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Investigation of Beach Erosion at Mission Bay

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SUMMARY This paper describes an investigation into the erosion of one of Auckland's city beaches. It describes the three phases of the investigation and comments upon the recommended remedial measures. A data collection exercise was undertaken and involved both field work and the review of historical records. Following this it was possible to formulate an hypothesis for the mechanics of the erosion. A mobile bed model was then constructed to investigate a series of proposed remedial schemes.

1. INTRODUCTION

Mission Bay, one of Auckland's most popular Eastern Suburbs beaches, is a beach that has experienced detrimental changes brought about by both man and nature. Figure 1 shows the location of the beach in relation to the Waitemata Harbour, whilst figure 2 shows the site plan. Until comparatively recently Mission Bay was not a residential suburb but a beach area used mainly for holidays out of the city. During the 1930's a waterfront road was built at the base of the cliffs and protected by a sea wall. At the same time the wharf which had served the ferry traffic was removed.

Historically the beach at Mission Bay had a natural source of sand from material washed out from the mouth of the Waikato River when it discharged through the Firth of Thames and from the erodible cliffs around the eastern beaches of Auckland, however since the construction of a sea wall all along the eastern suburbs coastline there is a severely reduced source of beach material. Also, prior to Rangitoto Island's appearance some 800 years ago the dominant fetch was from the north. Rangitoto sheltered the beach from waves coming from this direction, positioning the critical fetch between Rangitoto and Motuihe Island. A

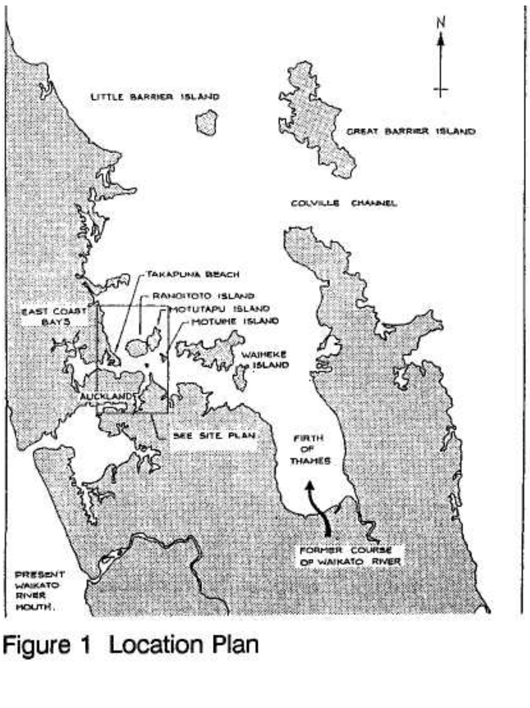

Figure 1 Location Plan

bay which has had any sediment supply to it cut off, such as Mission Bay, will erode to a specific shape. Once this shape is reached the beach will maintain "static equilibrium" (Hsu, Silvester, Xia (1)). This is where the incoming waves will refract into the bay and break simultaneously around the whole periphery. This implies that there is no longshore component of breaking wave energy and hence no littoral drift. Figure 3 shows the extent the beach would erode to using the theory presented in the paper by Hsu et al. and assuming the north-east fetch is critical. It can be assumed that Mission Bay therefore has been siowly eroding back to this shape, however the sea wall intersects the beach's natural profile. This obstacle prevents material being removed from the natural shore and exacerbates the problem.

The construction of buildings and roads in the Mission Bay area have rapidly increased from the first housing subdivisions located there in the 1930's. The increase in hard impermeable surfaces such as roofs and roads and the improvements in stormwater drainage design has lead to an increase in stormwater runoff passing through the stormwater channel at the Western end of Mission Bay Beach. At high tide the stormwater enters the sea as a jet which is diffused in the sea water, however, at low tides the stormwater cuts a channel through the soft transportable sand and transports it towards the water's edge, where it is in a position to be moved by the energy of the waves.

2. PRELIMINARY STUDY

The first part of the investigation consisted of a data collection exercise. Historical records of beach profile and plan shape were studied to try to determine a long term pattern. At the same time local residents came forward with various explanations for the disappearance of the beach. All this evidence was collated with a view to supplementing the recorded measurements with some visual observations. The start of the beach erosion apparently started at the time of the construction of a water front road and associated sea wall.

Beach profiles provide a history of beach sediment movement. Developing a complete physical history is important to provide some basis of comparison to the current changes occurring on the beach. The longer the recorded history the better the judgement can be. Mission Bay has only a short record of beach profiles, the first useful survey being started in 1977.

For this study two new locations on Mission Bay beach and two new locations on the beach by the Tamaki Yacht Club were included. Figure 4 shows plot of Mission Bay profile No. 1, a profile of the beach recorded by Nelson (4) in 1969 is shown, this is the only earlier record of the beach profile available. It illustrates how the large volume of sand contained in a berm of some 15m width has eroded away over the last 18 years.

The monthly records of the profiles produce no firm trends, the most noticeable results from these profiles are the large variation in sand movement which occurs at Mission Bay No. 1 and also they provide an illustration of the dynamic nature of the beach and the processes on it and shows the nature of short term profile variations. The large variations are due to the profile's location at the western end of the beach next to the stormwater channel. The rest of the profiles indicate movement of beach sediment, however the quantity of movement is not as significant as in the profile by the stormwater channel. The movement of beach material is shown to be highly dependent on the prevailing wind direction, during the north-easterly storms the sand is transported from east to west, however during the westerly winds which are milder but more frequent the sediment returns along the beach. This shows that the transport of material is not all in one direction and that a certain amount of dynamic equilibrium does exist.

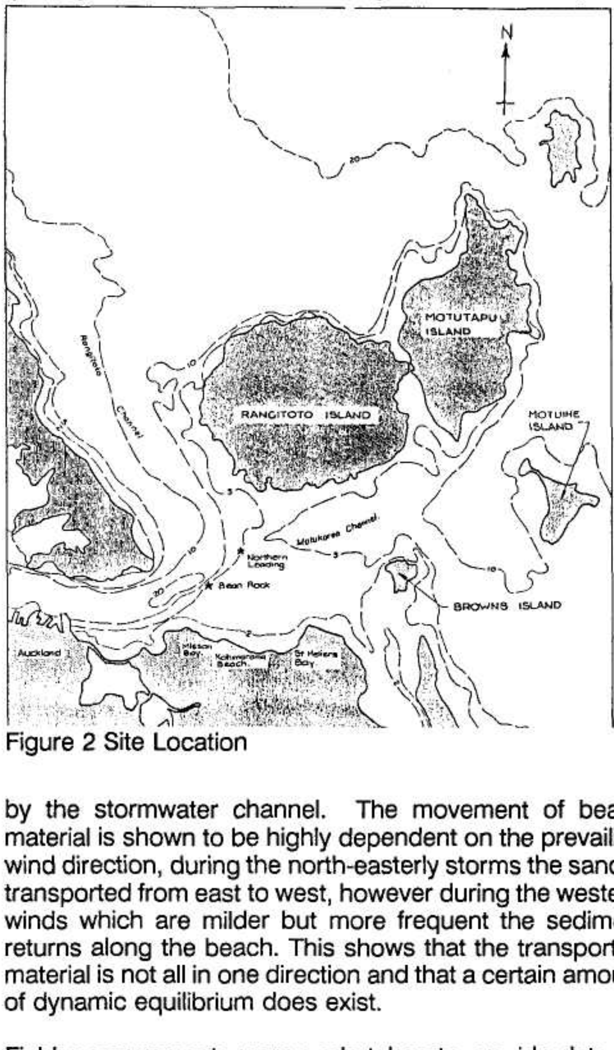

Figure 2 Site Location

Field measurements were undertaken to provide data for the prototype wavelength, the wave height and the wave period during a north-easterly storm. An "Inter-Ocean Systems Model S4" buoy was eventually hired to record wave heights. This was located in a position corresponding to the wave paddle in the model and activated every four hours to record a fifteen minute burst of data. A north-easterly storm recorded on the 16-12-87 at 00.00hrs provided the information used in this study. The final design wave had the following characteristics: Significant wave height = 0.5 metres, Wave period = 3.33 seconds and Wavelength = 16.50 metres.

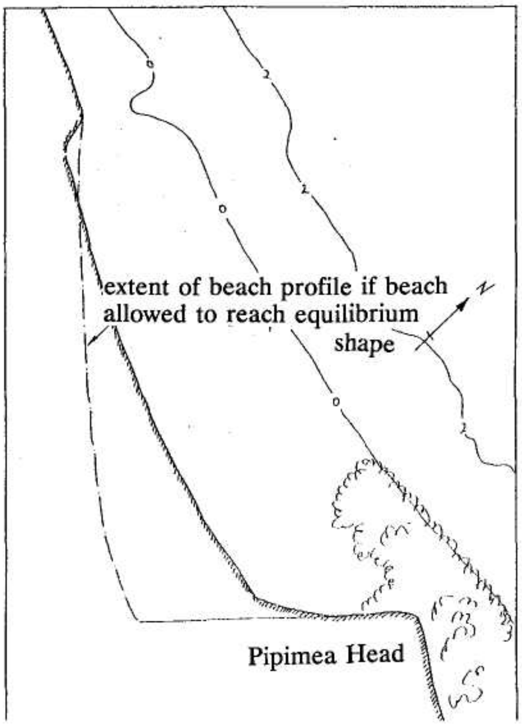

Figure 3 Equilibrium Shape for Mission Bay

A short computer study of the wave refraction in the area was undertaken at the same time as a wave data collection exercise was commenced in the field. Information gathered from these exercises was then used in the construction of a physical model of the area.

The stormwater runoff creates an unnatural gap in the beach's profile by removing the beach material at the western end of the beach. The beach, in an attempt to maintain equilibrium, displaces sand from along the beach to fill in the gap created by the stormwater. This cycle slowly reduces the level of the sand along the beach and exposes the sea wall which then serves to aggravate the problem.

From the windrose drawn from data recorded at a station in the Waitemata Harbour from 1955 to 1962 it was evident that the strongest wind condition comes from the East-North-East direction during the winter and spring seasons. The largest fetch is from Mission Bay to the North East between Rangitoto Island and Browns Island. This combination of large fetch and strong winds create the most lethal wave direction.

The waves from this direction reflect obliquely off the wall at high tide and continue to travel towards the west. This action of the waves breaking on the wall and reflecting off it creates a strong agitation motion by which the sand is brought into suspension and the continuing wave motion and the ensuing currents generated transport the sand towards the western end of the beach. At the western end of the beach the movement of the material is slowed down by the larger mass of sand at that point which encourages the waves to break on the beach rather than to reflect off the wall. However, the stormwater aggravates the condition by encouraging the sand to move around the sea wall and towards Bastion Point.

The causes of erosion at Mission Bay were identified as

1 The natural erosion of the beach between two headlands under predominantly North East storm conditions.
2 Interaction with sand at mid to low tide by the western stormwater outfall.
3 Reflection of the incident waves by the wall during a north easterly storm.

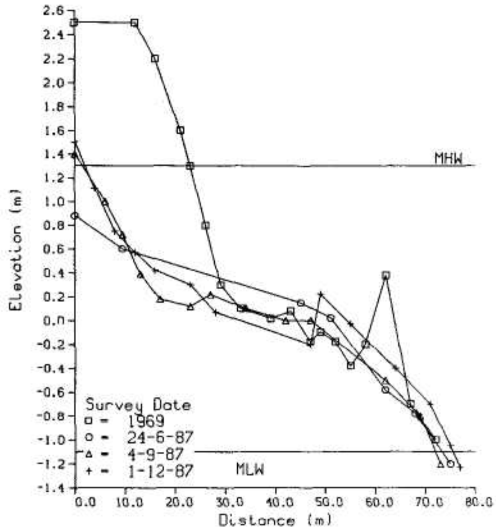

Figure 4 Beach Profiles at Mission Bay No 1

3. MOBILE BED MODEL

In order to determine the most suitable method for preventing further erosion of the beach and sea wall at mission bay, it was decided to construct a mobile bed model. The model was to be aligned to allow waves from the North East to be modelled. The model was constructed in a conventional manner using hardboard templates, granular fill and a plaster crust.

The model was built to a scale of 1:150 horizontal and 1:40 vertical. The granular material used was crushed coal from 2.00 mm to 67/J with a d^, of 1.14 mm. Coal has a specific gravity of 1.3 compared with sand which has a specific gravity of about 2.65, therefore, in the model the coal transports readily.

4. MODEL EXPERIMENTS

Approximately 25 different configurations were tested in the model. These tests can be conveniently classified into four groups

Control Experiments - These experiments provided a basis of comparison from which the other experiments could be judged. The controls consisted of runs with the beach as it is now with either the stormwater operating or not operating.

Retentive Experiments - In this section structures were constructed, such as groynes, breakwaters, sea walls and wharves at both eastern and western ends, on or near the foreshore, to retain the sand within the Mission Bay area.

Preventive Experiments - These aimed at preventing the waves from reflecting at the wall thus reducing the littoral drift of sand. This was done by the use of energy absorbers on the beach wall, building up the beach level and extending or constructing artificial reefs off Mission Bay Beach.

Stormwater - The remaining tests were specifically done to investigate the effects of stormwater on the beach at high and low tide. The stormwater was run at high and low tides through the eastern outfall and the western outfall.

Space precludes a full description of all these tests. This discussion is limited to an overview and highlighting of significant findings.

The control experiments were designed to "prove" the model in so far as the observed behaviour of the beach was reproduced under the predominant wave condition. This control run was performed with a variety of stormwater options. Physical parameters were adjusted until the model produced an accurate representation of the actual beach movement.

The remaining three groups of tests were concerned with various proposals to prevent the loss of sand from the main beach area at Mission Bay. The main philosophy when designing the remedial measures was to produce a scheme which interfered as little as possible with the natural forces which are at work. A range of measured were suggested by various people and most of these were tried. The following discussion outlines the findings of these tests.

5. RETENTIVE SCHEMES

Any of the retentive schemes also required some beach nourishment program to recover the sand which had already moved out of the locality.

A variety of sea walls and groynes were installed and tested during the experiment. The aim of these structures were either to (i) Contain the sand within the Mission Bay area, or (ii) Alter the incoming waves to effect a change in incoming wave patterns which would alter or stem the flow of sand.

Containing the sand involved either the construction of groynes or the extension of sea walls at the western end of the beach by the stormwater outlet area. Altering the incoming waves involved mainly changes at the eastern end of the beach. A test run was undertaken with a wharf located at the old wharf site at Pipimea Head.

6. PREVENTIVE SCHEMES

The reflected waves from the sea wall create an environment which transports the beach material westwards along the beach. To reduce the effect of the sea wall the reflective quality of the wall must be minimised.

Therefore, options to reduce the effect of the sea wall are:

1 Building up the beach level
2 Rubble energy absorbers
3 Fabricated energy absorbers
4 Offshore Solutions

Building up the beach level involves the placement of sand onto the beach to build up the beach profile to such a level that the wall is 'hidden' by the beach, such as the Engineering High Water Line (The Engineering High Water Line has an R.L of 11.5 m which is 1.2 m above the Mean High Water Springs). The incoming waves are thus dissipated by the beach itself and not reflected by the wall. This option has the benefit of creating a larger beach area and is a 'natural' and aesthetic solution. It is an option that has to be undertaken to some extent in conjunction with other works to protect the toe of the sea wall.

Placing rubble boulders along the face of the sea wall to above the Engineering High Water Line and of a sufficient size to resist the movement of the wave attack would reduce the reflected waves by presenting a rough permeable surface to dissipate the wave energy. This is an effective if not aesthetic solution.

Energy absorbers would attain the same result as the above option but by using state of the art technology currently available, e.g. such devices as seabees, gabions etc. Any such option, however, would need to be aesthetic and vandal proof.

In recent years a number of low crested breakwaters have been built or considered for use at a variety of locations. Most of these structures are intended to protect the beach or reduce the cost of beach maintenance. Both the physical model study and the computer study indicated that West Bastion Reef played some part in reducing the wave energy of the incident wave by reflection off the reefs surface, by absorption and by transmission over the top of the reef. To produce a significant reduction of wave energy the gaps in the reef would need to be filled in with rubble of some kind to bring the whole reef up to near the water surface. This study tested submerged offshore breakwaters involving the construction of large submerged and exposed breakwaters offshore to encourage the waves to break at these structures and not at the beach. However, due to the scale of the physical model it was impossible to determine the height of the reef below high water, the width of the crest and the side slope needed to cause the waves to break.

7. REMOVAL OF STORMWATER FLOW

The final set of trials were an attempt to illustrate the effect the various proposed stormwater flows would have on the beach with the beach profile as it is at present. Options tested in this area were:

1 Piping the stormwater under the beach
2 Transferring stormwater flow to Eastern end of beach
3 Separating the western stormwater outflow from the beach with a low rough groyne

The comparison between runs with no stormwater flow and a western stormwater out flow modelling a prototype flow of around 11 m^3/s, shows a marked increase in the transport of sediment along the beach to the Tamaki Yacht Club at Bastion Point with the operation of the stormwater. The option of moving the stormwater to the eastern end produced little extra movement. Piping the stormwater under the beach would nullify the effect of the stormwater by removing its destructive force from the beach and discharging it further out away from the sandy beach.

8. DISCUSSION

The construction of the sea wall combined with the natural changes of fetch alignment and the diminished sediment supply creates a condition which rapidly removes the beach material from the beach during a north-easterly storm. It is not possible to accurately quantify the amount of erosion any one problem had created and no single problem appears to be the dominant one. Therefore it can be deduced that the erosion is largely caused by a combination of beach alignment, the western stormwater outfall and the reflection off the sea wall.

The solutions tested in the wave tank have clearly indicated the problems that arise when a groyne or sea wall is used in an attempt to halt littoral drift or to affect a change in the incoming waves to push the sand back along the beach. The littoral drift continues around these structures and back reflection off these structures often caused detrimental scour at locations which were previously unharmed from the wave attack. These solutions which only focus on the immediate problem usually only provided partial success at solving the initial problem and usually created a new problem and also would block any returning sediment from replenishing the beach during a westerly or southerly wind.

It may be summarised that any solution which involves the construction of a structure to prevent the sand from moving or to alter its movement to a more favourable position tended to only be partially successful and usually created additional problems. The most effective solutions were the artificial beach nourishment scheme, the rip-rap and the extension to West Bastion Reef, all of which aimed to solve the erosion problem by treating the source of the problem. The offshore solution, the submerged West Bastion Reef extension, tested both in the wave tank and the wave flume offers a solution which would reduce the size of the north-easterly wave attack by transmission, reflection and absorption. However the structure would involve the movement of large volumes of material to create a reef extension that would be within the 0.5 metres from the M.H.W. to reduce the wave height by more than 50%. It has been left out of the preferred option to reduce beach erosion due to the large scope of work required. If the wave climate had waves of greater than four metres and have a longer wavelength this option would be more efficient and a definite favoured option.

Artificial beach nourishment to make up for the lack of a natural source of sediment supply is an exercise that has to be done to some extent whatever the main solution to reduce the beach erosion is to be. It was decided to use this option as the main solution to protect the sea wall and to reduce the littoral drift. If enough sediment is placed on the beach to provide a significant berm at high tide the waves will break on the beach rather than on the wall this reduces the amount of reflected waves thus reducing the rate of littoral drift and it will also protect the wall from the wave attack.

9. CONCLUSION

The experiments have shown the main causes of erosion and the most successful means of arresting the rate of littoral drift along Mission Bay. It can be concluded that the erosion is not caused by one major problem but occurs due to an accumulation of minor ones. It is the mixture of fetch orientation, climate, topography, the sea wall which induces the littoral drift and the stormwater channel combines with these forces to aggravate the problem. It is also evident that the situation is reversible, the beach sediments do return slowly during the predominantly south westerly winds. Therefore in evaluating the best form of coastal protection for Mission Bay it is important to allow the beneficial natural processes to continue unhindered and to assist it to achieve a beach that is as close to equilibrium as possible.

The following is a recommendation of work to be undertaken at Mission Bay beach to reduce the loss of sand from the beach and to provide protection to the sea wall.

Step 1 Modify the stormwater at the western end to reduce flow and to separate the flow from interacting with the sand.

Step 2 Build the beach up with sand to protect the wall and reduce the reflection of the incoming waves.

Step 3 Monitor sand movement by measuring beach profiles at regular intervals.

Step 4 Nourishment of sand back along the beach whenever necessary by truck or grader.

The first two steps would have to be carried out to initiate equilibrium on the beach. Step 3, a continuing monitoring programme, would then be implemented. From the information received future decisions can be made as to when beach nourishment would be required. If after observation it is found that the sand level is entirely adequate it requires no extra financial input, if however, further work is required a small amount can be done on an annual basis, rather than spending a huge amount initially and creating an inflexible structure that does not respond to future changes which may occur in the Auckland climate (such as possible rising sea levels).

The building up of the beach and the modification of the stormwater still leave the waves approaching the beach at an angle, to break and generate a longshore current which would induce littoral drift which implies that there would still be some movement of sand along the beach. These solutions offer a solution which provide assistance to the environment and allows the environment to continue without major interference from structures. It does not however totally halt the movement of beach sediment but aims to reduce the movement of sediment while maintaining the existing features of the beach.

There is an emphasis on a flexible unobtrusive low key solution rather than an inflexible large scale obtrusive one. The philosophy behind this recommendation is based on the observation during testing that any major structure creates major detrimental effects in wave patterns and sand movement and also that a dynamic equilibrium force does exist on the beach, bringing the beach sediment swept away in the north-easterly storms back during the westerly winds.

Designs which acknowledge the imbalance of nature's forces and attempt to provide for nature's losses provide a more lasting solution than one which imposes on nature in an attempt to control it.

10. ACKNOWLEDGEMENT

The funds for this investigation were provided by Auckland City Council.

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