VESSEL WAKES AND THEIR IMPACT ON RIVER BANKS

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BACKGROUND

In recent times, environmental considerations have been recognised as being important concerns in the vessel design process. As such, vessels which are environmentally friendly are being sought where operations will be in sensitive areas. One particular area of concern is the Lower Gordon River region located in the World Heritage Area in south-west Tasmania. The Gordon River region has long been recognised as an area of great natural beauty and as such is now one of Tasmania's major tourist attractions. A thriving tourist industry has been built up in the area and there are now a number of craft which regularly visit the river carrying tourists to explore the wilderness region.

Over the past ten years there has been an ever growing number of large, high speed tourist vessels making daily trips on the river. In conjunction with the increasing burden on the river, serious bank erosion has taken place, this has created the necessity for immediate action to remedy the problem. The erosion occurring to the river banks of the Lower Gordon is the primary reason for the research to be described here, however this is not a localised problem but is particularly relevant to many rivers and restricted waterways.

Many studies have been carried out on river bank erosion and vessel wavemaking although few have aimed at linking the two. So, in conjunction with the University of Tasmania, the Australian Maritime College has been investigating methods of reducing bank erosion from a combined hydrodynamic and geomorphologic standpoint.

A BRIEF HISTORY
(from Von Krusenstierna, 1990)

Captain James Kelly of Hobart discovered and named Macquarie Harbour and the Gordon and King Rivers in 1815-16. Kelly was searching for an easily accessible source of Huon Pine which at that time had already been recognised as a prime ship building timber. Kelly found excellent stands of Huon Pine on the foreshores of Macquarie Harbour and along the banks of the Lower Gordon River. As a result pine cutting became the predominant land use of the area for the next hundred years.

Within months of the discovery of Huon Pine in the area, the first "piners" had arrived. Exploration of the region was limited as it was felt that maintaining the isolation of thge area would discourage convicts from the nearby Sarah Island penal colony from escaping. The Sarah Island convict settlement was established in 1822 not far from the mouth of the Gordon River and was used until it's closure in 1833. Convict labour was used in felling Huon Pine, and shipbuilding on Sarah Island using the local timber.

After the closure of the penal settlement, pine cutting continued, but on a smaller scale. By the end of the century a mining boom had developed in the towns of Zeehan and Queenstown which used the town of Strahan as their port. By this time most of the commercially valuable timber along the banks of the river had been cut, so logs were cut from the upper reaches of the river and floated downstream where they were collected in booms near the river mouth. River traffic during this period was light, consisting mainly of small flat bottomed punts, and steamers picking up logs along the river. Following the Second World War, prices for Huon Pine were low and as the pining industry declined, tourism began to replace it as the major local industry.

Tourist cruises on the Gordon River have operated since the early 1900's. Tourism in the area received a major boost with completion of the road link between Strahan and Queenstown in the 1960's. As the demand for river cruises grew, so did the size of vessels using the river and the frequency of visits increased. During the summer of 1982-83 the river saw it's heaviest traffic ever during the preparation for the building of the Gordon below Franklin Dam. Up to 60 boat passages per day, consisting of Hydro-Electric Commission boats and barges, police and media boats, tourist launches and conservationist rafts.

The media coverage of the dam controversy produced an upsurge in tourism, prompting the tour operators to invest in new, bigger and faster vessels. By the mid 1980's three modern high speed (25 knots +) craft were making daily visits to the river, twice daily during the summer.

VESSEL WAKES

It is well known that when a vessel is moving on the water surface a wave pattern is formed. As the energy required to generate these waves forms part of the total power required to propel the vessel, naval architects have tried to develop hull shapes which reduce the energy in the wave pattern. Hull shapes that lower the wave energy only decrease the power required if they do not result in a greater increase in other forms of ship resistance, such as skin friction resistance, or form drag. The balance between the different components of resistance depends on the speed of the vessel or more correctly on the Froude Number.

The wave pattern generated by a vessel both trails the vessel and also radiates away from it. Consequently, an inconvenience caused is that the waves can strike nearby objects causing annoyance to other users of the waterway and damage to jetties, pontoons, and river banks. This characteristic of the wave pattern is only recently becoming of concern, as the environmental impact of high speed vessels in restricted waterways is being understood.

So when designing a vessel to operate in an environmentally sensitive area there are two different approaches possible:

- a specially designed low wake wave vessel; or
- modifications to an existing vessel design.

It is likely that the specially designed vessel will end up as a catamaran with maximum length, minimum demi-hull beam and minimum displacement. A good example of such a vessel is the Rivercat (Hornsby et al, 1991). This vessel has been designed with the aim of minimising the size of the generated wave pattern as an overriding consideration.

If the maximum wave size permitted in a given application is not too small, it may be possible to modify a conventional design to achieve the desired result at a lower cost, while retaining the desirable features of the conventional design. It may even be possible to retrofit these design modifications to an existing vessel.

VESSEL MODIFICATIONS

Although there is no doubt that a lower wake wave can be obtained using a specially designed vessel, if a suitably small wave can be obtained by modifying an existing vessel this will be preferable in many cases.

It is well known that there are three basic principles for reduction in the size of the wake wave system:

- avoidance;
- suppression; and
- cancellation.

Avoidance can be described as striving to locate the vessel, or the part of the vessel, that generates the pressure disturbance, as far from the free surface as is practicable. A submarine deeply submerged produces no appreciable surface waves, and as such the use of a SWATH (Small Waterplane Area Twin Hull) vessel may be a possible solution to the bank erosion problem. A SWATH type craft has the advantages of, good seakeeping qualities, and passenger carrying capability whilst creating minimal surface disturbance.

Suppression is the physical prevention of vertical water particle movement by a hull surface. Effective use of chines and spray rails is common practice, particularly on high speed vessels.

Cancellation is basically the destructive interference of one wave system on another, which is the concept made use of by bulbous bows. A vessel on the water surface generates wave systems at both the bow and stern. If these systems can be positioned a certain distance apart, the crests from the bow wave system will coincide with the troughs from the stern system, and each will be cancelled to some degree.

Avoidance and suppression are not easily achieved by modifications, however cancellation may be possible by altering the pressure distribution around the hull. As the largest wave is typically generated by the high pressure region at the bow, a reduction in pressure over this region should result in a smaller maximum wave height.

One means of accomplishing this is to locate a small lifting foil in the high pressure region with the angle of attack set so as to generate a low pressure region above the foil.

EXPERIMENTAL PROGRAM

Wigley Hull Model

As the aim of the investigation was to reduce the wave heights within the wake wave system, a hull form was required which exhibited a well defined wake wave pattern. A modification to the form defined by Wigley (1934) (see Figure 1) was chosen as it was known to exhibit a large bow wave, is wall sided allowing for convenient attachment of the foils, and there is substantial data available on the wave wake field from previous studies.

The modified Wigley hull form has parabolic waterline and section shapes defined by the following equation, using the coordinate system shown in Figure 2:

$$y = \frac{B}{2}\left[1-\left(\frac{2x}{L}\right)^2\right]\left[1-\left(\frac{z}{T}\right)^2\right] \qquad \text{Eq. 1}$$

For this model the length to breadth ratio (L/B) = 5.0, and the breadth to draft ratio (B/T) = 1.622.

The values of L/B and B/T chosen differed from Wigley's original model in order to be closer to those of a conventional vessel.

The principal particulars of the model are as follows:

Waterline Length (L) = 1.5 m
Maximum Beam (B) = 0.3 m
Draft (T) = 0.185 m
Displacement (Δ) = 37.379 kg (fresh water)

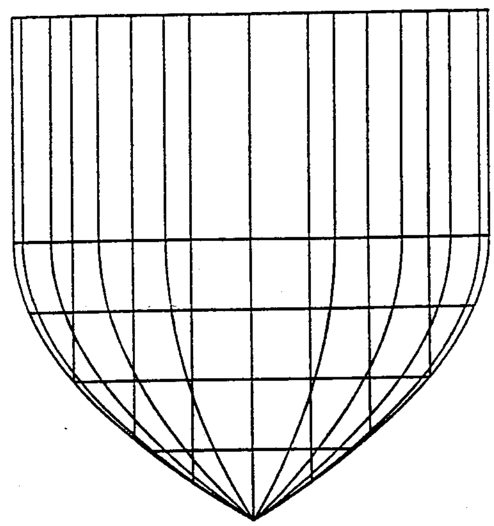


Figure 1: Wigley Hull Model Body Plan

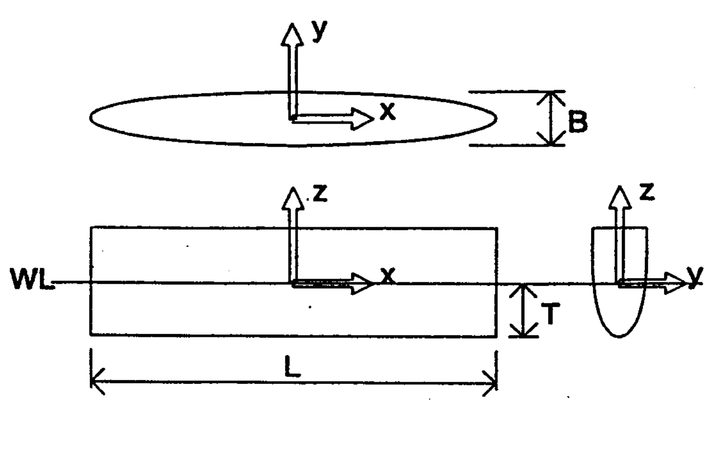


Figure 2: Wigley Hull Coordinate System

Foil Geometry

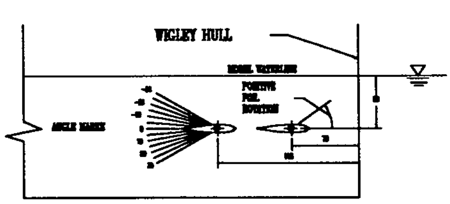
All the foils used were rectangular in plan form, with dimensions given in Table 1. Two different section shapes were used; the first a NACA 16-012 section, (Abbott & Von Doenhoff, 1959), and the second a flat plate with a radiused leading edge and tapered trailing edge.

All foils had a chord of 38mm and a thickness of 5mm.

Foil	Span (S) (in mm)	Non-Dimensional Span (S*)	Aspect Ratio (S/C)	Section Shape
A	216	1.44	5.68	NACA 16-012
I	216	1.44	5.68	Flat Plate
II	144	0.96	3.79	Flat Plate
III	100	0.67	2.63	Flat Plate
IV	40	0.27	1.05	Flat Plate

Table 1 : Foil Particulars

The foils were attached perpendicular to the centreline of the model and aligned horizontally. Positive foil angles represent rotation of the foil with the leading edge upwards and the trailing edge downwards as shown in Figure 3.



(dimensions in mm)

Figure 3 : Foil Attachment to Wigley Hull Model

TEST PROGRAM

As the shape of the measured wave profile will depend on the transverse distance of the measuring point from the centreline of the vessel, (Renilson & Lenz 1988) wave data was collected using an array of six wave probes, each at the same longitudinal position. Typical 3-D plots of the results are given in Figures 4 and 5, where the reduction in the height of the first crest caused by the presence of the foil can be seen clearly.

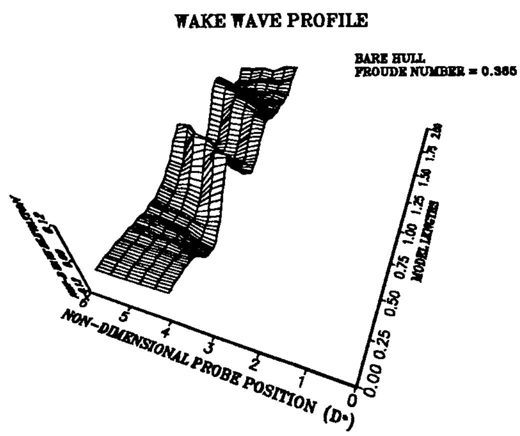


Figure 4 : 3-Dimensional Wave Profile Plot

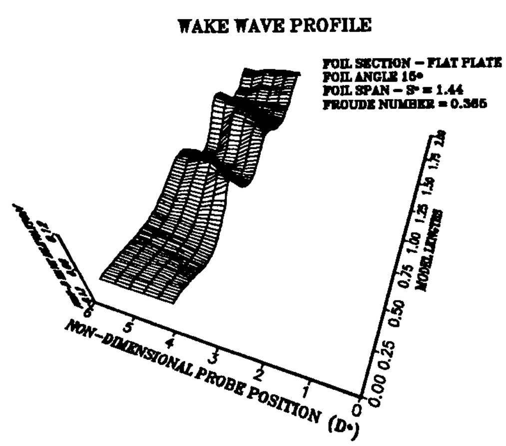


Figure 5 : 3-Dimensional Wave Profile Plot

Tests were carried out to investigate the effect of the following variables on the reduction in wave height:

i. Angle of incidence of the foil
ii. Longitudinal position of the foil
iii. Foil section shape
iv. Foil span

The different configurations tested are summarised in Table 2.

RESULTS AND DISCUSSION

At the time of conducting the foil tests, the simulated bank tests were uncompleted, and at that stage no conclusions had been drawn on the best wave parameter to use as a measure of the damage caused by the wave pattern. In accordance with previously published investigations (Sorensen, 1967, 1969, 1973a, 1973b) the single maximum wave height recorded as defined in Figure 6 was used as the basis for analysis.

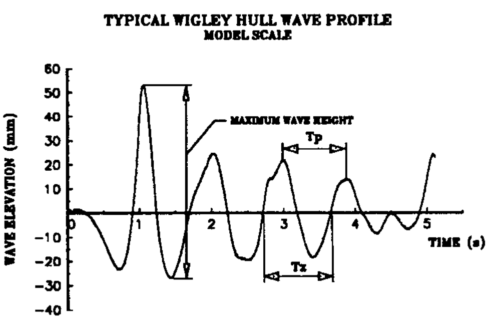


Figure 6 : Typical Wave Elevation Versus Time Plot

The Effect of the Angle of Incidence of the Foil

Figure 7 is a plot of the maximum non dimensionalised wave height, ($h_W^* = h_W/\nabla^{1/3}$) against Froude number for different angles of incidence of the foils. As can be seen, when the foils had a zero angle of incidence the maximum wave height is very similar to the bare hull condition.

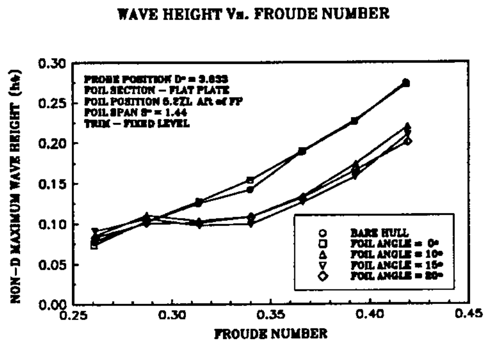


Figure 7 : The Effect of Varying Angle of Incidence of the Foil

When the foils had incidence angles of 10, 15 or 20 degrees there was a considerable reduction in the maximum wave height compared to the bare hull condition; however there is little difference between the wave heights generated at any of these three angles. Results for other configurations confirm this trend, indicating that incidence angles of anywhere between 10 to 20 degrees have similar effect.

The Effect of Longitudinal Position of the Foil

Initially the model was tested with no foils attached, and the wave pattern observed. The foils were then fitted at a longitudinal position of 10.9% aft of the FP which put them close to the bow wave crest.

During the tests it was noted that the foils were positioned slightly aft of the centre of the crest so they were moved forward to a new longitudinal position of 5.2% aft of the FP. As can be seen from Figure 8 the forward position reduced the wave height significantly compared to the original position. This result was similar for other configurations tested. Unfortunately, it was not convenient to attach the foils further forward on this model.

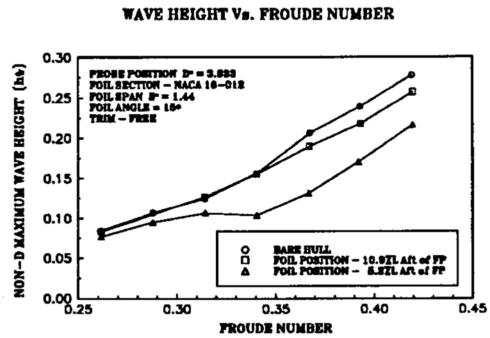


Figure 8 : The Effect of Varying Longitudinal Position of the Foil

The Effect of the Foil Section Shape

In order to simplify foil construction it was decided to investigate the effect of changing the section shape from the NACA profile to a profile consisting of a flat plate with radiused leading edge and tapered trailing edge.

As can be seen from Figure 9 the section shape makes very little difference to the wave height.

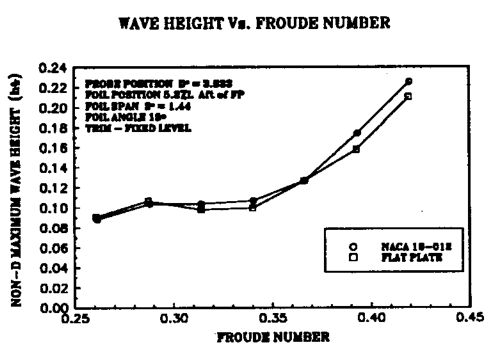


Figure 9 : Comparison of Foil Section Shapes

The Effect of Foil Span

In order to investigate the effect of span, tests were carried out on a further three foils as listed in Table 1.

Figure 10 shows a typical plot of wave height against span for three different transverse wave probe positions. Wave height decreases with increasing span, and is significantly reduced with the largest span. As expected, this result is not dependent on the transverse position of the measurement.

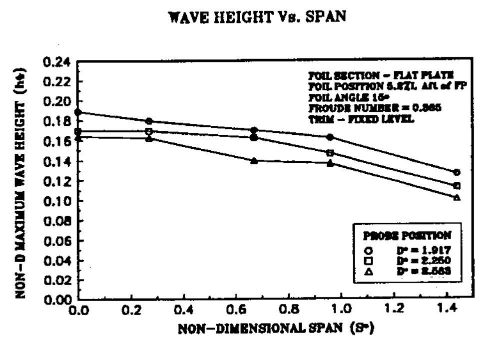
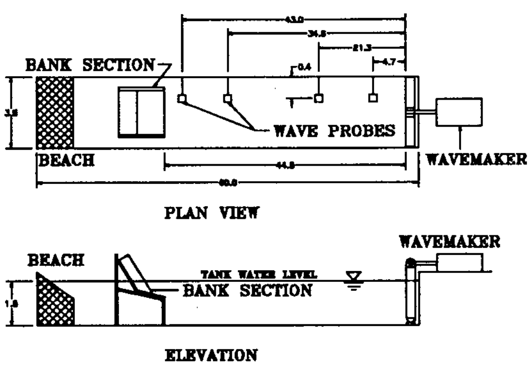


Figure 10 : Comparison of Foil Spans

LEVEE BANK SIMULATION

In order to gain a clearer understanding of the mechanisms at work during the erosion process, a simulated section of river bank was erected in the Australian Maritime College's towing tank. The bank was then subjected to attack by waves with varying characteristics and the effects measured. A significant advantage of this method was that the bank could be modelled at full scale, thus minimising any scale effects which may have occurred.

Prior to the bank tests, field trips were made to the Gordon River and soil samples collected which were subsequently analysed, allowing suitable sediment from the local region to be used to simulate the levee bank materials on the river. The model bank itself consisted mainly of two plywood boards, hinged to allow various bank geometries to be trialled, and a steel pipework scaffolding used to support the boards and bank sediment. The boards were angled to give a bank slope at the angle of repose for the sediment (27-30°) enabling the natural and noneroded levee bank morphology to be modelled. The bank was positioned approximately three quarters of the length of the tank away from the wavemaker as shown in Figure 11.



(Dimensions in metres)

Figure 11 : Schematic of the Towing Tank and Simulated Levee Bank

One of the main aims in carrying out the bank tests was to try and validate the underlying assumption that superposition could be applied to the erosion process. If this is the case, then using linearity, it is possible to combine the individual effects of each component into the overall effects for the whole wave train.

In order to determine which wave characteristics were the most significant in causing bank erosion, a matrix of regular wave types was trialled. This allowed certain wave properties to be easily calculated accurately, and if linearity could be assumed then simple addition of suitable waves could be used to predict the result of a vessel wake attacking a bank.

The matrix of wave types was developed with the general principle being to hold the wave frequency constant while varying the wave height, then hold the wave height constant and vary the wave frequency. In this way, a range of wave heights from 50 millimetres to 200 millimetres was covered in 25 mm steps. Frequencies ranged from 1.0 Hz to 2.0 Hz with increments of 0.1 Hz tested in between.

LEVEE BANK SIMULATION RESULTS

The magnitude of erosion was measured after each test by calculating the volume of eroded material and collecting suspended sediment in two wash bottles located offshore from the bank (Matthews et al, 1994). These erosion indices were then correlated with results obtained from data collected by two wave probes, one located near the wavemaker, the other adjacent to the bank. The results from the wave analysis consisted of measurements of the average, maximum and significant wave heights, the wave period, wavelength, and wave steepness. The phase and group velocities were also calculated along with the wave energy and power.

Using simple linear and curvilinear regression, the strongest correlations between the erosion indices and the wave parameters were measured for wave power ($r = 0.87$), average wave height ($r = 0.80$), and wave energy ($r = 0.78$).

Scatterplots of wave power, average wave height, and wave energy versus the total volume of sediment eroded are given in Figures 12, 13 and 14 respectively. The significance of each wave parameter in causing erosion (Ep) may be quantified by using the following equation:

% erosion caused by wave parameter (Ep)

$$Ep = r^2 \times 100$$

where r is the correlation coefficient.

For example, erosion of the model bank due to group velocity (r = 0.41) = $0.41^2 \times 100$ = 16.8%, ie. group velocity explains 16.8% of the erosion. Since most of the wave parameters are interrelated, the individual percentages cannot be added to give a total Ep value.

Observations from the tank tests suggested that wave height was the dominant control of erosion. In particular, the average wave height was most influential explaining 63.7% of the erosion compared to the maximum wave height (45.5%) and the significant wave height (50.0%). That erosion of the model levee bank was better explained by the average wave height rather than the maximum or significant wave height suggests that all components of a vessel wake have the potential to cause erosion. This is a significant finding, as many previous studies (Sorensen, 1969, 1973a, 1973b) have based analysis on the the single maximum wave height within a wave train. The results obtained from the present study indicate that using the maximum wave height may not be the best indicator of a vessels propensity to cause erosion.

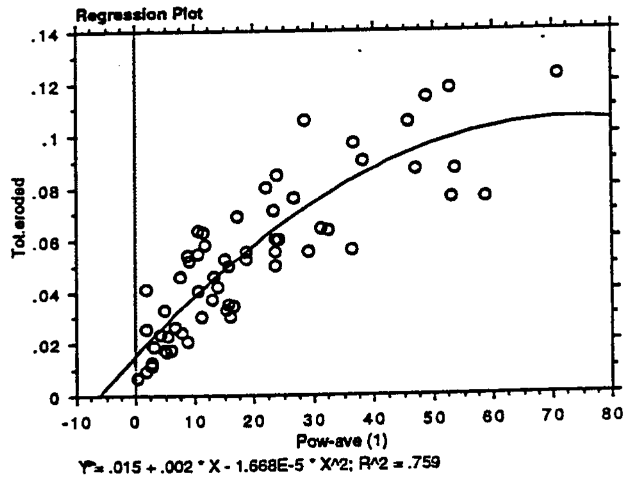


Figure 12 : Scatterplot of Total Volume Eroded Versus Wave Power

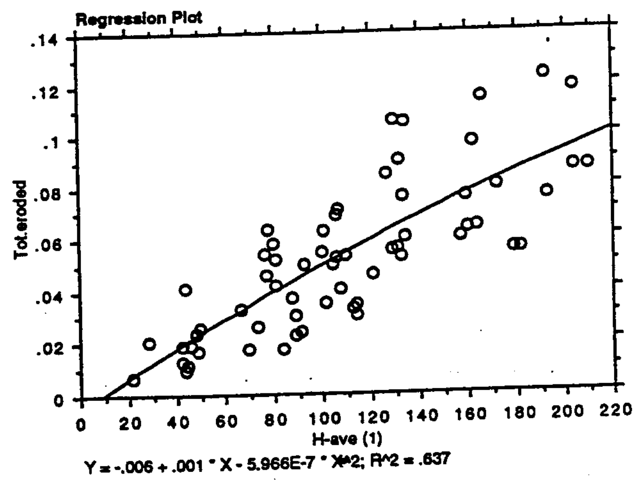


Figure 13 : Scatterplot of Total Volume Eroded Versus Average Wave Height

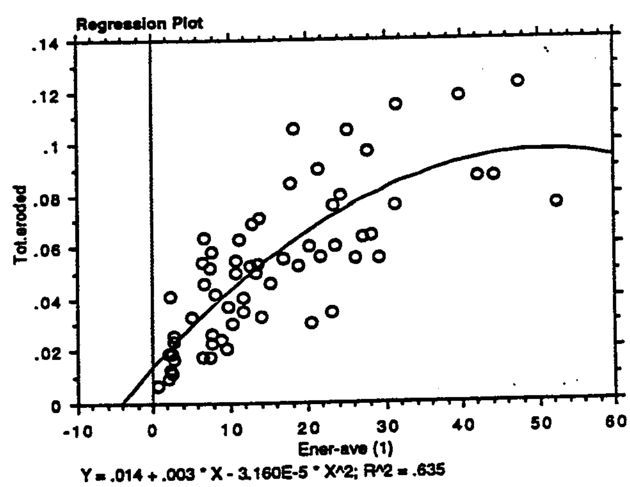


Figure 14 : Scatterplot of Total Volume Eroded Versus Wave Energy

During the simulated bank tests it became apparent that as well as the wave height, the wave period was also significant in causing erosion. Reducing the wave period for a given wave height, and hence increasing the wave steepness, did not increase the amount of erosion as might be expected. Instead, more erosion was recorded at longer wave periods due to the surging of breaking waves running up the model beach. At higher wave periods, the interval between successive waves striking the beach is greater, allowing time for the receding wave to wash eroded sediment from the foot of the slope, and expose fresh oversteepened bank material to the next wave.

CONCLUSIONS

a. The addition of a lifting foil with a positive angle of incidence of between 10 to 20 degrees close to the first wave crest reduces the maximum wave height generated in the wave pattern;

b. The angle of incidence of the lifting foil does not affect the size of the maximum wave, provided it is in the range 10 - 20 degrees;

c. The longitudinal position of the lifting foil is critical to the size of the maximum wave;

d. Increasing the span of the lifting foil decreases the size of the maximum wave;

e. The critical factor controlling erosion is the wave height and in particular, the average rather than the maximum wave height; and

f. The wave period is also a significant parameter in determining bank erosion particularly at higher periods.

ACKNOWLEDGMENTS

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NOTATION

Notation	Description	Units
B	Model Beam	m
C	Foil Chord Length	m
D	Probe Distance From Centreline	m
D*	Non-Dimensionalised Probe Position $D^* = 2D/B$	
Fr	Froude Number $Fr = U/\sqrt{gL}$	
g	Acceleration due to gravity ($g = 9.81\ m/s^2$)	m/s^2
h_w	Maximum Wave Height	m
h_w^*	Non-Dimensionalised Maximum Wave Height $h_w^* = h_w/\nabla^{1/3}$	
L	Model Length	m
S	Foil Span	m
S*	Non-Dimensionalised Foil Span $S^* = 2S/B$	
T	Model Draft	m
U	Model Velocity	m/s
x	Model Length coordinate	m
y	Model Beam coordinate	m
z	Model Draft coordinate	m
Δ	Displacement	kg
∇	Immersed Volume	m^3

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Test	Foil Section Shape	Span (S*)	Foil Angles (in degrees)	Foil Position (%L Aft of FP)	Trim
i.	Flat Plate	1.44	0	5.2	Fixed
	Flat Plate	1.44	10	5.2	Fixed
	Flat Plate	1.44	15	5.2	Fixed
	Flat Plate	1.44	20	5.2	Fixed
ii.	NACA 16-012	1.44	15	10.9	Free
	NACA 16-012	1.44	15	5.2	Free
iii.	NACA 16-012	1.44	15	5.2	Fixed
	Flat Plate	1.44	15	5.2	Fixed
iv.	Flat Plate	1.44	0, 15	5.2	Fixed
	Flat Plate	0.96	0, 15	5.2	Fixed
	Flat Plate	0.67	0, 15	5.2	Fixed
	Flat Plate	0.27	0, 15	5.2	Fixed

Table 2 : Model Test Configurations