SHORT AND LONG TERM IMPACTS OF THE CONSTRUCTION OF COAST DEFENCES ON COASTAL EROSION

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Abstract:

Significant coastal erosion of the Holderness coast, UK, started with sea level rise at the end of the last ice age. Over 30 villages have been lost since Roman times and historic records give erosion rates of 2m annually over the 50km frontage. Maps and charts have been analysed in order to evaluate the natural erosion rates, as well as those associated with coast protection works, built to protect three towns at the end of the 19th century. Natural erosion rates are very variable and, while sinusoidal bays are forming between the defences, these studies have revealed the impact of the defences, which can contain up to 20 groynes in a 2.3km frontage, are limited to between 1 and 2km downdrift.

In Dubai (United Arab Emirates), the impact of newly built fishing harbours on the downdrift coast is graphically illustrated by the presence of embayments, formed by standing edge waves. A relationship has been established between the distance offshore the harbour extends and its influence on the downdrift beach. The ratio appears to be between 7 and 9, which is similar to that of the Holderness coast, which appears to be between 8 and 10.

Keywords:

Defences, drift rates, impacts, erosion rates, Holderness, Dubai, wave climate, offshore bathymetry.

INTRODUCTION

The natural rates of coastal erosion or accretion can be affected by man-made changes, such as the construction of defences, or say, by offshore dredging. In the latter case, the deeper water will allow higher levels of wave energy onto the coast, and changes in water levels over the long term can have similar impacts. These offshore changes can also be brought about by changes in bank distribution, sea level rise and changes in wave climate.

The paper describes the detailed analysis of the impacts of coastal structures and the associated offshore changes, both in the bathymetry and of the local wave climate. While in the case of the Holderness Coast (UK) the analyses cover almost 150 years of data, in Dubai (United Arab Emirates, (UAE)), the observations were over a much shorter period.

The coast of Holderness has been eroding since the sea level rise at the end of the last ice age (Devensian) and is now some 3km inland of that in Roman times ie about 500 AD. This erosion has resulted in the loss of some 30 villages in the last 1000 years and there is little direct evidence that the rate of erosion has changed, even in the last 300 years (Maddrell et al, 1998). More recently, the bathymetric and cliff line survey data (since the middle of the 19th century), have been analysed and the relationship between natural changes offshore and rates of cliff erosion have been examined. In more recent years it has been possible to relate the variations in wave energy to both the bathymetric change and cliff erosion rates. However, the greatest impact on cliff erosion rates might appear to be directly connected to the construction of defences to protect the towns of Bridlington, Hornsea and Withernsea (see Figure 1). More recently, the impact of some relatively small defences at Mapleton have also been examined, and were the subject of Court proceedings (see Maddrell et al, 1999).

Figure 1 The Holderness Coast, UK

The Gulf Coast of the UAE contain a number of creeks which were used as harbours for many centuries. Development of the coast and the construction of harbours did not take place until 1960s, and since that time there has been very significant development, especially in Dubai. As the bed contained mainly exposed rock or cap rock, there have been few changes and thus the influence on the coast morphology is very small. The coast itself consists of a sandy shore, extending out to about –4m below Chart Datum (CD), with the sand being moved in an easterly direction. The impact of the construction of harbours in the coastal zone and the development of creeks has had a significant and predictable impact on the coastal morphology.

GEOLOGY

Holderness Coast

The Skipsea and Withernsea glacial tills of the Holderness Coast were deposited during the last advance of the Pleistocene ice sheet – the Devensian stage. The average sediment content of these tills would appear to be 74 - 84% silt and clay, 10 – 15% very fine sand, 5 – 10% coarse sand and 1% boulder (University of Manchester, 1983). Thus cliff erosion produces very little beach material.

Till soil strengths are generally weak, having been compacted and remoulded by wet based ice, which may account for its low degree of over-consolidation. Near Cowden (south of Mapleton), the tills have a peak angle of friction of 27° (1 in 2), but with an effective angle of friction after failure of 14º (1 in 4), but in the sandy/silty till is between 23º to 27º (Marsland and Powell, 1985).

Cliff erosion since the Flandrian sea level rise is continuing with current rates of up to 2m/year on average mainly due to wave action. The wave attack at the toe of the cliffs is particularly severe when coincident with high water (spring tides and surges).

Cliff failure normally occurs along a roughly semi-circular slip plain (in section and in plan), but can also be wedge shaped, and forms fissures along the top of the cliffs. Although these failure processes are most active in winter, they can also be significant in summer. The year on year rates of erosion depend partly on the height of the cliffs, with low cliffs retreating in a series of small bites, with larger, less regular bites, on the higher cliffs. Valentine (1971), based on his comparison of the 1852 and 1952 maps, suggests that the rate of erosion of the high cliffs (up to 25m high), is slower than that of the low cliffs, because of the higher soil strengths.

The tidal range is up to 6.5m and the net drift of tidal currents and fine sediment they carry is southwards on the flood, during spring tides only (Halcrow, 1986). Wave action is mainly from the north of the line normal to the coast and thus the net alongshore drift of the sands and gravels is southerly. This has led to the creation of a sinusoidal bay (Sylvester, 1976) held by the chalk cliffs of Flamborough Head in the north and the more mobile Spurn Head gravel spit in the south.

Some 2.86Mm^3 to 3.49Mm^3 of till is eroded annually along the 50km of coastline (see Figure 1), producing some 0.51Mm^3 to 0.83Mm^3 of fine sand or coarser material, which includes an allowance for the nearshore and offshore bed erosion. Only some 50% of the coarser sand and gravel is moved alongshore by wave action, with the rest remaining offshore and Valentine (1971) estimates that only 3% of this eroded material reaches Spurn Head. While the beaches at the toe of the cliffs do contain sands and gravels, their presence is a mixed blessing as they can easily be moved by wave action and may enhance till erosion due to their milling action.

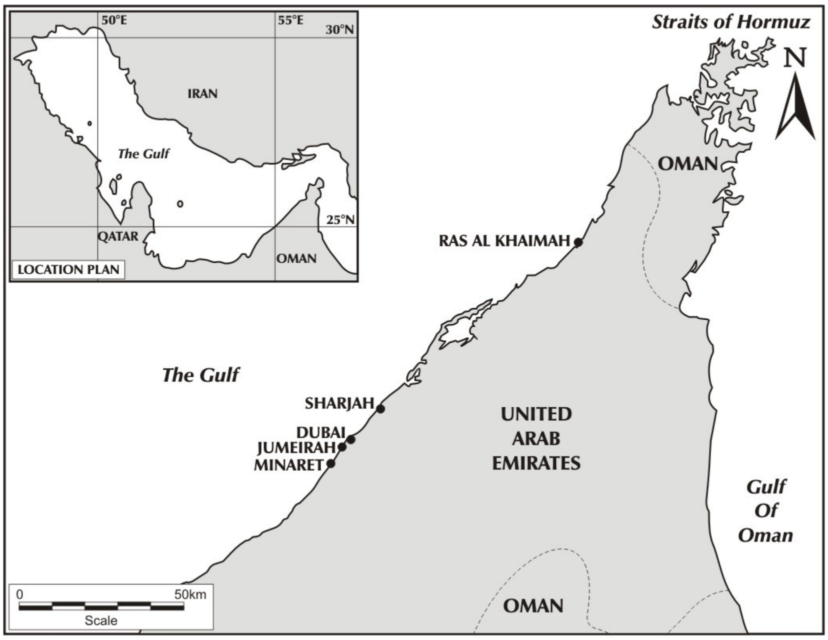

Figure 2 The coastline of the United Arab Emirates

Dubai, UAE

The coastal zone consists of dune sands, with occasional sabkas, which are present in low lying areas, mainly in Abu Dhabi. These sand deposits extend landward into the desert and also seawards down to the –4m CD contour. In deeper water, while sand is present, it tends to be confined to runnels which appear to be transport zones for the sands to the inshore zone. In general, offshore the seabed consists of either exposed rocks or cap rock, containing some areas of exposed sand.

The dominant winds and waves on the west coast of the UAE are from the north west. There is significantly alongshore transport, which is confined to the water depths above –4m CD. The net drift in the Dubai area is about 100,000m^3 annually and reduces gradually northwards to about 10,000m^3 near the Straits of Hormuz (see Figure 2). This change of drift reflects both the change in wave climate and of sediment type.

Historic Rates of Coast Erosion

Holderness

As explained earlier, the glacial tills of the Holderness Coast have been eroding since the rise in sea level at the end of the Pleistocene. However, it was only towards the end of the 19th Century did man attempt to prevent the erosion of the frontages of the three small towns along the coast ie Bridlington, Hornsea and Withernsea (see Figure 1). For example at Hornsea, protection started with a pair of groynes adjacent to the Marine Hotel in 1869, two further groynes were added downdrift in 1876 and a further five groynes were shown to south on the 1890/91 Ordnance Survey Map. Seawalls were added in the early part of the last century and at the present time Hornsea is protected by some 2 kilometres of concrete and rock defences, with some 18 groynes. The situation is similar at Withernsea, with defences first being built in the 19th Century and at the present time there is a substantial number of rock and wooden groynes (19) with rock and concrete seawalls, covering some 2.3km of coast.

These defences have been successful in mitigating coastal erosion locally, although there has been erosion of the seabed seaward of them. The net impact of the defences has been to trap some drift material both between the groynes and to the north (updrift side), which has led to starvation on the downdrift side. The net effect has been the creation of bays between the defences, which in general appear to take up a sinusoidal shape.

An understanding of the rates of coastal erosion has been obtained from the Ordnance Survey Maps from 1852 to the present day. These surveys have been supplemented by more recent aerial photographs, historical surveys together with the East Riding of Yorkshire Council (ERYC) annual cliff erosion surveys, which have been carried out at points on the coast roughly at 500m centres over a period of 50 years. This data, together with the bathymetric surveys from 1830 to 1984 have been examined using a Geographical Information System (GIS).

Table 1 shows the cliff erosion rates from 1852 to 1995 in the area immediately south of Hornsea taken from OS maps. As can be seen, overall the rate of erosion in this period has increased by a factor of 3 since 1852, with the largest increase being seen between 1908 and

1926, the period during which coastal defences were being built at Hornsea. It should, however, be noted that measurements in the central area of the Holderness Coast, at Mapleton church since 1786 give an average rate of erosion of almost 2m annually.

Table 1 The cliff erosion rates from 1852 to 1995 in the Hornsea to Cowden area

Period	Years	Average Erosion Rate, m/year	Comments (distances south of Hornsea)
1852-90	38	0.8	Lower rate around 2.6km
1890-1908	18	1.0	Low from 0 to 1.5km, but increased rate around 2km
1908-26	18	2.3	Main Hornsea defences being built. Highest rate (4m/year) immediately downdrift
1926-52	26	2.0	Highest rate starts at about 400m and then decreases
1952-72	20	2.0	Very low immediately south of Hornsea, with erosion peaks at about 600m and 1.4km and, south of Mappleton of up to 3m/year
1972-89	17	2.4	Generally higher south of Hornsea and decreasing southwards
1989-92	3	3.4	Short time period, main erosion area north of Mappleton and at Mappleton. Erosion low at Grange Farm
1992-95	3	3.3	Short time period, peaks of erosion to north, but main erosion area south of Mappleton

Figure 3 shows these erosion rates south of Hornsea in greater detail as rates between 1852 to 1908 and 1908 to 1995. As can be seen, the rates of erosion at particular positions along the coast are variable, perhaps more so in the earlier period. One conclusion that might be reached is that the defences at Hornsea are having a significant impact on the rates of coastal erosion. However, this is not borne out by a more detailed analysis in that the rates of erosion are very similar for considerable distances downdrift.

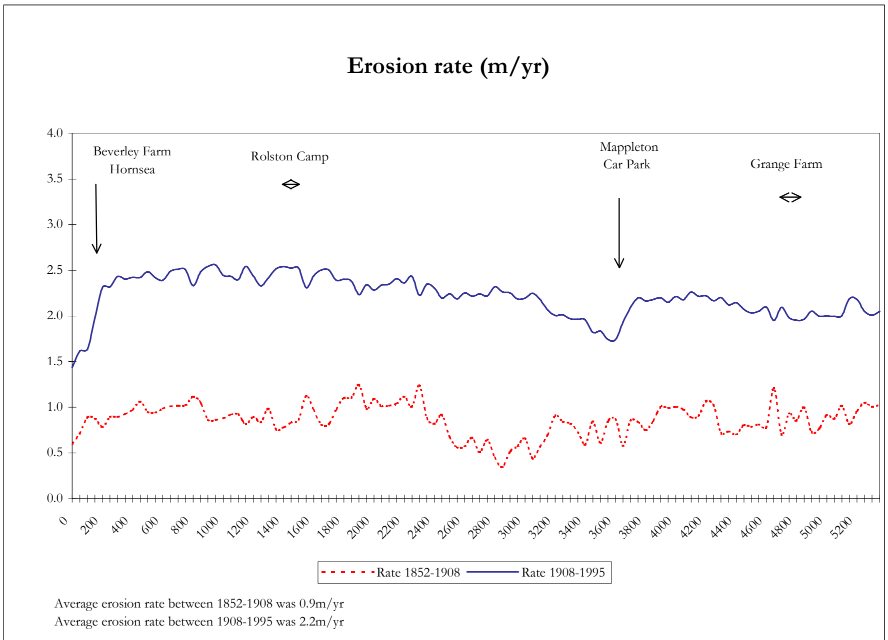

Figure 3 Erosion downdrift of Hornsea, 1952 to 1908 and 1908 to 1995

How the impact of the coastal structures can be quite limited is graphically illustrated at Withernsea where, following the construction of defences, the rate of erosion of the cliffs downdrift actually reduced. Figure 4 shows the average annual erosion rate in m/year for the periods prior to the defences being built ie 1852 to 1908 and the period post defences. It should be noted that the average annual erosion rate, for the coast shown on Figure 4, between 1852 and 1908 was 1.6m/year (for a period of 56 years), while after 1908 it was 0.9m/year (a period of 89 years). The equivalent erosion rate for the cliffs south of the area shown on Figure 4 were 1.8m and 1.2m/year respectively, ie a reduction of over 30% in the latter period. This clearly illustrates that the construction of the defences did not increase the general rate of erosion downdrift. While there does, however, appear to be a local peak in erosion immediately downdrift of the defences, it appears to illustrate that their impact is limited.

Cliff erosion is driven mainly by wave energy which, if it does not vary, is in turn controlled by and controls the local bathymetry. The comparison between the 1830 and 1890 charts show accretion in most of the inshore zone, which appear to be associated with low cliff erosion rates (see Figure 3). There were, however, several areas of much higher erosion rates (1.6 to 2.9m/year) between Withernsea and Easington. Previous authors have suggested that these high erosion rates were a result of seabed shelving steeply in this area and lack of protection from the dominate northerly and north easterly storms (Valentine, 1971). The trend of nearshore accretion was reversed in the period 1890 to 1929 and there was general, though not very marked erosion of the 5m and 10m contours, with erosion rates increasing locally (see Maddrell et al, 1999).

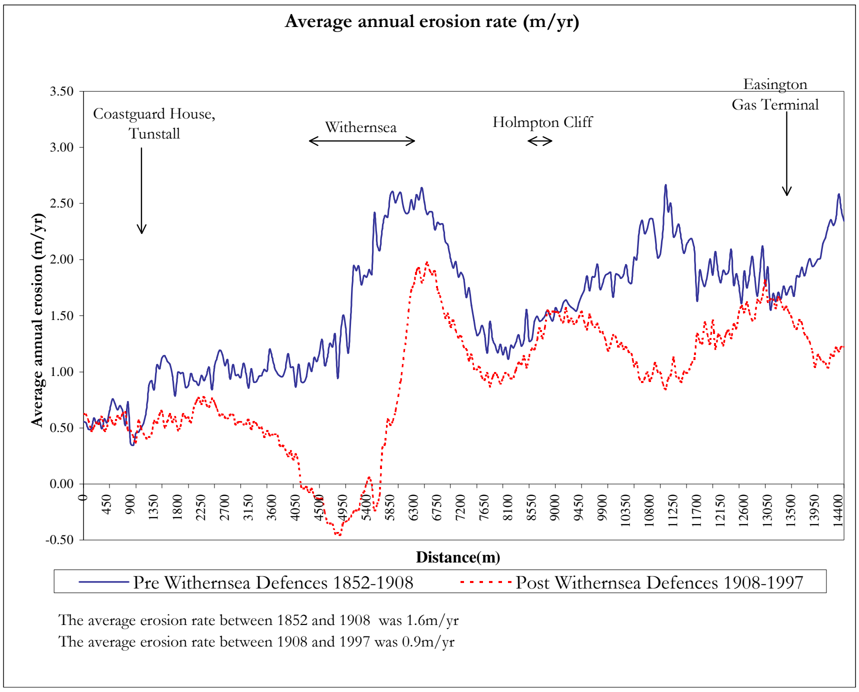

Figure 4 Erosion downdrift of Withernsea, 1852 to 1908 and 1908 to 1997

Between 1929 and 1950, the accretionary trend was re-established, with the 5m and 10m contours moving further offshore in general. Coastal erosion was reduced, apart from the area immediately to the south of Hornsea (1.5 to 2m/year) and Withernsea (0.9 to 1.7m/year). During the period 1950 to 1974 there was erosion of the 5m and 10m contours along much of the coastline, with the latter moving inshore by over 1km in places. There was some nearshore erosion between 1974 and 1984, which appear to have contributed to the increase in the average annual erosion rate between Hornsea and Withernsea of 1.2m/year to 2m/year.

There is also some evidence in the most recent period to show that the sands and gravels generated from the erosion of the tills in fact contribute to the accretion seen in the area of the 5m contour (see Halcrow 1986).

The impact of rainfall and wave energy and the associated a longshore energy, was also examined in the central area of Holderness for the period 1985 to 1995. The increase in rainfall is important in that it is reflected in the higher pore water pressures within the tills, which can reduce their factors of safety. This study indicated that the lower storm energy in 1987 led to reduced cliff erosion rates and the higher storm energies in 1988 and 1991 led to increases in coast erosion (see Maddrell et al, 1999). The significant increase in the relative annual storm of wave energy in 1994 appears to have been responsible for the noticeable increase in the cliff erosion rates seen both on the maps and in the erosion post measurements of ERYC.

Overall there appears to be a good correlation between the higher and lower storm energy rates and the rates of cliff erosion, despite the coarseness of the cliff erosion data (annual measurements), when compared to the information on wave and surge conditions. There was, however, no obvious link between rainfall (higher pore water pressure) and cliff erosion.

Dubai

In the last 30 years, there has been considerable development within the coastal zone, mainly of harbours, both major ports and fishing harbours, together with the development of creeks and the protective works required following downdrift erosion.

The winds are dominated by the thermal heating and cooling of the land mass, with strong onshore winds developing about 11:00am. These hydrothermal winds and the dominant storm, ‘shamal’ winds, tend to come from the NW, thus generating waves from the same sector. Sediment is therefore transported in an easterly direction, with the rate being about 100,000m^3/year near Dubai and reducing to nearer 10,000m^3/year near the straits Hormuz. The reason for the change in rate is not simply change the angle of wave approach, but also the coarseness of sediments. The drift is occasionally reversed as a result of NE storms called “nishi”, which have a shorter fetch lengths and durations. The tidal range is relevantly small ie less than 2m and thus the tidal currents are small and along the Dubai coast are predominantly semi-diurnal, being about 0.2m/sec and rarely exceeding 0.3m/sec. The non-tidal currents are variable throughout the year and result of a predominantly inward flow through the Straits of Hormuz as a result of between 3m and 4m of evaporation annually from the Gulf.

In addition to the formation of an offshore winter bar, the plan view of the beach shows a series of regular embayments defined by large and very regular cusps (see Werner and Fink, 1993 and Maddrell, 1995). These cusps appear to have been formed standing edge waves (Bowen and Inman, 1971), which are trapped nearshore by refraction.

Edge waves vary along the shore, having amplitudes which decay rapidly offshore. While important agents of morphological change, they can significantly modify the wind-wave field (Haines and Bowen, 1988). Resonant edge waves, possibly phase-locked, trapped at the shoreline by refraction, appear to create the small bay-like features on the UAE beaches with their consistent wave lengths of about 100m. Once formed by the winter storms, the bays and bars remain stable, influencing the local wave climate in such a way to be self maintaining for extended periods. They are only destroyed by higher incident waves (King, 1972) or, as in the case of the UAE, by the more quiescent(accretionary) spring and summer conditions.

The strong development of the embayments, showing the 'stressed' condition of the beaches, can be seen forming immediately downdrift of new structures, with their presence reducing with distance downdrift. Studies of the aerial photographs of the coastal zone, together with regular beach surveys down to the –4m CD contour, have shown that the zone length of embayments increases downdrift year on year until they reach an equilibrium.

A detailed examination of the coastal changes was carried out between the Minaret fishing harbour and Jumeirah fishing harbours, which indicated an average annual accretion rate updrift of some 25,000m^3 with downdrift erosion of 55,000m^3 (Maddrell, 1995). It is also apparent that all three harbours, which are very similar in size, have a similar effect on the downdrift beaches. At the present time, it is clear that accreted material is passing offshore at the harbours and, possibly, onshore again to the downdrift beaches. The beach embayments also appear to be good indicators of the impact of the creek entrance developments.

The length of the coast affected by the embayments was therefore examined in relation to the base width of the harbours and distance offshore to the roundheads of the main breakwaters, as well as with the entrance breakwaters for the creeks. Studies by Maddrell (1995) indicate that the latter ratio is more realistic in terms of immediate effect, while the former may be important in that it influences the time taken before material bypasses (see for example Kraus, 2000) and may produce its own edge waves. These studies show that the response of the downdrift beaches to construction was in all cases rapid (see Bruun, 2001 and Maddrell, 1990) and the ratio of the distance that the structures extended offshore and their influence downdrift would appear to be between about 7 and 9. This relationship applies even to harbours which lie within the 180m wide band of mobile sediments above the –4m CD contour. For major ports eg Jebel Ali, which extend for considerable distances offshore, the ratio appears to be about 3, but the ratio is perhaps less valid in this case and may be affected more by the rates of onshore transport, which are not affected by the port.

The zones of downdrift erosion seen in Dubai are the 'short distance' effects, described by Bruun (2001). There appears to be no evidence of his 'long distance deficit features', but this may well be because all the developments along the coast are masking such effects.

CONCLUSIONS

The rates of coastal erosion seen on the Holderness coast in historic times has been, on average, 2m/year, although the annual and local rates are very variable. For example, measurements from the church at Mapleton from 1786 to the present day reflect this average, but there are periods from the records which are almost 5m/year. More recent and more detailed records of coast erosion reflect their variability, both from year to year and laterally along the coast.

Coastal erosion is affected by changes in the offshore bathymetry, with local accretion reducing erosion rates, whilst offshore erosion is linked with more rapid rates of cliff loss.

Defences built to protect towns at the end of the 19th Century have stabilised the local coast but have also led to accretion to the north (updrift) and erosion to the south (downdrift). Bays are forming between the defended areas, which are generally taking a sinusoidal shape.

However, while it might be assumed that this shape is a reflection of the increased rate of erosion downdrift resulting from the construction of the defences, an examination of the long term historic information indicates that the impact of the defences, even though covering over 2km of coast, is very limited.

An examination of all the information on cliff erosion rates clearly shows their variability. While there are wide spread variations in the short term rates, say on a monthly to 10 year cycle, there are much longer term variations, with periods of about 60 years or more. The latter would appear to reflect the more major re-orientation of the coastline (see Maddrell et al, 1999).

Overall, the impact of the defences appears to limited to an area of about 1.5km immediately downdrift, certainly in the case of Withernsea and Hornsea.

The construction of harbours and the development of creeks in the UAE are immediately reflected in patterns of updrift accretion and downdrift erosion. This downdrift erosion can clearly be seen as a series of beach embayments which result from the beach being "stressed" as a result of the winter storms. These embayments appear to be the result of edge waves.

There would appear to be a relationship between both base width of the structure in the coastal zone and the distance it extends offshore with its impact on the downdrift beaches. In the case of the former the relationship is less clear, but it appears to be affecting the time period when the updrift accretion will bypass the structure. In the case of the latter, there appears to be a direct relationship between the distance offshore and the downdrift impact, which is between 7 and 9.

In the case of the Holderness Coast, the ratio of distance offshore to downdrift erosion would appear to be very similar ie between 8 and 10.

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