

## **Shore parallel pile row breakwaters, an example of an effective coastal protection scheme**

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### **SUMMARY**

At the West Coast of Malaysia, near the border with Thailand, the island Langkawi is located. On the exposed West Side of this island a natural sand spit has formed, in the lee of two small offshore islands. On this cusped spit a beach resort has been built. Shortly after construction of the resort the owner became aware that the shoreline of the spit was eroding. Several measures were tried by the owner to halt the erosion, none of them were successful.

As palm trees started to topple into the sea, and wave run up flooded the swimming pool, a permanent solution became quite urgent. The spit had been slowly eroding before construction of the beach resort, most probably due to a change in environmental boundary conditions. Rapid erosion after construction of the beach resort occurred due to modification of the shoreline position to fit the architectural plan.

Two solutions were considered to stop the beach erosion; increasing the size of the offshore islands by rock breakwaters and construction of shore parallel breakwaters.

Because of economic reasons shore parallel breakwaters located at a distance of 75 m from the shoreline were chosen. To minimise the visual impact of the breakwaters, they have been designed and constructed as pile rows. Two pile rows of ca. 120 m length were built consisting of 350 mm concrete spun piles with a gap width of 70 mm. The distance between both pile rows is 210 m. The height of the pile rows is ca. 1.5 to 2 m above the seabed.

The effectiveness of the pile row breakwaters in stabilising the shoreline has been monitored, and is better than expected. Although the proposed beach replenishment was not carried out, the beach was restored well beyond its original plan shape within one monsoon season, by sand trapped in the lee side of the pile rows

### **LOCATION**

Langkawi is an island on the West Coast of Malaysia. The Pelangi Beach resort on this island was constructed on an existing spit in the lee of two small islands. Waves diffract around the two offshore islands, creating a natural cusped spit. A section of Admiralty Chart 834 is given in Figure 1 together with a key plan. Note that the depths are given in Fathoms.

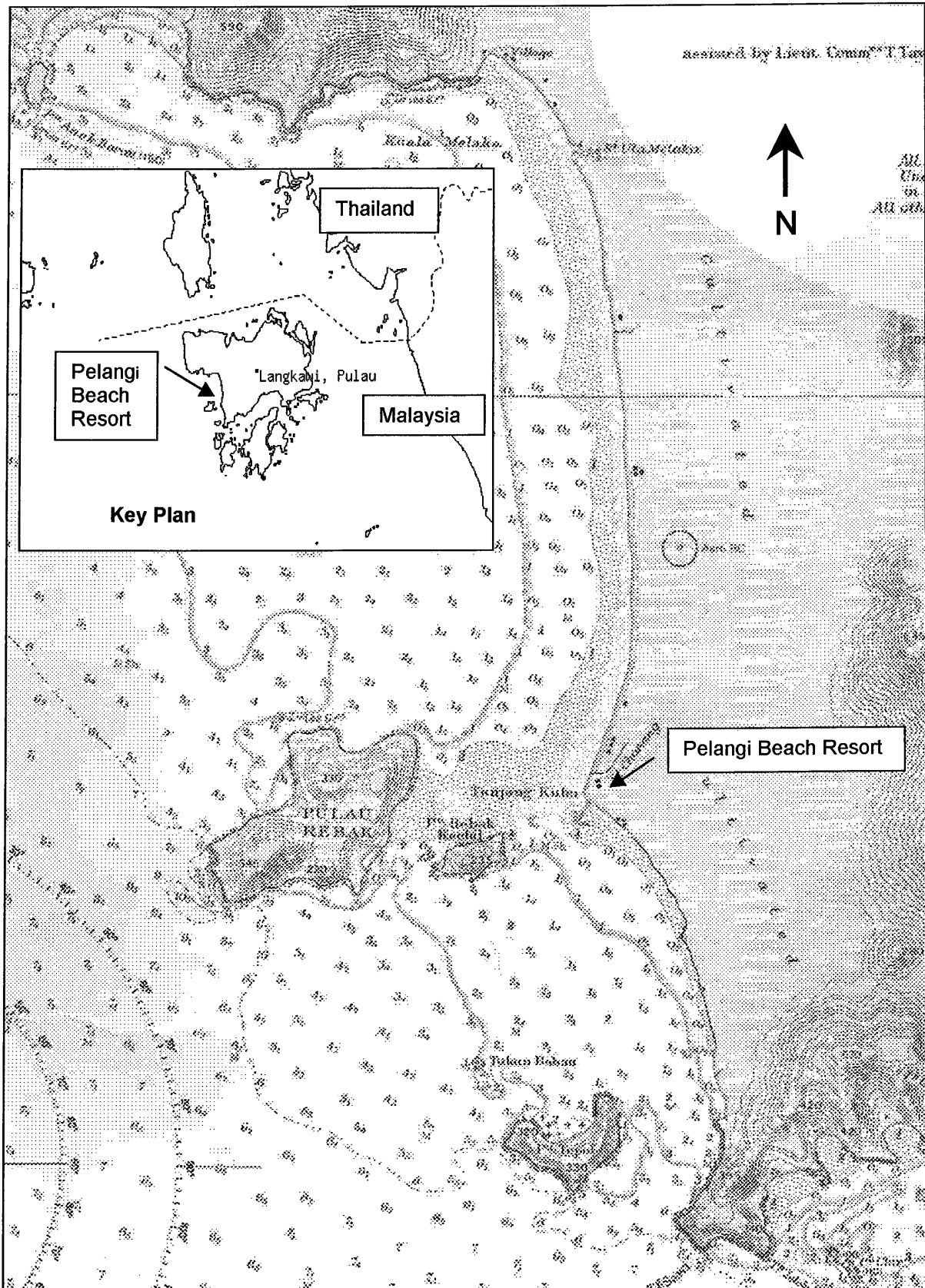


Figure 1 Bathymetry near the site

## **PROBLEM ANALYSIS**

The location for the Pelangi Beach Resort was chosen, as it is one of the most beautiful locations on the beach on the West Coast of Langkawi. However, the location is morphological sensitive, as the shape of the spit depends on local wave climate, and the sediment supply by a small river. After analysis of historic charts and maps it was concluded that before construction of the resort the spit had been eroding at a rate of ca. 1.5 m per year.

An analysis was made of the shore line position using spiral beach theory [Silvester, Reference 1]. A complicating fact is that during higher stages of the tide a tidal current runs over the submerged part of the cusped spit with a velocity of ca. 0.6 m/s. The analysis showed that the beaches north and south of the Pelangi Beach Resort do have shape, which can be described by a logarithmic spiral. However, due to the tidal flow the tip of the cusped spit does not follow the spiral shape.

From the bathymetric charts only erosion of the shoreline could be observed. The foreshore (CD -5 and CD -10 m contour lines) was found to be stable.

The mouth of a small river, Sungai Chenang, is located near the tip of the spit. The discharge of this river is in the order of 20 m<sup>3</sup>/s. One of the causes of the retreating shoreline may be a decline in sediment supply to the spit by this river, due to a reduction in forest clearing.

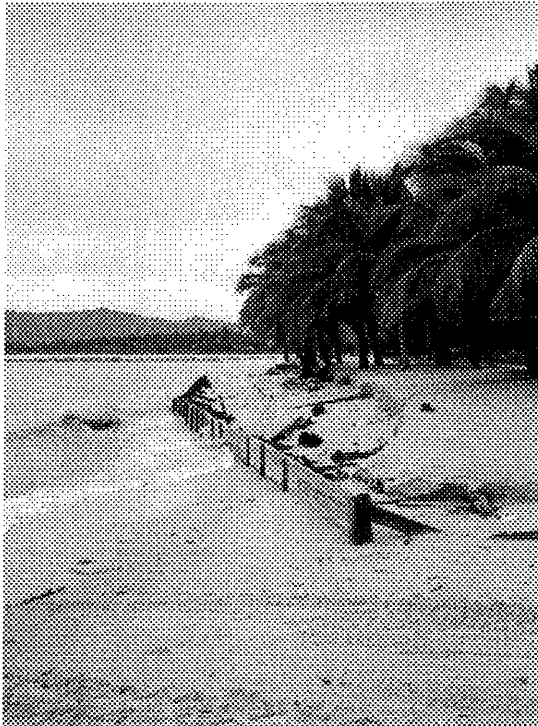
Another cause may be a change in environmental conditions, such as wave conditions, water levels and tidal currents. However, in the scope of the project it was not possible to do a detailed analysis of historic variations in these environmental conditions.

During construction of the beach resort it was decided to enlarge the spit, by reclamation, based on the architectural layout. The plan shape of the shoreline was changed, differing significantly from the original logarithmic spiral shape. At some locations the new shoreline was put over 20 m seawards. The river mouth was relocated 100 m to the north.

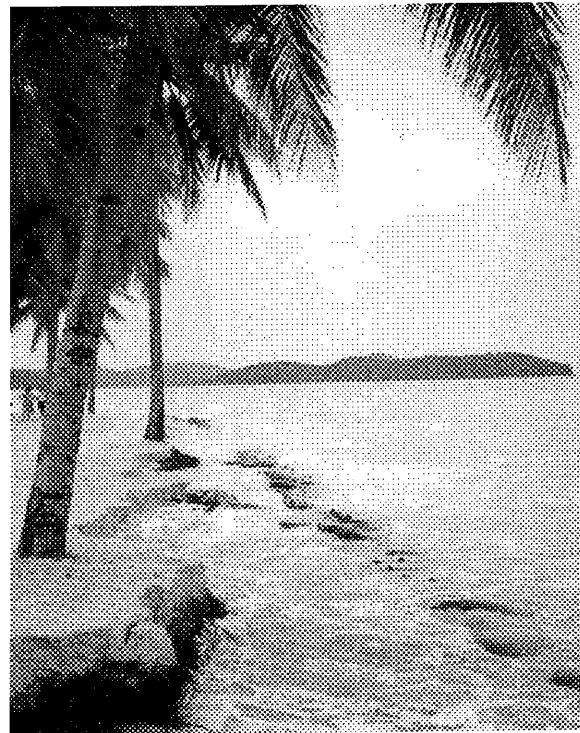
The initial rapid erosion, which took place directly after the construction of the resort, was caused by nature trying to restore the natural shape of the spit, as it was just before construction of the resort. This was concluded after comparison of bathymetric charts of 1989, before resort construction, and 1994, after resort construction.

The beach was severely eroded over a length of 300m causing palm trees to topple into the sea. Due to the beach erosion, wave run up reached the swimming pool, leading to flooding with salt water.

The resort owners tried several measures to stop the erosion. However, none of them were successful. First interlocking concrete blocks were put on the beach, but these disappeared below the sand after a storm. The remaining blocks are now in use as pavement for footpaths. Then small wooden walls were applied, but these were overtopped and undermined, as shown in photograph 1. Finally sandbags and rock were put on the beach, providing an unsightly view, as shown in photograph 2. After each storm new sandbags had to be placed, and the beach had to be reshaped with bulldozers.



Photograph 1. Failed wooden wall



Photograph 2: Sand bag protection

### **BOUNDARY CONDITIONS**

The tide at the Pelangi Beach resort is semidiurnal with a daily inequality. The tide range is 2.1 m, with Mean High Water Spring at CD +2.8 m and Mean Low Water Spring at CD +0.7 m. Tidal currents of up to 0.6 m/s occur over the submerged sand bar which connects the spit with the offshore islands.

The wave climate at the project location is governed by the monsoons. During the south-west monsoon from May to September the wind and wind wave direction is generally west. Some swell occurs from the north-west and south-west direction. During the south-east monsoon only swell from south-western directions is present. The daily wave climate has a significant wave height of ca. 0.5 m. The extreme nearshore wave height is depth limited due to the shallow foreshore.

The foreshore has a slope of less than 1:400. The slope of the beach face is ca. 1:25. The  $D_{50}$  of the beach sand is ca. 200  $\mu\text{m}$  and the  $D_{90}$  300  $\mu\text{m}$ . The shape of the beaches north and south of the spit can be described by a logarithmic spiral [Silvester, Reference 1].

The soil conditions can be characterised as loose to medium dense sand up to 6 m below seabed level.

### **DESIGN**

The recreational use of the beach required that a solution should have minimum impact on the beach, and would not endanger recreation along the beach. To provide a solution, which would stop the erosion of the shoreline, two options were considered. Initially the option of providing more shelter from wave action by adding breakwaters to the offshore islands was considered. However, this option was rejected from an economical point of view.

As an alternative, two parallel breakwaters were proposed, 75 m offshore, near the +0.5 m CD depth contour. In this way the spit is stabilised in its present geometry and the erosion is halted. Additionally a replenishment of the beach was foreseen, so the final equilibrium beach plan shape would be reached directly after construction and the impact on neighbouring beaches would be minimal.

Instead of selecting rubble mound as breakwater type, it was decided to design two pile rows. As the foreshore is very flat the nearshore wave height is considerably reduced in height. The nearshore design significant wave height at the CD +0.5 m contour is 1.35 m, and the maximum wave height just over 2 m. Therefore the design wave climate at the proposed breakwater is relatively mild. Although the beach erosion led to palm trees falling into the sea, relatively light measures could be taken to stop the erosion.

The concept of pile rows was developed to have a "light" protective structure on the beach, which would not have a large visual impact. Conventional rubble mound breakwaters would be quite massive, and would hinder the view from the beach to the offshore islands. Also they would lead to rip currents near the breakwater heads which could be dangerous for swimmers.

The pile rows have been designed for a transmission coefficient of ca. 0.6 at high tide. The goal was to restore the beach to its position just after completion of the beach resort. The pile rows were designed to form salients, using the figures of theory and field data from Hanson and Kraus [Reference 2]. The pile rows were placed 75 m offshore from the High Water line. The northern pile row has a length of 120 m and the southern 140 m. The distance between both pile rows is 210 m.

The crest level has been set at CD +3.0 m, 0.2 m above Mean High Water Spring, to limit the visual impact, and as wave transmission through overtopping is allowed. The wave transmission through the gaps between the piles has been determined using the equations of Hayashi, Grune and Kohlhasse [Reference 3 and 4]. These equations are based on pile rows that are not overtopped. Wave overtopping at high tide has been determined using Figure 7-38 of the Shore Protection Manual, which is based on Goda's data. [Reference 5].

Originally it was planned to build the pile rows using suitable hard wood piles of 200 mm diameter. However, even in a hard wood producing country as Malaysia the price of concrete piles turned out to be lower than of hard wood piles. Therefore the final design and construction took place with concrete spun piles.

The pile row breakwaters consist of individual 350 mm diameter round piles with gaps of 70 mm in between. The initial height of the piles above the seabed is 1.5 m for the northern pile row and 2.2 m for the southern pile row. In the design a scour depth of 0.5 m has been taken into account. The local scour around the piles can be calculated using the figures of Hayashi and Shirai [Reference 6]. With a gap width of 70 mm and a diameter of 350 mm a maximum scouring depth of 0.25 m can be calculated. This scouring depth has also been observed inat the site. An extra allowance of 0.25 m was made for global scour (future seabed changes).

At low tide, when people can walk up to the pile rows, it is still possible to see through the pile rows because of the 70 mm gaps. At Mean High Water Spring the top 0.2 m of the pile is visible, and at Mean High Water Neap the top 1 m. The northern pile row has a pile length of 5.5 m, and the southern 6.5 m. The wave loading on the piles has been calculated according to

British Standard 6349, part 1, with a reflection coefficient of 0.8. [Reference 7]. Geotechnical stability of the sheet pile wall has been determined with a sheet pile wall program.

An advantage of the pile rows compared to rubble mound breakwaters is that the pile rows do not block cross shore sediment transport. Normally with rubble mound breakwater types scour holes develop in front of the breakwaters due to wave reflection. Scour protection has to be provided to prevent the armour layer from sliding down. With the transparent pile rows only local scour around the piles occurs. This scour is limited to a depth less than the pile diameter.

Since no differential water levels can exist between front and back of the pile row, the intensity of rip currents is negligible.

A beach replenishment of ca. 15,000 m<sup>3</sup> was foreseen at the beach behind the two pile rows, using 400 µm D<sub>50</sub> sand. This beach replenishment was proposed to reach the final beach layout shortly after construction of the pile rows and to prevent erosion of the neighbouring beaches.

Figure 2 shows the layout with the pile rows and proposed beach replenishment. A typical cross section is given in Figure 3.

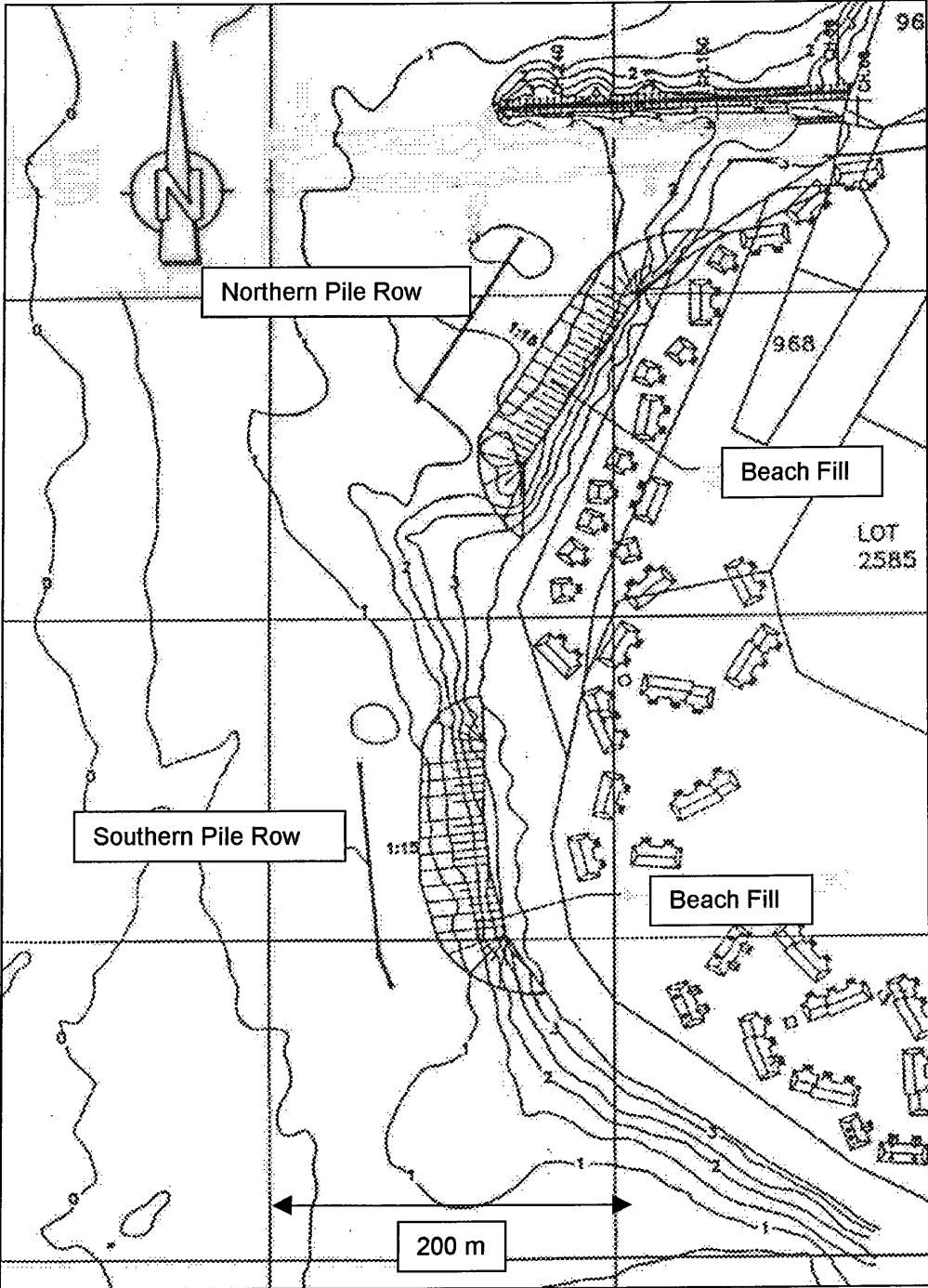


Figure 2 Layout of pile rows and beach replenishment

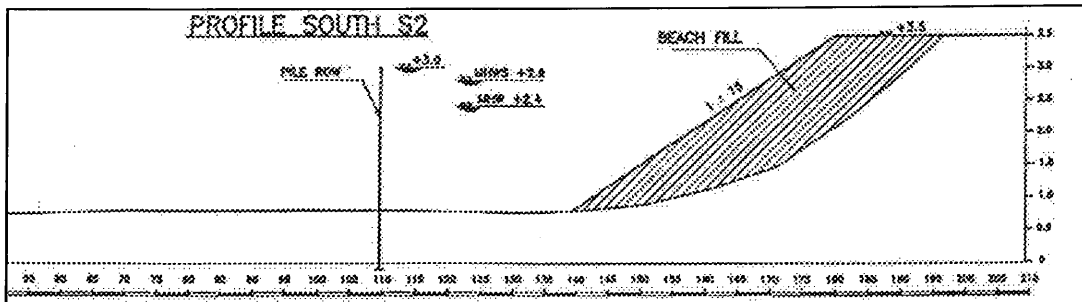


Figure 2: Typical cross section (Note different vertical and horizontal scale)

## CONSTRUCTION

Construction of the pile rows started in August 1995 and was completed in October 1995. Pile driving took place with a conventional land based piling rig during low tide. Pile driving went very easy due to the presence of soft sands. During construction a storm occurred in which an offshore barge went adrift and collided with the northern pile row. This required replacement of a few piles because of concrete cracking.

Because of the difficulty to obtain sand on Langkawi and resulting high costs the Client did not carry out the proposed beach replenishment.

The construction cost of the pile rows in 1995 was approximately US\$ 200.000, or US\$770/m.

## PERFORMANCE

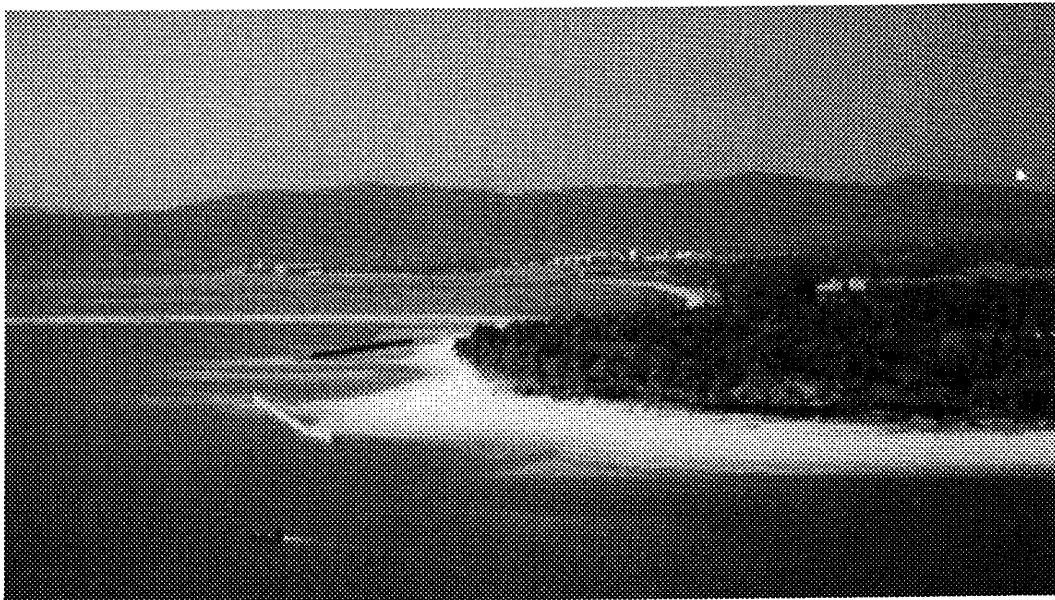
A year later, in October 1996 after the south-west monsoon, the Client reported that the beach had accreted in the lee of both pile rows. The sand bank which had been present in between the two pile rows had been eroded, sand had moved to the lee of the pile rows as no replenishment had been carried out.

In February 1998, two years after construction, a follow up visit was carried out. At the moment of arrival the positive effect of the pile rows was obvious: the beach has restored completely in the lee of both pile rows. Although no replenishment was carried out after construction, the coastline has developed seaward over almost the full length of the beach at the resort. The situation during this visit was fully satisfactory for the client, except for some corrosion problems of the steel pile caps [which were not immediately coated after construction].

In general the pile rows performed very well. The salient sand bodies on the lee side of the pile rows almost developed into shore connecting tombolo's. The volume of sand trapped behind the pile row is more than was expected. Since the Client did not carry out the designed beach replenishment, the material trapped behind the structures was eroded from neighbouring beaches.

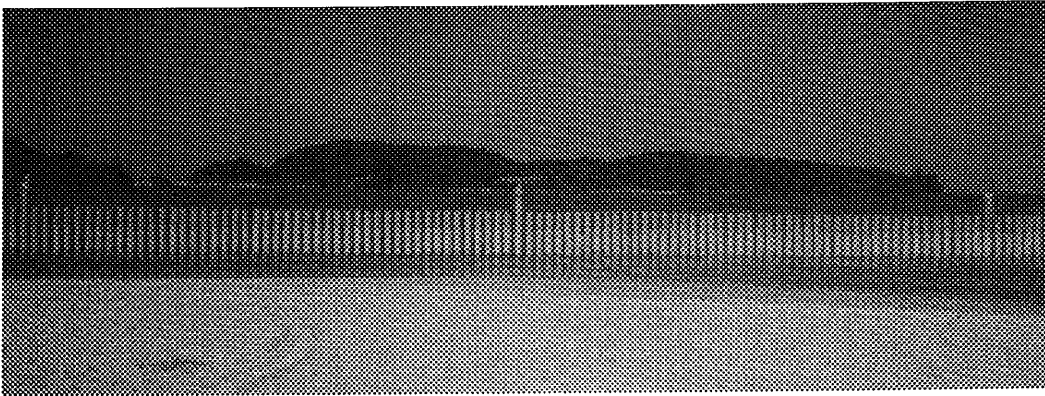


Photograph 3. Southern pile row at low water level



Photograph 4. Overview of the beach resort with pile rows, seen from the south

The beach south of the structures is a spiral beach of approximately 2km length. The total volume of sand trapped behind the breakwaters is small in comparison with this large stretch of beach, and no erosion can be observed south of the beach resort.



Photograph 5. Southern pile row seen from the east

Minor erosion around the piles can be observed. The scour along the pile rows is generally less than one pile diameter. The open structure also allows cross shore transport to propagate through the pile rows. This is illustrated clearly by small sand bars which develop through the pile rows, continuing on both the exposed and lee side of the piles.

In photograph 6 the situation is shown before the pile rows were built. The location of the pile rows and the present shape of the beach is also indicated. It clearly shows the positive effect of the pile rows on the beach. After construction of the pile rows no more maintenance of the beach has been required.



Photograph 6. Situation before and after construction of pile rows

### **COMPARISON WITH PILE ROW STRUCTURES AT OTHER LOCATIONS**

In the southern part of the Netherlands pile rows have been applied at several locations in order to stabilise the beaches. However, the pile rows have always been applied as groins, at a right angle to the beach. A study has been done to the effect of these pile row groins by the Ministry of Public works [Reference 8 and 9]. The conclusion of this study is that the effect of the pile rows as groins is minimal. Only at locations with a dominant wave direction pile row groins have some effect on the beach. It can be concluded that the experience with pile row groins is not very positive. However, pile rows have not been used as shore parallel breakwaters in the Netherlands. Pile rows are often used as breakwaters for marinas, but no case studies have been found of pile rows as shore parallel breakwaters.

It is believed that the pile rows at the Pelangi Beach resort are very effective because they function as normal shore parallel breakwaters, providing a sheltered zone in their lee. Although the tidal variation and currents are considerable, the advantage of the location is the rather flat foreshore, and relatively mild wave climate.

From the accretion, which has occurred in the lee side of the pile rows, it can be concluded that the gap width between the piles could have been larger, or that the top of the piles could have been half a meter lower. The purpose of the pile rows was to return the beach to approximately its shape just after construction of the resort. However, from photograph 4 it can be observed that in the lee of the southern pile row the salient almost developed into a tombolo. The new beach width in the lee of the pile rows is more than 20 m larger than anticipated. Therefore a higher wave transmission could have been allowed by either increasing the gap width, or lowering the crest height. The latter could still be done, by driving the piles deeper. However, the beach resort is quite happy with the new wide beach.

### **CONCLUSIONS**

For the location of the Pelangi beach resort, the pile row breakwaters are very effective in restoring the beach. The beach was restored within one year, even without the proposed replenishment. The pile rows are only of minor visual impact, and recreation is unhindered. New for this type of structure is the open nature of the breakwater. Normally shore parallel breakwaters are impermeable to sediment. The pile rows at Langkawi show that the development of the coast line can proceed without being interrupted by the breakwater. The example of the sand bar through the southern pile row shows that this actually takes place.

The pile row breakwater is economically attractive, especially since the cost per unit length does not vary to the square of the depth, as with conventional rubble mound breakwaters.

The pile row breakwaters can easily be adjusted by changing the crest level or adding or removing piles. In this way the breakwaters can be tuned for the required beach response. As at the Pelangi Beach resort more beach accretion occurred than expected, it could be decided to lower the crest height to further reduce the visual impact.

## REFERENCES

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