LAND-CLAIM AND SEA DEFENCE: LABOUR COSTS OF HISTORIC EARTH BANKS IN HOLOCENE COASTAL LOWLANDS, NW EUROPE

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Human interventions over the last two millennia have ensured that the Holocene coastal lowlands of North-west Europe, to which the Severn Estuary Levels modestly contribute, are now almost totally embanked and divided from the sea, leaving only diminutive areas of active coastal marsh as survivals (Allen 1997a, 2000; Rippon 2000). The three kinds of archaeologically significant monument which define this process of land-claim are seabanks, traditionally built of local marsh sediment, together with outfalls, until the last 200 years or so constructed of wood, and a hierachy of drainage channels and ditches.

Seabanks are paramount among these engineered works. From a strategist's standpoint, the first bank to be constructed on a coastal marsh is an offensive structure (Allen 1997b), for its purpose - in brief, wealth-creation - is to facilitate the transformation of the natural marsh, fit only for various largely seasonal uses, into a landscape that can be permanently settled and either farmed pastorally or extensively cultivated for a wide range of crops. In each case the land is increased in economic value, by up to an order of magnitude. Subsequently, a number of late-Holocene geological factors have combined gradually to force the banks into their present, strategically defensive role (Allen 1997b, 1999). Indeed, in their contemporary form, they are commonly described and treated as 'the sea defences'. This is especially true in Britain, so much so that, even in archaeological circles, the original purpose of these critical monuments has largely been forgotten, and they have accordingly attracted little interest especially from a technological standpoint. Consequently, the aim of this note is briefly to explore some of the cost implications of erecting the banks and of responding to the geological factors that force their change, as engineered structures, from an offensive to a defensive capability.

GEOLOGICAL FORCING FACTORS

The act of enclosing an area of coastal salt marsh by an earth bank at once denies the enclosed portion further supplies of suspended tidal silt, although vegetable matter may continue to be accumulated by plants indigenous to the enclosure (Allen 1997a, 2000). Effectively, the ground surface within the land-claim becomes fossilized, in contrast to the surviving part of the marsh where silt introduced by the tide can continue to accumulate along with plant material. Over the last two millennia, three geological factors in particular - sea-level rise, changes in the range of the astronomical tide, and sediment compaction - have combined to ensure that those salt marshes surviving outside areas of coastal land-claim have grown significantly in altitude relative to the enclosed parts because of continued tidal siltation. This phenomenon of a progressively increasing altitude-deficit between fossilized and active marshes is widely reported from Britain (eg Allen 1991; Shennan 1992), the Atlantic coast of France (eg Verger 1968), and the eastern shores of the North Sea (eg De Smet and Wiggers 1960; Vos and van Heeringen 1997). The older enclosures in areas of former Holocene tidal marshland not uncommonly lie a few metres below the adjoining modern marshes, and deficits of several or more metres are not unknown, especially where thick peats lie beneath.

Although the details of its behaviour remain obscure, and are likely to have varied from place to place, there can be little doubt that relative mean sea level in much of North-west Europe has risen on average by the order of 1 mm annually during the last two millennia (Lambeck 1995, 1996, 1997; Lambeck *et al.* 1998; Shennan *et al* 2000a). Simultaneously, astronomical tidal ranges have also changed, on both long and short terms (Austin 1991; Woodworth *et al* 1991; Hinton 1992, 1995; Shennan *et al* 2000b) and also, especially in estuaries, as the result of human interference (eg Coen 1988; Garniel and Mierwald 1996; Van der Spek 1997; Vos and Van Heeringen 1997). In the Severn Estuary, for example, the rate of increase in tidal range over recent decades is of the same order as that of mean relative sea level, although in some parts of North-west Europe the tidal range is currently declining with time. Their combined change is critical for the upward growth of salt marshes, which is limited by the altitude reached by extreme high tides. It should be noted, finally, that the observed tide at a place invariably includes meteorological components, which are most markedly expressed as storm surges (Pugh 1987). Varying in magnitude and frequency over time, these have little influence on salt-marsh heights in North-west Europe, but they do affect seabank design, as water levels during a surge can rise by as much as about 4 m above normal (eg Rossiter 1954).

Sediment compaction, ubiquitous in its action, is a significant process where thick, interbedded silts and peats have accumulated in Holocene coastal lowlands (De Glopper 1973; Hutchinson 1980; Hawkins 1984; Smith 1985; Nieuwenhuis and Schokking 1997; Haslett *et al* 1998; Allen 1999; Kooi 2000; Shennan *et al* 2000a). Lowering the ground surface at rates which can in magnitude compare with or exceed that of contemporaneous sea-level rise, compaction embraces a complex set of mechanisms which range from the mechanical compression of the mineral/organic skeleton of the sediment to the bacterial-fungal or oxidative decay of contained vegetable matter. Compaction is continuous, progressive and irreversible, and can result in the lowering of beds by several metres below their altitude at the time of deposition. It is especially noticeable within land-claims, where sediment deposition has effectively ceased, and water-tables have been significantly lowered following drainage.

Once erected, seabanks have in their own right compacted the underlying sediments (Lambe and Whitman 1969), for they are localised, weighty structures standing proud to heights measured in metres. Depending on the thickness and character of these deposits, and the scale of the structure, the base of the bank may eventually sink below the surroundings by amounts ranging from a few to many decimetres (Verger 1968). A peat-rich substrate is especially susceptible to compaction beneath a superincumbent load, as is graphically demonstrated by the clay dwelling mounds of the Glastonbury lake village in the main Somerset Level (Coles and Minnitt 1995).

Because of the simultaneous action of these geological factors, it has been necessary at frequent intervals to raise the height of seabanks erected in North-west European coastal lowlands, in order to ensure that the structures remained effective in their increasingly defensive role. How can the scale of such engineered banks be specified, and what are the resource implications of erecting and then repeatedly raising them?

UNIT VOLUME OF A SEABANK

The first part of the question may be answered as follows. Figure 1 shows a representative bank in cross-section at the time of land-claim. Assuming that the structure is of uniform cross-sectional dimensions, the bulk volume of material required for the creation of the bank is the product of the length of the bank L and the unit volume V, that is, the bulk volume of material present in unit length. Given the overall height h of the bank, and the unequal widths w_1, w_2 and w_3 of the faces and top, we find from the geometry of the cross-section that

$$V = h^2(a/2 + b + c/2) \ \ (\mathrm{m}^3/\mathrm{m})$$

where the ratios $a=w_1/h$, $b=w_2/h$ and $c=w_3/h$.

The formula states that the unit volume increases as the *square* of the overall height, as previously intimated (Allen 1997b).

Now suppose that the bank has been raised in height by a number of increments while salt marsh continued to build up on its seaward side. The cross-sectional geometry of the modified bank is more complex because of the height-deficit across it, but at any stage can be described by a formula of the previous general character. Referring for the sake of argument to the original formula, it will be seen that the incremental increase in the unit volume per incremental increase in height is proportional to the *overall* height measured from the original marsh surface. Hence, in the general case, and assuming that the cross-sectional form remains much the same, for equal increases in height over a period of time in response to geological forcing, roughly linearly increasing volumes of material must be added to the bank. This conclusion has profound implications for the cost of maintaining banks. For example, assuming no change to a, b and c in the above formula, the symmetrical addition of a volume of material equal to the initial unit volume is only enough to raise the bank shown in Fig. 1 by roughly 40% of its original height.

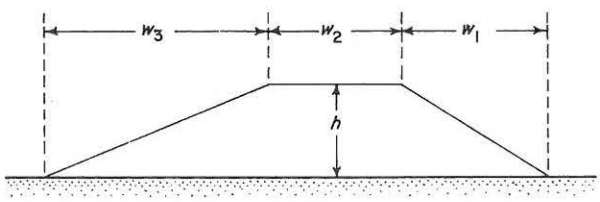

Figure 1: Cross-section of an idealised seabank, showing the critical dimensions.

IMPLICATIONS OF ERECTING AND RAISING SEABANKS

The charge on resources of erecting and maintaining banks is more difficult to specify. Even where documents may give money costs, inflation has ensured that the figures involved have little meaning, even on a comparative basis at some specified time. Rather more telling, although subject to acknowledged uncertainties, are estimates of labour costs, in man-days, made on the basis of plausible assumptions about working methods and recognised constants of labour (Hurst 1904; Rea 1941; DeLaine 1997).

It is here supposed that, up to the mid-late 19th century, seabanks in the North-west European coastal lands were built by hand from locally available marsh sediments using spades and mattocks, and some combination of baskets, stretchers, barrows and carts. In most cases, a proportion at least of the necessary sediment would have been secured by cutting a back-ditch almost immediately to landward of the line of the bank, with the remainder coming from scrapes or shallow borrow-pits up to tens of metres distant on the marsh. To the more exposed banks may have been added on the seaward side a partial or complete protective facing of either faggots, wood or stone. A range of work activities is here implied which, at the minimum, may be taken to be digging and throwing up marsh turf and silt, moving and placing the material, allowing time for a degree of settlement of the emplaced sediment to occur and, last of all, ramming or rolling it into the final shape of the bank. Given the tenaciousness of most marsh silts - the term 'bungum' has long been used in the Gwent Levels - it would not be unreasonable to assign of the order of 0.5 man-days to the hand-building by a small gang of each cubic metre of a seabank under this minimum regime. From the mid-late 19th century, however, new technology, beginning with the use of steam power, revolutionised working methods and allowed seabanks to be engineered much more quickly and to a considerably greater size.

Some idea of the cost in labour of erecting the first bank on a coastal marsh may be glimpsed from the Wentlooge Level, Gwent, believed to have been enclosed by the Roman military in order to create a planned landscape (Allen and Fulford 1986; Fulford *et al* 1994). A unit volume of about 4 m^3/m seems plausible, and the total length would have been about 15 km, giving a total volume of 60,000 m^3. Its construction could, therefore, have occupied 100 men for 300 days or 500 men for 60 days. A further insight into actual labour costs may be gained from a selection of historical seabanks (Figure 2) which have either been surveyed or reconstructed in profile, so that their final scale is known, or excavated, revealing their initial and final forms and the phases between (Grieve 1978; Hallewas 1984; Mazure 1984; Brand 1985; Hearne *et al* 1995; Ey 1997). The earliest of the selected banks - all of medieval date - are small, with unit volumes chiefly in the order of 5 m^3/m. One-metre lengths of such banks may, therefore, have been constructed on the order of 2.5 man-days. Where these banks have subsequently been raised before the mid-late 19th century, the increments of unit volume vary from roughly 1-5 times the unit volume of the initial structure. Hence, because of the 'square rule' noted above, raising the structures in the face of sea-level rise, changes in tidal range, and compaction can be very much more costly in terms of labour than erecting the banks in the first place. On the order of 10-15 man-days may have been required to raise one-metre lengths of some banks to their form in the early 19th century.

Conditions in the North-west European lowlands had so changed by modern times that majestic proportions were required of the structures being engineered. Even in the early 19th century new banks (Fig. 2, no. 7) with unit volumes of the order of 50 m^3/m were necessary and, being still hand-built, called for the order of 25 man-days of work for each one-metre length. By the mid-late 20th century, however, seabanks with footprints measuring 50-100 m and unit volumes of several hundred m^3/m were being planned and built, but with the aid of powered excavating and hydraulic machinery demanding little labour (Kramer 1969; Mazure 1984). The construction of such majestic edifices may have been promoted in part by an apparent acceleration over the modern period in the rate of rise of water levels (eg Allen 1991; Woodworth *et al* 1991; Gehrels *et al* 2002).

DISCUSSION

The 'costs' and also the 'risks' of land-claim to which Rippon (2000) has alluded are several and various.

The analysis above suggests that up to the mid-late 19th century the cost in labour of erecting seabanks was considerable, perhaps comparing with or even exceeding the combined costs of building outfalls and digging primary drains linked to back-ditches. Under the impact of a set of unfavourable geological factors in the late Holocene, forcing the structures into an increasingly defensive role, the subsequent labour costs of raising the banks increased non-linearly as they grew ever more voluminous. To these costs must be added the growing demand on labour for the repair after storms of banks of increasing size, when breaches could arise every few hundred metres (Grieve 1959; Van Veen 1962; Summers 1978), whether or not raising was also either ordered or required. It is not surprising that, under these circumstances, landholders and others sought economies as well as lower risks from flooding, especially when favoured by technological change. Perhaps the commonest and most widespread monumental expression of this search is the field evidence from many places for the significant shortening of seabanks, especially by the transfer at many different times of outfalls on primary ditches and former creeks to locations nearer the sea (eg Grieve 1959; Van Veen 1962; Allen and Rippon 1995; Garniel and Mierwald 1996; Allen 1997b). Labour costs which escalate as demonstrated above, and others not examined here, represent an economic treadmill, which are unlikely to have been anticipated at the time land-claim was mooted. Much more attention from archaeologists than hitherto is required if seabanks are to be properly understood in terms of their construction, maintenance and costs to the individuals and communities that conceived, built and inherited them.

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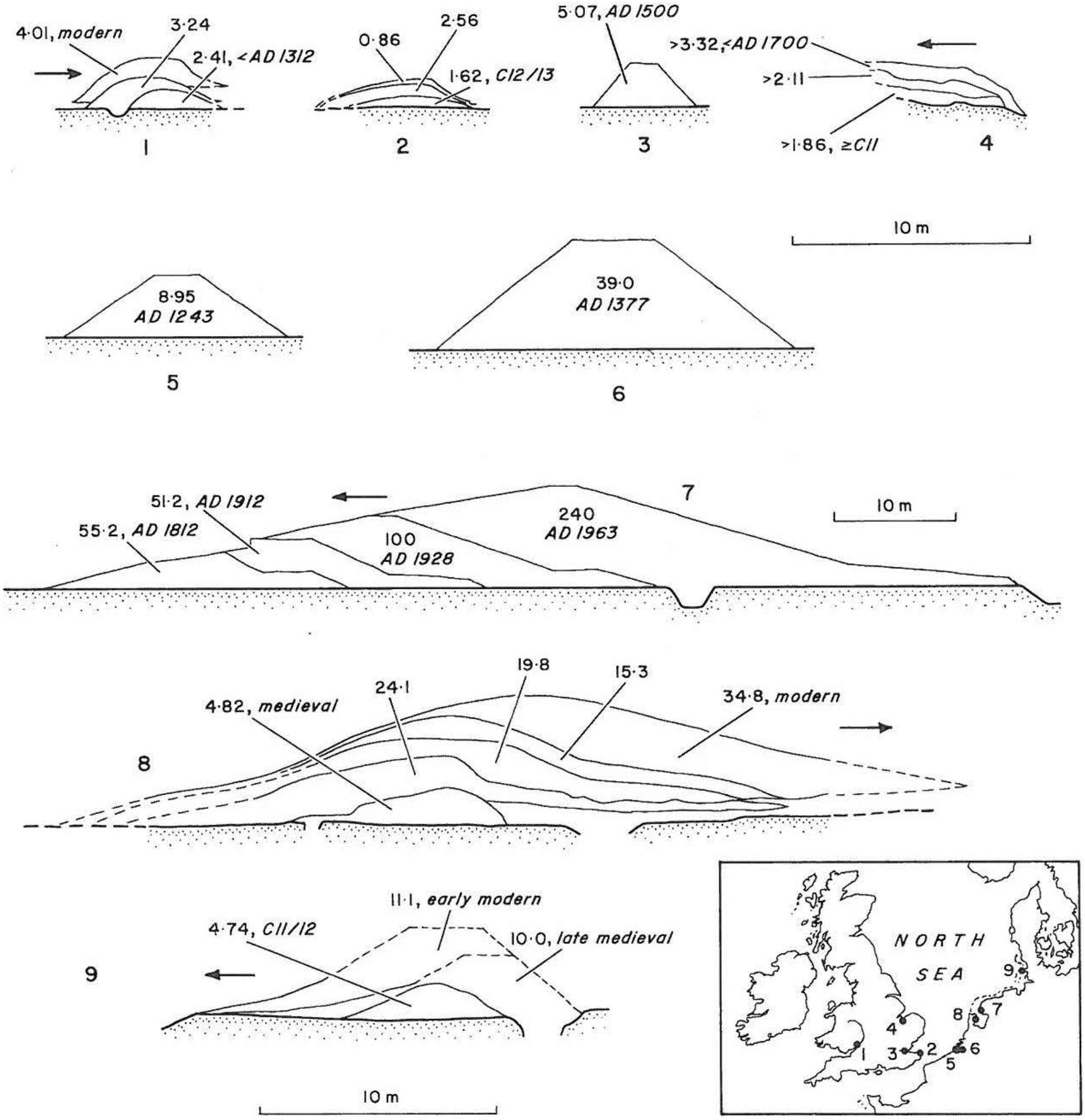

Figure 2: Historic seabanks in Northwest Europe in cross-section, as reconstructed from excavations and/or documentary sources. The seaward direction, where known, is shown by the arrow. Known phases of construction are distinguished where these have been recognised; the first figure given is the unit volume of the phase (in m^3/m) and the figure in italics its date. 1 - Lydney Level, Severn Estuary (1995). 2 - Sandwich Bay (after Hearne et al *1995). 3 - Rainham, Thames Estuary (after Grieve 1978). 4 - Banklands, Clenchwarton, Fenland (after Crowson 2000). 5 - Mouth of Westerschelde, The Netherlands (after Brand 1985). 6 - Western Zeeuws-Vlaanderen, The Netherlands (after Brand 1985). 7 - Coast of Wadden Zee, The Netherlands (after Mazure 1984). 8 - Niedorp, Westfriesland, The Netherlands (after Hallewas 1984). 9 - St. Johannis-Koog, Eiderstedt (after Ey 1997). Note that the scale for the bank numbered 7 is half that of the other examples.*

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