The Use of Clay to Improve Sea Wall Resilience

Document: 1 Version: 1.0

Essex Coastal Organisation

12 August 2013

Halcrow

The Use of Clay to Improve Sea Wall Resilience

Document: 1 Version: 1.0

Essex Coastal Organisation

12 August 2013

Halcrow Group Limited
Endeavour House, Forder Way, Cygnet Park, Peterborough, PE7 8GX
tel +44 (0)1733 560 033 fax +44 (0)1733 427 988
halcrow.com

Document history

The Use of Clay to Improve Sea Wall Resilience

Essex Coastal Organisation

This document has been issued and amended as follows:

Version	Date	Description	Created by	Verified by	Approved by
1.0	12/08/2013	Final Issue	Shaun Wersching / John Cowley	Phillip McLoughlin	Phillip McLoughlin

This report has benefitted from the generosity and support of the Environment Agency and Essex County Council who funded the drafting of the report and the National Farmers Union and Country Land and Business Association who facilitated the report preparation. Special thanks are provided to the Essex Coastal Organisation and notably Andrew St Joseph (AKMstjoseph@aol.com) who provided valued insight into the requirements of coastal landowners in Essex and project managed the drafting of the report.

Introduction to Managing Coastal Change and Essex Coastal Organisation

Managing Coastal Change (MCC) was a farmer-led project, set up to help farmers help themselves adapt to change on the Essex coast. Launched in January 2007 with funding from Defra, the project aimed to raise awareness among land managers of emerging coastal plans and strategies, and to investigate and understand the extent to which those plans are accepted by local landowners. MCC sought to bridge gaps in communication within and outside the farming community. Since its launch more than 100 coastal farmers and land managers have been involved, with local groups established to explore the best way forward in their own area. Although Defra funding has now ended, the MCC project continued with the financial support of the Environment Agency and Essex County Council.

The Essex Coastal Organisation was formed in 2011 by the majority of the coastal landowners in Essex who wished to maintain communication on flooding issues. It is farmer led and represents and provides information to its members in relation to the following two aims:

> To support and represent the interests of private landowners and occupiers of the coast in their role as custodians of the coastal environment in Essex.
>
> To assist, where possible, people and rural property under threat of flooding.

Contents

1 Introduction

The objective of this advice note is to provide practical considerations on the selection and use of clay to assist landowners in maintaining their rural sea walls (flood embankments). It outlines what is feasible to do in practical terms to assist in the management of the sea walls to try and make them last as long as possible. This advice note considers the use of unreinforced earthworks (i.e. it excludes the use of geotextiles) to strengthen existing sea walls. Although geotextiles can be beneficial in spreading the loading from and strengthening the earthworks their use can be complex and has best effect under a new embankment. Specific professional advice should be sought where the used geotextile is considered beneficial (BS EN 13251. Geotextiles and geotextile-related products provide characteristics required for use in earthworks).

Details on the consenting process including planning, waste and environmental issues were not required as part of this commission.

Due to the variability of clays, sites and constraints, the guidance provided is general and non-site specific. Users would be expected to seek specific professional advice to suit their individual circumstances.

2 The function of a flood embankment

Flood embankments are fixed earth fill structures typically constructed from locally sourced materials to hold back high water levels. Vehicle access along the embankment for the purpose of maintenance is usually provided by forming the flood embankment with a wide crest or a berm. The current minimum crest width required by the Environment Agency for vehicular access is 4m, although there are circumstances where this may be relaxed. Where the flood embankment is high, nominally greater than 4m, a landward berm is likely to be required for either stability (See Figure 7.1) or to improve maintenance access on the landward slope.

The principal forces that act on a flood embankment and the foundation soils come from:

- Hydraulic loads from the flood water acting horizontally, based on an estimate of the design flood still water levels within a given period, with an allowance for freeboard (risk allowance) and an assessment of wave action (wave run up) on the face of the flood embankment.
- The interaction of the hydraulic loads with the internal structure of the flood embankment and foundation soils.
- Imposed loads, usually on the crest, from stockpiling materials or movement of construction/maintenance vehicles.
- Self-weight of the flood embankment.

Flood embankments need to be carefully designed and constructed to prevent failure under its full loading for the duration of their design life. In addition, the maximum credible flood conditions should be considered as floods can exceed the design event and may overtop the flood embankment but should not cause failure where the amount of overtopping is small.

2.1 Freeboard (risk allowance) and other allowances

Freeboard is a risk allowance added to the estimated flood (still) water level to allow for uncertainties in the calculations and wave action (wave run up). The estimated flood water level, plus the freeboard allowance, gives the (minimum) design flood defence level for the embankment. The risk allowance varies from location to location but generally is greater on open estuaries compared to sheltered creeks.

An additional allowance over and above the freeboard allowance is made for construction tolerances, settlement and long-term deterioration of the crest, which may include a 'sacrificial' thickness to allow for fissuring by raising the zone of potential fissuring above the flood level (Section 4.4). Earthworks construction tolerance is typically nil to +50mm. The settlement of a flood embankment will be ongoing at a diminishing rate following initial construction or the completion of works to increase the size of the embankment. Where practical the flood embankment is constructed to a level to allow for the anticipated settlement that could occur over the design life or is managed by raising the crest level periodically over the design life.

Deterioration (including rutting) can result from livestock walking or vehicles/ agricultural machinery running over the flood embankment. The affects can be minimised by putting in place control measures, such as restricting access to livestock or vehicles which cause damage to the crest, and maintaining a good grass sward.

2.2 Still water level

Still water level is used to determine the flood defence height. It is estimated for sea defences from an analysis and extrapolation of historical tides (including tidal variation, meteorological surge, and an allowance of sea level rise and settlement of landmass over a defined period). Still water level may vary along the planned defence length as a result of the interaction of the water with the bed profile and land form. For example, a funnel shape estuary can generate a rise in still water level toward the narrow section. This is evident around the Essex coast where still water levels are higher at Southend than at Harwich due to the funnelling of the North Sea into the English Channel. Still water level is also determined by the return period (the average length of time separating flood events of a similar magnitude: a 100-year flood will occur <u>on average</u> once in every 100 years). The longer the time period adopted for the design the greater the probability of a more extreme flood event occurring and the higher the still water level will be. However, the relationship between still water level and return period is not linear but increases at a diminishing rate with increase in time. Extreme water level predictions are available in the Essex and South Suffolk Shoreline Management Plan (SMP) Appendix C, dated 15 October 2010 (http://www.suffolksmp2.org.uk/publicdocuments/finalsmp/Appendix%20C_%20Baseline%20Processes.pdf).

The still water level chosen for the design of the flood defence is defined by the responsible authority/owner based on the costs of the construction works and the estimated value of the flood damages avoided. The greatest benefit to cost ratio is typically used to select the optimum defence height, though other considerations such as political and socio-economic factors and affordability are taken into account. Where the target return period is short the flood embankment should be designed with sufficient resilience to withstand overtopping.

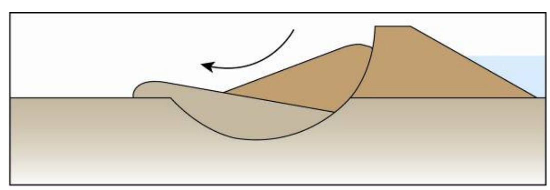
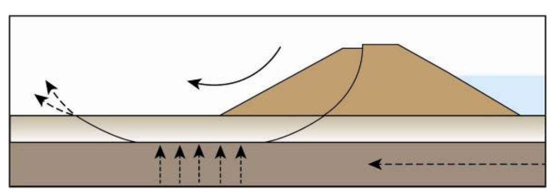
Estimates for low and high still water levels are required for the earthwork design to allow the impact of the changing water level (draw down) and erosion forces (waves and currents) on the embankment to be assessed.

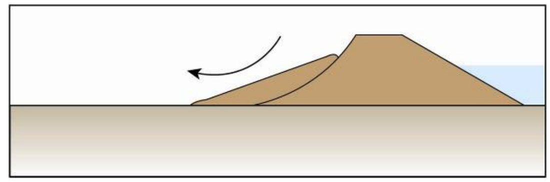
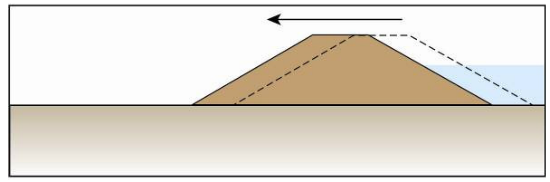
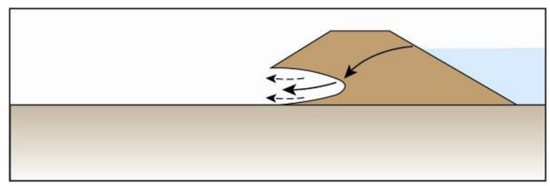
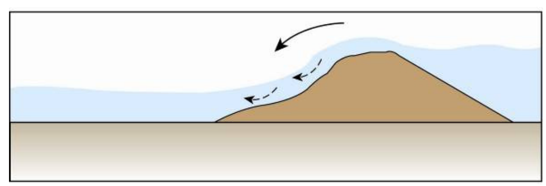
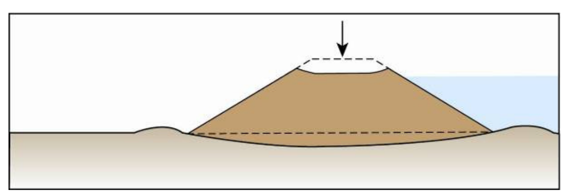
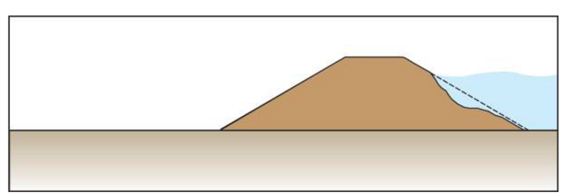
2.3 Wave action

For coastal defences, waves are caused by the swell of the sea and wind passing over the surface. Sea waves can generate very large dynamic forces (due to the large body of water) which need to be accounted for in the design of the embankment. Wind generated waves do not give rise to such large forces impacting on the embankment, but can lead to erosion of the crest and some flooding from overtopping. Wind generated waves are a function of the wind speed, the surface length of open water over which the wind blows (the fetch) and the depth of water leading up to the embankment foreshore. Landowners should determine the alignment of their defences relative to the prevalent wind direction to assist in identifying this risk (i.e. exposed northerly facing sea walls will be more at risk to northerly winds than south facing sea walls).

2.4 Typical failure mechanisms

Some typical causes of embankment failure and the resulting mechanisms are presented in Table 2.1.

Table 2.1: Some typical causes of embankment failure and sketches of the mechanisms	
(a) Deep seated rotational failure of the embankment and soft foundation soils as the loading exceeds the strength of the embankment fill and foundation soils. Although the existing embankment and underlying foundation soils may be well consolidated and gained in strength, having been constructed many decades ago, adding new material increases the risk of a slip occurring, especially into the adjacent soke/borrow dyke.	
(b) Rotational failure of the embankment as a result of the uplift of the clays/peats on the landward side where they are underlain by high permeability sands and gravels in hydraulic continuity with the flood waters on the waterside.	

(c) Shallow slip surfaces within the embankment side slopes resulting from softening of the earth fill as a result of the ingress of water and over steep slopes.	
(d) Landward sideways sliding of the embankment on the soft ground foundation soils under the horizontal force from the flood water where the embankment has insufficient weight.	
(e) Seepage through porous material (sand/silts) or fissures/cracks (clays) which can result in the movement of water and soil particles (piping). This causes a progressive shortening of the seepage path, and an increase in the seepage quantity and mobilised soil particles, resulting in the development of a progressive failure. The presence of animal burrows that intercept the internal seepage can accelerate the rate of erosion and the onset of failure.	
(f) Crest and landward slope erosion due to overtopping which is worsened when the embankment material is non-cohesive or a highly fissured (cracked) clay.	
(g) Settlement of the embankment crest below the defence level when the embankment is founded on soft compressible soils, which can promote early overtopping.	
(h) Seaward slope erosion due to wave and current action which is worsened when the embankment material is non-cohesive or highly fissured (cracked) clay.	

Halcrow

The presence of a soke or borrow dyke close to the landward toe of the flood embankment can have a detrimental influence on stability (including sideways sliding, slip circle rotation) as it increases the effective embankment height. The stability of the embankment will be reduced further where the water level in the soke dyke is lowered rapidly.

Where the soke dyke intercepts or the base level approaches a more permeable layer in the foundation soils, the quantity of seepage and the potential for piping (the progressive removal of soil particles from within the body of the embankment or foundation soils by the flow of seepage water) to occur within the soke dyke is increased. If the seepage path exits in the soke dyke the lowing of the water level in the soke dyke will increases the water head differential across the embankment during a high water/flood event, increasing the potential for piping to occur.

3 Key visual factors

As an aid for visual inspection, Table 3.1 presents typical cause-consequence scenarios for typical behaviours of flood embankments.

Table 3.1: Typical cause-consequence scenarios for typical behaviours of flood embankments

Affected element	Cause	Consequence
Ground condition below the embankment	Settlement: Consolidation of highly compressible clays and organic soils forming the embankment foundation.	Lowered crest level(s) leading to overtopping and possible breach.
	Deep rotational failure: Insufficient shear strength of founding soils during or shortly after construction or, hydraulic uplift of clays/peats on landward side that overlay sands or gravels that are in hydraulic continuity with floodwaters.	Crest settlement and embankment deformation leading to overtopping and possible breach.
	Seepage and piping: Critical hydraulic head acting across higher permeability non cohesive soils in foundation soil resulting in the movement of soil particles.	Pipe (void) growth on landward side migrating to seaward side leading to breach.
	Lateral sliding: Horizontal block movement of a section of the embankment landward due to insufficient shear strength of foundation soils and light weight embankment fill under the horizontal thrust of the flood waters.	Embankment breach.
Secondary structures through embankment (including sluices).	Material failure: Erosion along soil/structure interface or direct failure of the structure.	Development of seepage path and potential for piping, leading to breach.
	Operational failure: Human error, vandalism or mechanical, electrical or control failure.	Unregulated release of flood water to landward side leading to flooding.

Surface and toe protection measures	Uplift of protection: High residual water pressure below the revetment from within the sea wall as a result of rapid lowering of the floodwater and wave action causing uplift of the revetment on the seaward face.	Seaward face erosion, and potential for instability and failure.
	Hydraulic loading: Extreme and rapidly varying water levels and pressures, especially during storm driven wave action.	Movement of blocks of surface protection leading to erosion of waterside face, and potential for instability and failure.
Embankment earthworks	Seepage: Through desiccation fissures in clay fill. Can occur without overtopping of embankment.	Slumping of landward slope and degradation of crest leading to breach.
	Seepage and piping: Critical hydraulic gradient acting across higher permeability non-cohesive materials within embankment. Can be initiated/ exacerbated by animal burrows and tree roots.	Pipe growth on landward side migrating to seaward side leading to breach.
	Erosion of landward face and crest: Seepage through the zone of fissures soils immediately below the crest without overtopping and where excessive overtopping occurs.	Crest lowering leading to breach.
	Vegetation cover: Plays an important role in stabilising surfaces via root mat which can increase erosion resistance and reduce drying of the subsoil.	Surface erosion leading to breach in severe cases.
	Erosion of waterside face and toe: River currents, waves and boat wash, and lower vegetation cover, can result in greater erosion.	Instability of waterside face, potentially leading to instability and breach.
	Softening of clay fill: Where firm/stiff clays have been used to form the embankment with steep side slopes, water (precipitation) will be absorbed by the near surface layer of fill causing it to soften and loose strength.	Shallow surface slip of embankment slopes, leading to an increased risk of erosion and the potential formation of a breach.
	Continuity of flood defence: Each end of the defence need to be suitably tied in to an existing defence of higher ground.	Risk of outflanking or creating points of weakness potentially leading to erosion, instability and breach.

4 General attributes of clays

In selecting a suitable cohesive material for fill, consideration should be given to some of the fundamental soil properties:

- Moisture content,
- Plasticity,
- Grading (clay content).

and to the engineering properties that these impart to the clay:

- Strength,
- Permeability,
- Compaction characteristics,
- Cracking and fissuring potential,
- Erosion resistance.

The effects of the fundamental soil properties on the engineering behaviour of the clay are summarised qualitatively in Table 4.1. Tables 4.2 to 4.8 provide further details of the effects of each of the principal fundamental soil properties on the engineering behaviour of the clay. Table 4.1 aims to show that there can be conflicting interests (favourable and unfavourable behaviours) between the effects of the fundamental soil properties on the engineering behaviour. Therefore, the process of identifying suitable clay for the construction of flood embankments is one of compromise. Within limits it is possible to mitigate residual adverse properties through engineering design.

Any materials used for the construction of a flood embankment should be free of brick, rubble, artificial fibres or other materials of a 'made ground' nature, as well as being free from leachates that are harmful to the natural environment of the site. Fill materials should be free from rhizomania and other diseases and also from unwanted/invasive plant species. The fill materials should conform to the Environment Agency's 'Guidance on the Disposal of Contaminated Soils', Version 3, April 2001. Section 7.5 details other materials that are unsuitable for the construction of flood embankments.

Table 4.1: Effects of the fundamental soil properties on engineering properties

Fundamental soil properties	Effects of an increase in the fundamental soil properties on the engineering properties				
	Strength	Permeability	Compaction characteristics	Cracking / fissuring potential	Erosion resistance
Moisture content	Reduce	Increase relative of OMC*	Ease of compaction increased.	Increase	Reduce
Plasticity	Increase	Reduce	Reduction in MDD# and increase in OMC*.	Increase	Increase
Grading – clay content	Increase	Reduce	Reduction in MDD# and increase in OMC*.	Increase	Increase

#MDD denoted Maximum dry density *OMC denotes: Optimum moisture content

4.1 Strength

An acceptable range of strengths, field methods of assessing strength, consequences of exceeding these limits, together with potential methods of mitigating them are presented in Table 4.2.

Table 4.2: Strength classification

Strength	Acceptable range: 40 to 150kPa (highlighted in bold below)	
Field assessment	Strength	Field test.
	Very soft 0 to 20kPa	Extruded between fingers when squeezed in hand (tooth paste consistency).
	Soft 20 to 40kPa	Moulded by light finger pressure.
	Firm 40 to 75kPa	**Can be moulded by strong finger pressure.**
	Stiff 75 to 150kPa	**Can not be moulded by fingers. Can be indented by thumb.**
	Very stiff >150kPa	Can be indented by thumb nail.
Low strength	• Poor trafficability by wheeled plant resulting in excessive rutting. • Slumping/instability of embankment profile. Excessive cracking of embankment surface when drying.	• Spread clay out and allow to air dry to required strength. Use in non-structural elements of the embankment where only increase in mass is required (toe berms).
High strength	• Poor compaction with light plant leading to network of connected voids through body of embankment. • Formation of a shallow slip surface on steep sided slopes as clay softens in the longer term.	• Use larger compaction plant or limit strength to suit available plant. Excavate trial pits to visually assess and ensure that a uniform clay mass has been achieved by compaction. Spread clay out, add water if necessary, and allow it to softening to required strength.

Note: kPa = kilopascals, the SI derived unit for pressure and compressive strength.

In general the lower acceptable strength of 40kPa is slightly wetter than the lower limit for typical farmland cultivation.

4.2 Permeability

There is no established simple field method for assessing the permeability of the clay. In general, the permeability of a clay will be adequate for the construction of a typical embankment. However, some exceptions are presented in Table 4.3.

Table 4.3: Permeability classification

Permeability	Acceptable range: less than 10^{-6} m/sec (Intact clay)	
Field assessment	None.	
	Field observation	**Engineering mitigation**
Low permeability	• Not an issue.	• None required.
High permeability	• Increase in permeability due to the formation of desiccation cracking or fissuring post construction. • Poor compaction resulting in a network of connecting voids through body of embankment.	• Ensure freeboard of at least 0.9m depth to ensure zone of fissuring is above still water level or install impermeable barrier through crest over depth of potential fissuring, circa 1.2m depth. • Ensure adequate compaction is achieved.

4.3 Compaction

Compaction is the mechanical process of removing air from a soil. Compaction should achieve a uniform clay mass with at worst only minimal small isolated voids remaining between the original un-compacted blocks of clay. The compactive effort required to achieve this will increase as the strength of the clay increases. Visual indications that an acceptable level of compaction has been achieved are presented in Table 4.4. A suggested method of undertaking the compaction of clay fill is presented in Section 7.10.

Table 4.4: Compaction classification

Compaction	Acceptable range: Uniform clay mass with at worst only minimal small isolated voids	
Field assessment	Excavate trial pits in compacted fill. Use a hand tool (spade) to prepare a broken surface over the wall of the trial pit to ensure that any voids are not concealed by the smearing action generated over the cut face.	
	Field observation	**Engineering mitigation**
Low compaction	• Visual evidence of voids within clay mass.	• Increase compaction effort.
High compaction	• Clays can be over compacted, causing then to have a spongy behaviour; i.e. excess deformation under the wheels or drum of the compaction plant.	• Do not over compact. • If over compaction occurs, allow time for soil to consolidate (settle and strengthen).

4.4 Cracking and fissuring

The development of cracks and fissures in a soil is the result of a reduction in soil volume due to drying. The degree of desiccation and therefore cracking and fissuring is a function of the soil characteristics and placement moisture content.

The clay content and mineralogy of a soil controls the amount of volume change that a soil can experience during drying. These are reflected in the plasticity index of the soil.

The higher the soil plasticity index the more susceptible it will be to fissuring. The plasticity index can be used to classify the fissuring potential of a soil into one of 4 broad categories; very high, high, medium or low. Table 4.5 presents a classification of fissuring potential of a soil relative to plasticity index. (NB Plasticity index boundaries overlap in the table). Table 4.6 presents a simple field test for assessing plasticity index.

Table 4.5: Cracking and fissuring potential of clay

Plastic Index %	Shrinkage potential
>35	**Very High**
22-48	**High**
12-32	**Medium**
<18	**Low**

Table 4.6: Field test for assessment of plasticity

Plasticity	Acceptable range: Plasticity between 10% and 40%			
	Plasticity	**Plasticity index (%)**	**Dry strength**	**Field test on Air Dry sample.**
Field assessment	Non plastic Slight plasticity Medium plasticity High Plasticity	0 to 3 3 to 15 15 to 30 >30	Very low Slight Medium High	Falls apart easily Easily crushed with fingers Difficult to crush with fingers Impossible to crush with fingers
	Field observation		**Engineering mitigation**	
Low plasticity	• Large change in strength for small changes in moisture content. • Increased erosion potential.		• Use in zone of freeboard to reduced development of surface fissuring over crest, provided erosion resistance is acceptable. • Use in core of embankment.	
High plasticity	• Difficult to compact when 'dry' due to very high strength. • Potential for significant surface cracking and fissuring.		• Increase freeboard to 0.9m to ensure the zone of fissuring is generally above defence level or install impermeable barrier through crest over depth of potential fissuring, circa 1.2m depth. • Use in core of embankment.	

4.5 Erosion resistant

Various mechanisms can be distinguished that are responsible for the erosion of clay in embankments including:

- dispersion of fine particles in stationary water.
- mechanical removal of fine particles by the flow of water or breaking waves.

Table 4.7 presents a field test for assessing potential for erosion due to dispersion in water and Table 4.8 presents a field test of assessing potential for erosion due to mechanical action by the flow of water and breaking waves.

Table 4.7: Dispersion in water

Dispersion	Acceptable range: Grade 1 and 2		
Field assessment	Take several intact lumps of soils circa 10mm diameter and place in a clear grass container of water placed on a stable surface. Observe the behaviour of the soil lumps after 5 to 10 minutes. (Actual test requires use of dispersive agent in water but use of water can provide indication of dispersion potential)		
	Grade	**Reaction**	**Description**
	1	No reaction	Crumbs may slake (break off), but no sign of cloudiness caused by clay particles in suspension.
	2	Slight reaction	Bare hint of cloudiness in water at surface of crumb.
	3	Moderate reaction	Easily recognisable cloud of clay particles in suspension, usually spreading out in thin streaks on bottom of beaker.
	4	Strong reaction	Clay particle cloud covers nearly the whole bottom of the beaker, usually as a thick skin.

Table 4.8: Mechanical erosion

Erosion Resistance	Acceptable range: For moderate erosion resistance or better: Plasticity > 18% (Essentially Medium plasticity – Table 4.6). Fines must be predominantly clay rather than silt.	
Field assessment	A simple field test to distinguish between clays and silts comprises: Repeatedly roll and remould a lump of soil to a thread on the palm of the hand until it has dried sufficiently to break at a diameter of about 3 mm. In this condition: • Inorganic clays of high plasticity are fairly stiff and tough. • Low plasticity clays are softer and more crumbly. • Inorganic silts give a weak and often soft thread that breaks up, crumbles readily, and may be difficult to form. A soil can be tested for the absence of clay by forming a pat of soil, moistened to be soft but not sticky, in the open horizontal palm of the hand. The side of the hand is then jarred against the other hand several times. This may cause a shiny film of water to appear on the surface of the pat. When the pat is squeezed or pressed with the fingers, the surface dulls as the pat stiffens and finally crumbles. These reactions are marked only for predominantly silt-size material and fine sand, and normally indicate the presence of these materials and the absence of any significant clay content.	
	Field observation	**Engineering mitigation**
Low erosion resistance	• Rills (channels) forming over surface of stockpile and embankment due to surface run-off.	• Confine to core of embankment.
High erosion resistance	• No formation of rills over surface of stockpile or embankment due to surface run-off.	• None required.

5 Ground conditions

The soils on which the embankment is placed have a significant influence on its performance.

The underlying solid geology in the area of the Essex coastline is the Thames Group, formally known as the London Clay Group, and comprises silty clay/mudstone, sandy silts and sandy clayey silts of marine origin. Where the solid geology is overlain by superficial deposits these may comprise either River Terrace Deposits, consisting of sands and gravels, locally with lenses of silt, clay or peat, or Alluvium consisting of soft to firm compressible silty clays which can contain layers of silt, sand, peat and basal gravel. A stronger, desiccated zone, between 0.5m and 1.5m thick, may be present over the surface of the alluvium. Usually the clay forming the dessicated zone is brown in colour with those below this zone blue/grey in colour.

For the purposes of assessing the performance of a flood embankment the solid geology represents a competent, low permeability boundary. Issues relating to the construction and performance of the embankment will result from the superficial deposits laid above the solid geology, which between then will have properties that include low strength, light weight and high permeability. The lateral variation in the composition of the superficial deposits could be quite marked over a short distance, reflecting the complexity of the environment in which they were deposited.

Embankments constructed on soft compressible deposits can fail during construction when the shear resistance mobilised by the load from the embankment fill and construction plant exceeds the strength of the soft foundation soils. This is particularly true where a seawall has been placed across an old creek bed, as mentioned in Table 5.1.

Box 5.1 Estimate of maximum height of embankment based on undrained shear strength of foundation soil.

Assuming a notional load of 10kPa from construction plant and a density of 20kN/m^3 for the embankment fill, the critical embankment height (H_c) for a new embankment at which the factor of safety is around unity (that is, it is on the point of failure) may be estimated approximately from:

Hc = 0.25 x strength of the foundation soil* – 0.5m

Note: * see Table 4.2.

During the 1953 storm surge, numerous breaches occurred in the Essex flood embankments. The main failure mechanisms under hydraulic load were:

- Seepage through the fissures in the embankment resulting in failure of the landward slope and degradation of the crest.
- Under seepage through the sands and gravels which are connected hydraulically to the river, causing uplift of the clays and peats or ‘boiling’ in the fine sand and silts on the landward side of the embankment.

For a designed embankment such failures are likely to be associated with ground conditions that are locally at variance with those assessed from the ground investigation.

Features in the landscape such as subtle variations in elevation, changes in vegetation cover or, within a mono-crop, changes in colour, and changes in soil colour may give pointers to the presence of problematic foundation soils. These features may be evident from at least one of the following;

- An overview of the surface topography and vegetation cover from a site walk over.
- Soil exposures within open excavations, such as the soke dyke.
- Inspection of aerial photographs. These can be viewed on-line for free via Google Earth, Google Maps and Bing Maps. (It is worth looking at a site on both Google and Bing as they used different photo sources which may provide coverage of the site at different times of the year. Google Earth also includes an option to view historic imagery. Features evident on an image taken at one time of the year may not be visible on another image taken at a different time.)

Some of the features of interest are summarised in Table 5.1.

Table 5.1 Surface observation and correlations with ground conditions

Localised field observation	Possible cause	Potential implications on embankment performance
• Low ground at variance with the general topography. • Darker soil colour. • Peat deposits. • Rutting by earth moving plant. • Encountering weaker or more organic soils. • Areas of more or less vigorous plant growth. • Localised failure in excavations (side slopes and base heave).	• Possible historic channels infilled with weaker/softer or organic/peat soils. • Peat beds close to the surface.	• Greater thickness of fill placed to achieve defence level. • Larger settlements due to greater compressibility of foundation soils and increased fill thickness required to maintain defence level in the longer term. • Instability due to weaker foundation soils and greater loading from increased fill thickness. • Fill sourced from these deposits may be unacceptable or prone to increased shrinkage/ fissuring.

Table 5.1 (cont) Surface observation and correlations with ground conditions

Localised field observation	Possible cause	Potential implications on embankment performance
•	•	•
• Higher ground at variance with the general topography. • Lighter soil colour. • Non-rutting by earth moving plant. • Seepage. • Areas of more or less vigorous plant growth. • Non-cohesive deposits, more permeable horizons or land drains.	• Possible historic channels infilled with course grained soils. • Possible deposits of course grained material laid down during a flash flood.	• Less settlement due to lower compressibility foundation soil. • Seepage and piping through higher permeability foundation soil. • Instability through up lift on landside where higher permeability soil is capped by lower permeability soil. • Fill unacceptable or occurrence of seepage, piping and erosion where fill is used.

If works are to be undertaken where such features are evident in the landscape, it is recommended that specific professional advice is sought to evaluate their impact on the proposed works.

6 Typical design cases

6.1 Strengthening steep sea wall by slackening its slope

Strengthening an existing sea wall slope by placing additional material to slacken the side slope will make it more resistant to breaching when overtopped because:

1. There is more material to be eroded before a breach can fully develop.
2. The reduced gradient would reduce the velocity of the flowing water reducing its erosion potential.
3. Reduced the potential for shallow slips, caused by softening of the embankment fill, and deep seated rotational failure.

Where new material is placed against an existing embankment slope or over sloping ground is should be benched in (Section 7.9).

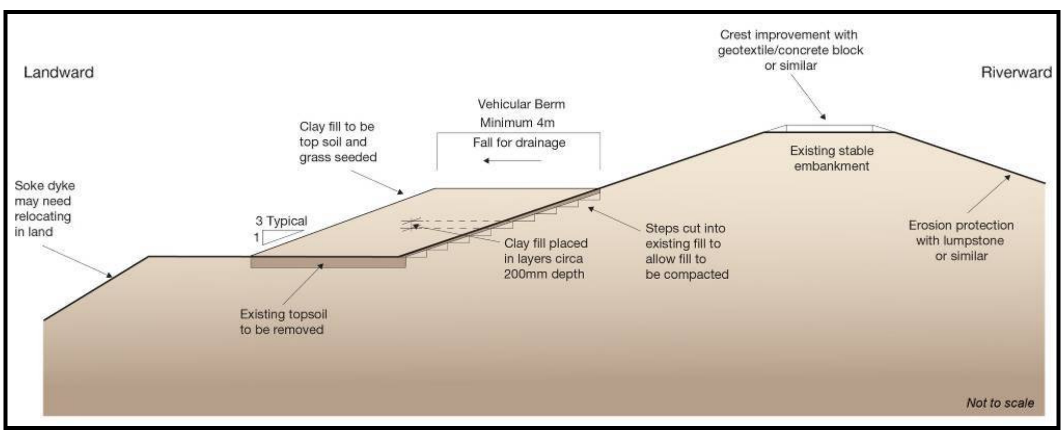
Table 6.1 provides an indication of the likely additional volumes of cohesive material required per metre run of sea wall strengthening work. In selecting suitable fill material special attention should be made to the clay parameters of plasticity (Table 4.6 above) and mechanical erosion resistance (Table 4.8 above), and ensuring a good grass sward.

Table 6.1: Net clay fill volumes for new berm construction per metre length *(1)					
Embankment Slope 1 in (n) (vertical to horizontal distance)	n from existing 1.5 to proposed 2.0	n from existing 1.5 to proposed 2.5	n from existing 1.5 to proposed 3.0	n from existing 2.0 to proposed 2.5	n from existing 2.0 to proposed 3.0
Height (m)	Volume *(2) (3) (4) (m^3/m)				
1.0	0.3	0.5	0.8	0.3	0.5
1.5	0.6	1.1	1.7	0.6	1.1
2.0	1.0	2.0	3.0	1.0	2.0
2.5	1.6	3.1	4.7	1.6	3.1
3.0	2.3	4.5	6.8	2.3	4.5
*(1)	Due to various losses in the construction process, the gross volume of required materials could be 20-40% greater than the net. Users should factor up the required fill to allow for these losses.				
*(2)	Volumes assume one side of embankment only.				
*(3)	Volumes assume topsoil fill equals topsoil excavated. If topsoil depth is excessive additional clay volume may be required to replace the excavated topsoil.				
*(4)	Additional temporary volume will be required in order to over fill the slope to achieve adequate compact, this temporary volume can be excavated and reissued.				

6.2 Strengthening high sea wall by introduction of berm (split level folding)

Figure 6.1 shows how a sea wall can be strengthened with a berm to make it more resistant to breaching when overtopped. A berm is a relatively narrow bench or shelf which is provided to break the continuity of a long slope.

Figure 6.1: Strengthening a sea wall with a berm (split level folding)



The berm will make the sea wall more resistant to breaching when overtopped:

1. As there is more material to be eroded before a breach can fully develop.

2. The reduced gradient would reduce the velocity of the flowing water reducing its erosion potential.

Where new material is placed against an existing embankment slope or over sloping ground it should be benched into the existing material (Section 7.9).

A berm provided at a suitably high level will afford the additional benefit of improving stability and providing an access along the landward side of the sea wall, allow repairs and maintenance to be undertaken (see plate 6.1), and consequently is generally considered preferable to slackening the slope.

Plate 6.1 – High level access berm

So the berm can be used in the event of a breach it should be at a level that is above mean spring tides (minimum 3m above ordnance datum (AOD) and raised in line with future sea level rises. The berm in Plate 6.2 is not located at a suitably high level and unless raised is likely to be wet and unusable post breach (due to regular inundation by tide). The concrete covered crest shown in Plate 6.2 will alleviate the risk of crest erosion when overtopped. However, the length of the adjacent back slope will increase the risk of landward slope erosion during overtopping (see Table 2.1(f)). The raising of the berm will reduce this erosion risk by breaking the slope into two smaller lengths and reducing the flow velocity.

Plate 6.2 – Low level access berm (Note concrete covered crest)

Maintaining a good grass sward will reduce this erosion risk. Strengthening the grass sward with geotextiles/ wire mesh can assist in binding the slope material together and alleviate the risk of grass clumps being washed out when overtopped exposing the underlying material to erosion and washout. Should additional clay be placed over such an installed geotextile then the grass sward including the geotextile would need to be removed to enable the clay to be benched into the existing material.

It should be noted that a breach through an access berm would cut the original access route provided along the berm so the regular provision of widened sections to act as turning points and passing places would be beneficial to the transporting of repair material. The use of specialist plant, including tracked dumpers that can pivot on its axis (Plate 6.3), can help in the transporting of materials, especially in less favourable (wetter) ground conditions.

Plate 6.3 – Specialist plant tracked dumper

Table 6.2 provides an indication of the likely volumes of cohesive material required per metre run of sea wall berm construction.

Table 6.2: Net clay fill volumes for new berm construction per metre length *(1)					
Berm width (m)	2.0	3.0	4.0	5.0	Additional volume for extra 1m berm width *(4) (m³/m)
Height (m)	Volume *(2) (3) (m³/m)				
1.0	2.0	3.0	4.0	5.0	1.0
1.5	3.0	4.5	6.0	7.5	1.5
2.0	4.0	6.0	8.0	10.0	2.0
2.5	5.0	7.5	10.0	12.5	2.5
3.0	6.0	9.0	12.0	15.0	3.0
*(1)	Due to various losses in the construction process, the gross volume of required materials could be 20-40% greater than the net. Users should factor up the required fill to allow for these losses.				
*(2)	Volumes assume berm side slope is same as embankment slope.				
*(3)	Volumes assume topsoil fill equals topsoil excavated. If topsoil depth is excessive additional clay volume may be required to replace the excavated topsoil.				
*(4)	Additional volumes assume berm slope is same as embankment slope.				

As a simple example from the above table, a 0.5 ha hole dug in clay to a depth of two metres (for example for a farm irrigation reservoir) would make 10,000 m^3 of clay available assuming the clay was not required round the bank. The volume of clay would be enough for a 3m high 5m wide berm for circa 500m of length (assuming 30% losses in the construction process).

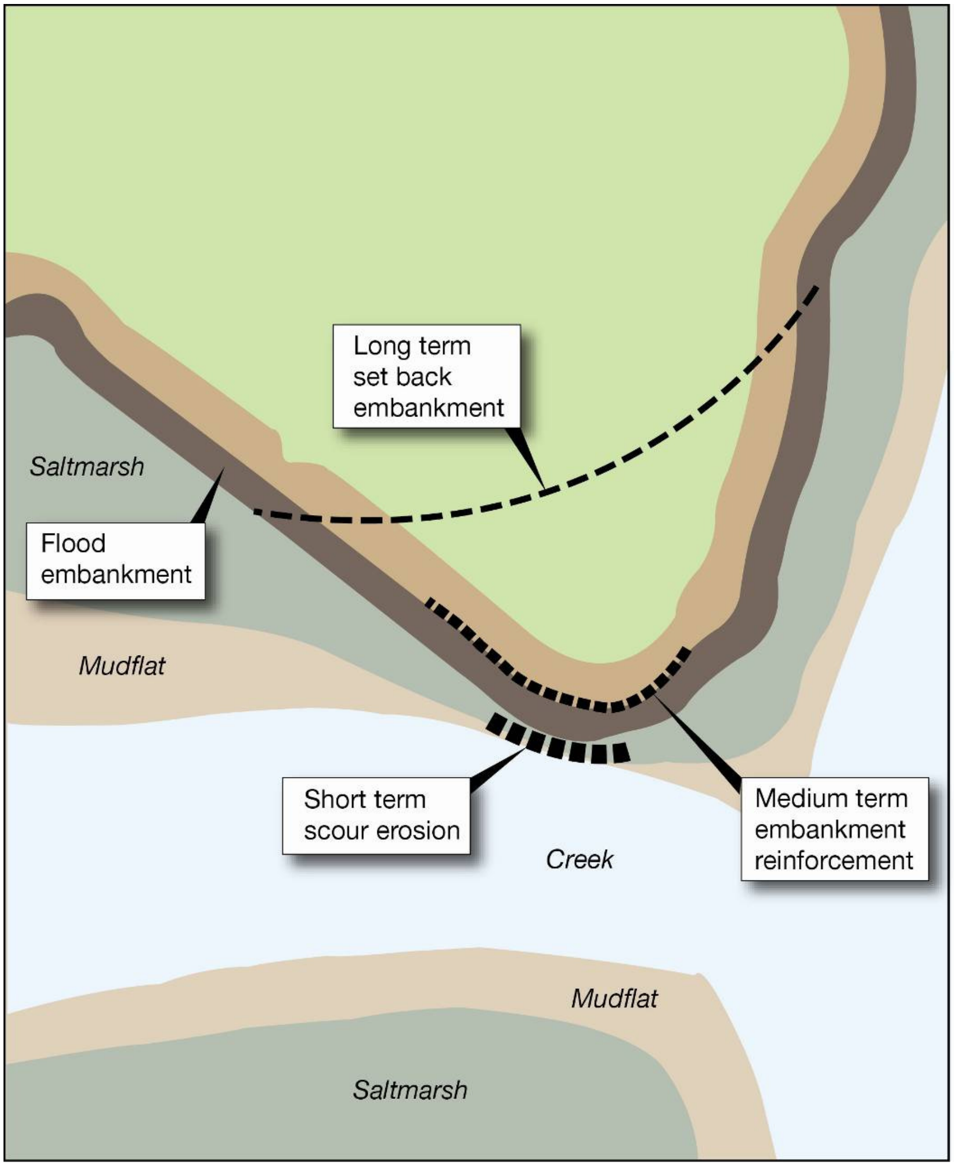
6.3 Secondary counter wall

The construction of a secondary wall can protect the land behind it in the event of overtopping or breaching of the primary defence. Figure 6.2 illustrates erosion of the mudflat/saltmarsh fronting the flood embankment by a creek which will lead to a reduction in the stability of the flood embankment. Left unchecked the erosion will continue, removing weight from the embankment toe, until the sea wall slips. The erosion is more pronounced as it is on the outside of the bend. There could also be impacts from wave action created by passing boats. Staking marker posts and making regular measurements of the remaining saltmarsh might help in predicting the rate of erosion and a timeframe for intervention.

The provision of scour protection (including steel sheet piles or lump stone) would help in the short term. The channel face, if steeper and deeper, could make these works extensive. An underwater survey would help determine the shape of the channel and hence the amount of erosion control works that would be required. Continued maintenance and refurbishment of the works is likely to be required. Strengthening the embankment back face would add resilience to the wall in the medium term in case the front face is eroded or slips. Construction of a secondary counter wall to the same height as the principal defence, to straighten or shorten the defence across the vulnerable bend, would allow the river to naturally migrate and is a more sustainable solution. The ends of the new sea wall would be benched into the existing sea wall. The land between the original and secondary walls could be used to source fill for the secondary sea wall. A calculation needs to be made between the length of the secondary wall and available fill from the land.

No material should be taken from circa 40m in front of the secondary sea wall as it provides the toe/erosion support to the new wall. The land between the original and secondary walls could be at a lower ground level than the saltmarsh. To protect the new wall the land in front (circa 20-40m) could be raised to create conditions for saltmarsh to establish. Mudflats and saltmarsh can provide a natural sea defence to dissipate wave energy avoiding the need for expensive hard concrete revetment. At Wallasea Island, Essex, dredged sediments were beneficially used for this purpose.

Figure 6.2: Strengthening a sea wall with a secondary sea wall



If the original defence is to be prematurely breached there could be potential for selling the land between the secondary and original defences as compensatory habitat. Any drainage ditches through the secondary defence would need to have control structures to allow surface water drainage through the secondary defence or tie into the primary defence drains beyond the line of the secondary defence.

A sub option of the secondary counter wall is to construct it to a lower crest level than the existing sea wall with the intention of containing an element of water from a partial breach or from overtopping for a short period of time during which time the breach can be repaired and the water evacuated from the land. Secondary counter walls can be used to break large flood compartments into a number of smaller cells. Such banks also improve dry access to the sea wall itself for repairs in the event of a breach.

Table 6.3 provides an indication of the likely volumes of clay required per metre run of new embankment construction (excluding any ground raising to create conditions for saltmarsh to establish).

Table 6.3: Net clay fill volumes for new embankment construction per metre length *(1)					
Embankment Slope *(2) 1 in (n) (vertical to horizontal distance)	n = 2.0	n = 2.5	n = 3.0	n = 3.5	Additional volume for extra 1m crest width *(6) (m3/m)
Height (m)	Volume *(3) (4) (5) (m^3/m)				
1.0	6.0	6.5	7.0	7.5	1.0
1.5	10.5	11.6	12.8	13.9	1.5
2.0	16.0	18.0	20.0	22.0	2.0
2.5	22.5*(7)	25.6	28.8	31.9	2.5
3.0	30.0*(7)	34.5*(7)	39.0	43.5	3.0
*(1)	Due to various losses in the construction process, the gross volume of required materials could be 20-40% greater than the net. Users should factor up the required fill to allow for these losses.				
*(2)	Volumes assume embankment slope is same on each side.				
*(3)	Volumes are based on 4m wide embankment crest.				
*(4)	Volumes assume topsoil fill equals topsoil excavated. If topsoil depth is excessive additional clay volume may be required to replace the excavated topsoil.				
*(5)	No allowance for any key trench excavation/filling.				
*(6)	Additional volumes assume same side slope as embankment.				
*(7)	Increased risk of instability during construction and in the longer term.				

7 General construction techniques and issues

The following section describes general construction techniques that are considered to be good practice when undertaking earthworks operations. It is acknowledged that the approach to compaction of the fill material will be undertaken using earthworks plant and therefore the approach described in this section takes that into account. Nevertheless, this does not mitigate the landowner from any legal obligations they have in undertaking such work in relation to construction legislation and environmental, and health and safety issues.

BS 6031 'Code of Practice for Earthworks' provides guidance on the placement of fill materials. Earthworks should be designed, constructed and maintained in accordance with this code.

7.1 Competency of personnel

It is recommended that a competent earthworks controller should be identified who will be responsible for ensuring that the fill materials are suitably conditioned (made suitable for compaction) and compacted. The controller should have a specialist supervisory role. It is preferable that the controller is not an equipment operator or working ganger / labourer in order to undertake the role with their undivided attention.

7.2 Health and Safety

The works should be planned in such a way as to minimise risk to site personnel and the public. Health and safety are prime considerations when undertaking work. This is given legislative backing via a number of directives including; Health and Safety at Work Act (1974); management of Health and Safety at Work Regulations (1992); Construction (Design and Management) Regulations (2007). Planning should allow for the safe movement of vehicles and personnel. This should include a one way traffic system, designated passing places and avoidance of reversing.

7.3 Environmental issues

The effects of the works on habitats, conservation and landscape (including access/rights of way) need to be considered.

7.4 Temporary storage of materials

To minimise the risk of slips with temporary stockpiles, material should be stored in heaps less than 3m high, with side slopes no steeper than 1 in 3. They should be located where they will not affect the stability of adjacent structures, flood embankments or soke dykes. All surfaces should be graded to shed water and finished with a smooth surface to limit the risk of water infiltration. Surface water runoff should be controlled and treated to prevent silt entering watercourses.

7.5 Clearance of existing vegetation

It is common practice to remove vegetation and organic matter over the areas to be filled. Topsoil is also stripped over the area and can be stored in a temporary stockpile for reuse. Unsuitable material should not be used within the flood embankment. Material containing the following can be considered to be unsuitable:

a) Organic material, peat or any marsh or swamp material.

b) Logs, roots, stumps or any perishable material.

c) Any material prone to combustion.

d) Any material having any hazardous chemical or physical properties.

e) Contaminated materials, including controlled wastes (as defined in the Environmental Protection Act 1990, Part 11A).

7.6 Relocating soke dykes

For embankment stability and access a minimum distance of around 10m is recommended between the landward toe of the embankment and the seaward edge of the soke dyke. For embankments over 3m high this distance may need to be increased. To provide space it may be necessary to infill the existing soke dyke and redigging a soke dyke inland. The original soke dyke should be cleared of soft silt and all organic material removed prior to backfilling in layers as per the embankment construction to reduce the amount of future settlement. A berm width of over 10m could allow a hay crop to be harvested mechanically.

7.7 Typical embankment geometry

The slope face angle of an embankment is expressed either in degrees to the horizontal or as a gradient (1 vertical in X horizontal). Typically embankments could be constructed to a height of 3m above the existing ground level, with slopes of 1V in 3H and a crest width of 4 metres with minimal technical input providing the river channel and soke dyke are greater than 10m from the embankment toe. Above 3m loadings, stability and settlement could be critical, and it is recommended that specific professional advice is sought.

7.8 Crest width

Embankment crest widths depend on the quantity and nature of the clay used, overall stability of the embankment, available land and requirements for access. A widened crest would facilitate greater access and provide additional width for any future crest raising by placing material only on the crest but this would result in a corresponding reduction in crest width and ease of access. This has occurred on the Dengie Marshes (Plate 7.1). The crest raising will reduce the volume of overtopping although the risk of crest and landward slope erosion when overtopped (Table 2.1(f)), or seepage and erosion through the fissures, will be worsened due to the increased length of the landward slope and narrowness of the crest.

Plate 7.1 – narrowed crest width due to previous wall raising

The growth of vegetation makes the edge of a crest difficult to identify notably when driving vehicles and so for safety purposes the crest width should ideally be increased to circa 4m where vehicular access is required.

7.9 Benching/keying into existing material

To ensure that there is a good bond and prevent the formation of a potential plane of weakness that could become a slip surface, new material should not be placed directly against an existing sloping surface or to vegetation. Vegetation (including topsoil) should be removed and benches or steps should be cut into the existing slope to allow new material to be keyed in. These steps should be about twice the layer depth at which the clay fill is being placed. So, for a 200mm compacted layer thickness the height of the step would be 400mm (see Figure 6.1). The horizontal length between steps should not be less than twice the step height, giving a maximum equivalent slope of 1 vertical in 2 horizontal.

7.10 Compaction of clay

The compaction of material by tracking with earth moving plant could be acceptable for a secondary structure, such as a berm, which is placed to improve access and that has only limited structural performance, as a lower standard of compaction may be acceptable. However, for structural significant element, such as the main embankment, specialist compaction plant, such as a tamping or sheep's foot roller, is recommended.

It is assumed that the compaction of the placed fill material will be undertaken by the landowner using earth moving plant to track in the placed material. It is also assumed that no in situ or laboratory tests will be undertaken to assess the adequacy of the compaction achieved. Therefore, the assessment of the adequacy of compaction will need to be made qualitatively and trials will need to be undertaken to determine a suitable maximum layer thickness and the number of passes of the earthmoving plant required. A means of visually assessing the adequacy of compaction on site is suggested in Table 4.4, above.

As a starting point, it is suggested that the trial commence with 200mm thick compacted layers with no more than 8 passes of the compaction plant. Site compaction trials elsewhere suggest that there is little increase in the degree of compaction for passes greater than 8 to 10. One pass is considered as a movement in one direction. Up to three layers should be placed and compacted over the trial area before an excavation is formed in the top two layers and the material inspected to assess the level of compaction achieved. Where adequate compaction is considered to have been achieved then the trial could be repeated with fewer passes. Where the compaction is not considered to be adequate then the trial should be repeated with a reduced layer thickness. A minimum practical layer thickness might be 100mm. If after reducing the layer thickness, adequate compaction can not be achieved then it is likely the clay is too strong for the mass of the earth moving plant used to provide the compaction. In this case there are two options available:

- Obtain specialist compaction plant suitable for compaction of the clay fill – this may require the stability of the embankment to be assessed.
- Reduce the strength of the clay by adding water and allowing it to be conditioned to a strength that can be compacted by the plant; noting the minimum strength requirement stated in Table 4.1, above.

Individual compacted layers should be keyed together. The surface of any fill layer which has been made smooth by traffic or the compaction process should be scarified (e.g. using teeth of excavator bucket) to loosen the surface to a depth of about 50mm prior to placing the next layer. If the surface has dried out it should also be scarified; adding some water, if appropriate, and blended in to the next layer of loose fill before compaction.

The embankment should be compacted to the edge of the fill to minimise the potential for precipitation to ingress into the finished slope surface. As water ingress could cause the surface material to soften, leading to the potential development of shallow slip failures. The issue of poor edge compaction can be overcome to some extent by placing and compacting fill material to a profile that is at least 0.5m wider than the required slope profile, and trimming the slope back once the embankment is complete.

7.11 Weather related issues

No frozen or ice bearing material should be used in the construction of the embankment. Filling operations should not be carried out during periods of frost (below 1^0C) or rain as this will reduce the strength of the placed material. The fill materials will be prone to softening by rainfall, especially if disturbed by trafficking plant at the time, and to drying out and cracking in warm dry weather.

The fill should be placed and compacted to a cross fall so that surface water will run off during construction and ponding does not occur. Particular attention should be paid to achieving a cross fall and smooth surface where filling is haltered for any period. Prior to restarting filling operations, the surface may need to be scarified in accordance with Section 7.10, above, to achieve a satisfactory bond between layers.

7.12 Settlement/consolidation

It is assumed that any additional fill material placed by the landowners will only be for widening the existing embankment. The raising of crest levels is not considered in this document as this would increase the loading and the potential for instability. Under these circumstances more detailed consideration by a specialist is recommended. The amount of settlement depends principally on the underlying soil properties and the height of fill. When widening an embankment the loading from the new fill can cause some settlement under the new fill and some additional settlement of the existing embankment. As a result of variability in the foundation soils the settlement is unlikely to be even along the embankment and differential settlement can develop. As a rule of thumb, localised low spots within the existing embankment can be indicative of locations where the foundation soils are weaker and more compressible. High spots may be indicative of areas where the foundations' soils may be stronger and less compressible, though they may have a higher permeability (Table 5.1 above).

The fill material itself will settle under self weight. This is usually small when compared with the settlement resulting from the foundation soil, but it will be increased by poor compactions of the fill.

In general some allowance for settlement can be made by constructing the fill to a height of circa 100mm above the planned fill height. While this document is not aimed at addressing the issues of crest raising, there may be a need to raise the crest over time to maintain the defence level as a result of settlement of the embankment and rising sea level. This is outside the scope of this document and specific professional advice should be sought.

7.13 Construction rates

The fill should be placed in nominally horizontal layers and should be brought up at a uniform rate, maintaining a generally level profile along the section parallel with the existing embankment.

The thickness of the placed fill material should be reference to the level of the surrounding fields. The rate of placement and compaction of fill can be unrestricted up to a height of 1.5m. Thereafter the rate of placement should be limited to two layers per week to 2.5m. The restricted rate of placement will allow the stability of the embankment to be visually monitored for any signs of distress during construction such as:

- Formation of tension cracks parallel with the line of the embankment,
- Heave at the toe of the embankment,
- Heave in the base of the soke dyke,
- Partial closure of the soke dyke.

Any further filling from 2.5m to 3m should be left for 1 year to allow the foundation soil to gain in strength, following which fill can be placed at a rate of 1 layer per week. Filling above a thickness of 3m should not be undertaken without seeking specific professional advice.

An observation and response plan to look for signs of instability during the works should be in place. Some indications of features to look for are considered above. Should any of these be observed then prompt action should be taken to:

- Back fill the soke dyke;
- Back fill the soke dyke and form a berm against the landward toe circa 1.5m height by at least 5m wide;
- Remove material form the top of the embankment (circa 1m); and
- Call in a specialist adviser.

7.14 Access ramps

Vehicular access ramps typically at a gradient of 1Vertical to 10Horizontal should be provided at regular intervals to allow access on to and between the embankment crest and berm from existing site access points.

7.15 Topsoiling and grass seeding

Topsoil should only be stripped, moved or reinstated when soil moisture conditions will not result in damage to the soil structure.

The embankment faces should be topsoiled to a thickness of about 150mm and topsoil cultivated to prepare it for grass seeding during the next appropriate season. The use of coir (hessian) matting can provide temporary protection at the time of the works to allow time for grass to grow. Any barren patches or areas of poor seed growth should be made good.

When the grass is firm under foot and is generally 75mm to 100mm high, the first (initial) cut can be made so as to leave about 40mm of growth. A further cut should be delayed for about three weeks to allow regrowth. Any weed growth should be controlled by the application of accepted herbicides in accordance with the relevant manufacturer’s instructions.

8 Maintenance

All flood embankments should undergo routine inspections and will require maintenance in order to preserve serviceability. Aspects of inspection and maintenance can include:

1. **Inspections** – Survey own sea wall(s) at least every year and especially after major storms. Look particularly for faults that can seen to be changing (dated records and photos can aid in comparison over time).

2. **Earthwork repairs** – Apart from minor works, the large scale additions of material to the embankment is a major project and there may be other methods of enhancing the quality of embankment, including maintaining a close knit grass sward by haying or grazing, reinforcing the top surface so that it is less likely to be eroded and breach if overtopped. Consider sourcing clay from your own land to reduce transportation costs. The potential for importing unsuitable material also becomes less of an issue. Circa 10,000m^3 come from a 2m deep excavation over 0.5ha. The resulting hole could be used as a fishing lake or water resource reservoir. Imported clay could be placed at a temporary storage facility rather than being added direct to a wall where it can be conditioned, if necessary, and rates of clay placement are not pressured by delivery rates to site.

3. **Access** – Providing a raised berm will assist in gaining access.

4. **Collaboration** – Often sea walls protect more than one landowner and so being aware of one's neighbours and working with then with common solutions for shared problems is beneficial, e.g. shared access.

5. **Drainage** – An annual inspection should occur to ensure that surface water is captured and directed away from the earthworks, issues include; removing silt from the soke dyke; effective operation of outfalls; and infilling of ruts and local areas of settlement to avoid ponding of water. Special inspections after heavy rain would assist in identifying potential problem areas. A watch should be kept of the infiltration of soil or water through pipe joints, as this could create voids in the fill material and remedial works should be undertaken if evidence if infiltration is observed.

6. **Vegetation** – Regular cutting will enable the bank to be inspected for any signs of instability. Cuttings should be collected and removed so as not to damage the remaining vegetation. Trees and shrubs should be discouraged from growing on or close to the flood embankment. Shrubs in particular should be removed as they deprive the seawall vegetation of moisture and their presence increases the likelihood that badgers will take up residence on the seawall. Tree falls should be removed and any damage to the embankment repaired (root balls that can create seepage paths should be removed and the resulting hole reinstated with clay material).

7. **Animal damage** (including rabbit, badger and fox burrows) – Reference is required to the relevant legal obligations.

8. **Prevention of erosion** – Areas of erosion should be reinstated to prevent further deterioration and to maintain the stability of the embankment. The use of geotextile and rock armour can alleviate the risk of its reoccurrence.

9. **Settled areas** – Areas of settlement should be reinstated by removal of topsoil and benching in new clay material prior to reinstating the topsoil and grass coverage. If settlement continues the repair work will need to be repeated.

Good dated records of maintenance works undertaken as part of the asset management process should be maintained to capture problems, especially those reoccurring issues which may identify additional underlying problems.

9 Further reading

BS EN 13251. Geotextiles and geotextile-related products. Characteristics required for use in earthworks). British Standards Institution. 12-May-2011 (available to buy http://shop.bsigroup.com/)

BS 6031 Code of practice for earthworks. British Standard Institution. 2009 (available to buy http://shop.bsigroup.com/)

Caterpillar performance handbook edition 27. Caterpillar. (free download http://nees.ucsd.edu/facilities/docs/Performance_Handbook_416C.pdf)

Environmental good practice on site. Chant-Hall G, Charles P and Connolly S, CIRIA C650. 2005 (available to buy http://www.ciria.org)

Manual of contract documents for highway works volume 1 – Specification for highway works series 600 – Earthworks. Highways Agency (free download http://www.dft.gov.uk/ha/standards/mchw/vol1/pdfs/series_0600.pdf)

Management of flood embankments – a good practice review. Defra R&D Technical Report FD2411/TR1. November 2007 (free download http://evidence.environment-agency.gov.uk/FCERM/Libraries/FCERM_Project_Documents/FD2411_6509_TRP_pdf.sflb.ashx)

Protection of river and canal banks, Hemphill and Bramley, CIRIA B9. 1989 (available to buy http://www.ciria.org)

Revetment systems against wave attack – a design manual. McConnell K.J. Thomas Telford. 1998 (available to buy http://www.thomastelford.com/)

River and channel revetments – A design manual. Escaramia M, Thomas Telford. 1998 (available to buy http://www.thomastelford.com/)

Use of vegetation in civil engineering. CIRCA C708. 2007 (available to buy http://www.ciria.org)