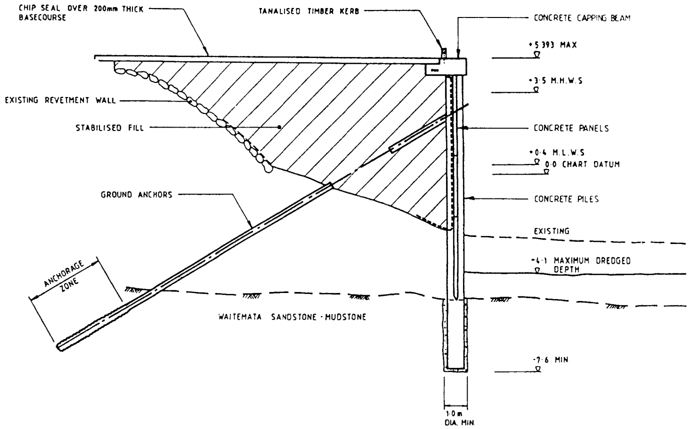

Figure 1 - Typical Quay Wall Section

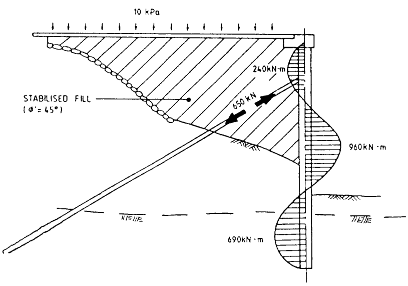

Figure 2 - Design Loads per Span (Structural)

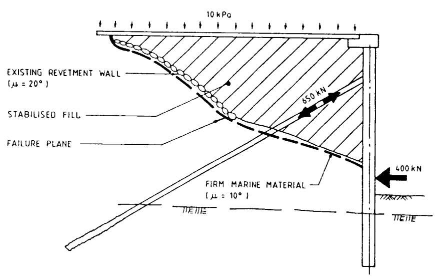

Figure 3 - Design Loads per Span (Stability)

Ordinary Portland cement proved to be the most effective additive. From the laboratory testing the target ratio of cement to marine mud was 20% of the dry solid weight and the expected gain in shear strength was in the order of 100 kPa. It was also found that the cementatious process produced a product with a very low permeability.

3.3 Design of the Wall Elements

Given the long term use of the quay structure for the fishing industry it was decided that the service load for the reclamation would be 10 kPa. It was estimated that if the mudcrete achieved a long term shear strength of 100 kPa throughout then there would be very little load transfer to the wharf. After due consideration of this issue, including a peer review by an external expert, it was decided that the long term loadings on the wharf would be based on:

- An effective friction angle of 45° which would be representative of material that broke up into large blocks.
- A tidal lag of 1 metre in height even though the concrete panels incorporated horizontal vents.

Based on analysing the above loading conditions the resultant moments are shown in Figure 2. Sizing of the structure required 750mm diameter octagonal soldier piles at 4 metre spacings, 200mm thick concrete panels and 40 mm diameter 'dywidag' anchor bars.

3.4 Overall Stability of the Structure

The reclamation is positioned between the quay wall and an existing revetment and founded on a combination of marine mud and clay material. If the reclamation remained intact as a single block then there was a potential failure plane along the revetment/reclamation interface. This loading case is illustrated in Figure 3 and was assessed to have an overall factor of safety of 1.5.

4 Environmental Factors

The potential discharge of contaminants to the natural environment was a prime concern with this project. The solidification/stabilisation process assisted in reducing contaminated discharges in two ways. Firstly by reducing the leachate strength and secondly by reducing the permeability of the material. Standard practice is to measure the leachate strength by a TCLP (toxicity characterisation leaching procedure) test which reduces the specimen to an acidic environment. This testing procedure was undertaken but was not considered to be appropriate for the mudcrete and so the leachate was also extracted with seawater. The results are shown in Table 1 for the contaminants of most concern.

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Table 1 - Assessed Leachate Effects on Water Quality

Parameter	Sample	Concentration (mg/m^3)			
		Copper	Lead	Zinc	Mercury
TCLP leachate	Untreated	40	74	1,300	0.4
	20% cement	220	33	10	0.5
Seawater leachate	Untreated	70	<1	80	<0.1
	20% cement	260	<1	10	<0.1
Ambient levels	Seawater	1	<1	8	<0.1
USEPA chronic criteria	-	3	6	86	0.025
Required dilution to meet criteria	-	130	Nil	Nil	(probably nil)

From these results copper was not stabilised by cement and was in fact amplified some four fold by the process. For this case dilution was necessary to reduce the copper leachate levels to the USEPA chronic criteria. The maximum groundwater flow through the leachate was estimated as 0.5 m^3/day and the tidal exchange within the eastern viaduct basin was 25,000m^3/day. The available dilution was therefore 1 to 50,000 compared to the 1 to 130 required.

5 Construction of the Project

5.1 Quay Wall

The quay wall was constructed using precast concrete panels spanning between precast concrete piles. Precast piles were inserted into bored holes that had been drilled down into the hard sandstone layer.

Once positioned the fresh concrete was pumped around the base of the piles to set them in position. The plant and equipment used in the construction of the quay wall was operated from flat top barges. Each precast pile was tied back near the top with a ground anchor grouted into the foundation rock behind the reclamation area. These 40mm diameter anchors were drilled and subsequently installed from purpose built platforms cantilevered off each precast pile in turn. The top end of each anchor was positioned below high tide level dictating that the operation could only be performed over part of the tidal cycle. Once the anchor was in position the head was sealed off and the free section of the anchor was flushed out with fresh water and a hydraulic head exerted within the tube, greater than the tidal level. This ensured that corrosion of the anchor would not occur from tidal influence during construction.

5.2 Reclamation Using Mudcrete

The stabilisation of unconsolidated marine sediments prior to placement in a reclamation had not been previously performed in New Zealand. The requirements of the project were that it needed to be ready in time for the arrival of the Whitbread fleet resulting in a construction period of only three months.

The chosen methods were trialled and refined off site prior to the commencement of the work. All plant used to dredge and stabilise the sediment was operated from flat top barges. Dredging was performed by hydraulic excavators discharing to shallow mixing bins on the barges. Cement was sprinkled over the surface of the dredgings and mixing performed using a modified stabiliser hoe adapted to fit on to the beam of a hydraulic excavator. Once mixed the mudcrete was placed using hydraulic excavators operating either from the barges or from within the reclamation. When placing the material below sea level a clam shell bucket was used.

Problems were experienced at the beginning of this operation with the mixing consistency of the mudcrete. This was overcome by respecifying the cement content in terms of bulk quantity rather than dry weight. It was found that an application rate of about 100 kg of cement per m^3 of dredging achieved the target shear strengths. The clam shell bucket also had to be modified to prevent the mudcrete sticking to the bucket and not being released.

Once mixed and placed the mudcrete set sufficiently so that it could be walked on after one day and could be subject to construction plant after 3 to 4 days. Shear strengths of over 200 kPa were usually obtained after 7 days curing. On completion of the reclamation work, a layer of roading basecourse aggregate was placed and compacted on top of the mudcrete and was sealed with a bituminous chip seal.

5.3 Contractual Matters

Construction was carried out by Downer and Company Ltd who are a large New Zealand civil contractor. Final construction costs for the project were approximately NZ$2.5m which was within budget. The project was completed on programme within a six month period.

6 Post Construction Monitoring

6.1 Geotechnical Investigations

Six months after completion of the construction, two boreholes were drilled

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and samples were tested for their shear strength. The material encountered in each of the boreholes was variable. It ranged from well mixed cemented material through to cemented material and further through to soft clay. Some voids in the material were also observed. The shear strength of the well mixed cemented material was high at around 400 kPa. This is compared to a target strength of 100 kPa in 7 days as specified in the original contract. Placement of the material while in a more or less liquid state during construction influenced the final geotechnical properties in the material. It appears that the well mixed material within the clam shell remained intact but on the perimeter of each load the material had a lower strength or was a soft clay material. In effect, the reclamation is competent lumps of material surrounded by a weakly cemented matrix. This structure is analogous to large boulders placed in a stock pile surrounded by a weakly bonded material.

6.2 Chemical Contaminants

The level of contaminants in the mudcrete material were generally higher than the material tested as part of the design as shown in Table 2.

Table 2 - Results of Post-Construction Contaminant Testing

Contaminant		Bulk Sediment Chemistry (mg/kg)	Standard TCLP (mg/m^3)	Seawater Elutriate (mg/m^3)
(a)	Pre-Construction			
	Copper	43	220	260
	Lead	45	33	<1
	Zinc	150	10	10
	Mercury	1.3	0.5	<0.1
(b)	Post-Construction			
Copper	- average	66	67.5	200
	- maximum	94	80	400
Lead	- average	108	<50	<100
	- maximum	308	<50	<100
Zinc	- average	161	150	<100
	- maximum	239	300	<100
Mercury	- average	0.18	<0.1	<0.1
	- maximum	0.35	0.1	<0.1

Leaching strength from standard TCLP tests were higher for zinc but generally lower for all other contaminants. The results of the seawater elutriation tests show that for all materials except copper the results were less than the detection limits. For copper, however, relatively high concentration of leachate were released and this was consistent with earlier studies. This confirmed the need for immediate dilution to obtain copper concentration less than the USEPA standard for marine waters.

7 Conclusion

This project is a good example of how a material which has traditionally been treated as a waste product can be used as a valuable resource. Stabilisation of the dredged material using ordinary Portland cement proved to be cost effective and provided an environmentally acceptable solution. Both the design and construction phases of the project required unique solutions which were treated as challenges by both the designers and the contractors.

Reconstruction of the eastern Viaduct Basin using mudcrete provides the opportunity for further research into this product. Mudcrete has the potential to be used on much larger structures. With suitably selected design criteria, such structures could be much lighter than conventional quay structures. The focus of this research would be to define strength parameters such as effective cohesion and effective angle of friction for its long term use. While mudcrete appears to be chemically stable, the leaching strength of copper appears to exceed marine discharge standards. More research into copper release and investigation of additional reagents to suppress the potential leaching of copper should be undertaken.

8 Acknowledgements

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