Evaluating the Performance, Cost and Amenity Value of Timber & Rock Groyne Beach Management Structures: Deriving a Coastal Management Scheme for Central Felixstowe

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Introduction

Timber groynes have been used in UK beach management schemes for centuries whilst building groynes with quarried rock only began in the early 1980s. The capital costs of schemes using rock groynes are usually greater than for equivalent timber groynes. However, the current UK policy of appraising coastal protection schemes on the basis of whole life cost, i.e. including maintenance expenditure, means that rock groyne schemes can often be economically favourable over a 100 year period. As part of the Central Felixstowe Project Appraisal Report, a study to identify an appropriate long-term scheme to protect a 1.3km section of seafront, Suffolk Coastal District Council (SCDC) commissioned a review to compare timber and rock groynes. This examined the efficiency and performance of groynes constructed from timber, rock or hybrid materials alongside the cost of construction, maintenance expenditure, aesthetic value, sustainability and health & safety considerations.

Background

Groynes are shore-normal structures, i.e. oriented perpendicular to beach contours in the surf zone. Groynes are designed to alter longshore currents, reducing transport of beach sediments and changing beach plan-shape, which improves retention of beach sediment (Fleming 1990 & CIRIA 2010). The enhanced beach width can both create or improve an amenity function and can provide protection to backshore defences that may otherwise become exposed and vulnerable. A series of groynes along a coastline is known as a field of groynes.

The main design characteristics of a groyne scheme can be summarised by their:

- Length, i.e. distance from the crest of the beach to their seaward end;
- Spacing, i.e. distance apart along the shoreline; and
- Profile, i.e. the height of the crest of the groyne above the beach surface.

Note here that the length and especially the profile of any groyne, varies according to the changing profile and width of the beach. Generally in designing a groyne system, the length of groynes is measured relative to the intended beach crest position, e.g. after an initial recharge and subsequent beach reorientation.

Other groyne characteristics include:

- Permeability, i.e. the extent to which currents and sediment can travel through them;
- Orientation, i.e. some groynes are built at an angle to the beach; and
- Roughness or wave absorption, i.e. the extent to which they dissipate the energy of waves and currents they encounter, for example timber groynes may reflect wave energy, whilst rock groynes are more dissipative.

Once a groyne field is in place, beach material will collect against the updrift side of the groynes until the volumetric capacity of the bay is exceeded and the material collected spills into the adjacent bay. As beach material collects against the updrift side of the groynes, the beach orientation will tend towards the wave direction at breaking, forming a saw-tooth beach plan shape between the groynes (Figure 1), which will continuously realign according to prevailing wave conditions (Van Rijn, 2004).

Figure 1: A plan view of a typical timber groyne field showing a saw-tooth beach plan shape

As with the placement of any structure or obstruction on any shoreline within a zone of active littoral drift, a groyne scheme will cause impacts on the downdrift shoreline as a result of the reduced sediment input and these effects must be carefully considered. To reduce problems of beach erosion downdrift of the last groyne, the groyne bays should be recharged immediately after their construction. It may also be helpful to "taper off" groyne lengths in the downdrift direction where practicable.

Traditionally groynes in the UK have been constructed from a combination of timber, sheet piles and/or concrete. More recently rock, open stone asphalt, cribwork and plastic groynes have been trialled, with rock presently being the most prevalent construction material.

The use of timber groynes as beach control structures

Timber groynes have been used to manage beaches around the UK coastline for hundreds of years (Crossman & Simm 2004). Timber groynes are now more commonly constructed of tropical hardwoods such as Ekki and Greenheart rather than the more traditionally used woods such as Oak which have a shorter lifespan and are prone to cracking under the constant wetting and drying processes of the intertidal environment. One of the benefits of using timber is that it is relatively lightweight and has a good strength to weight ratio. Timber groynes also have a smaller overall footprint, when compared to rock groynes, which can prove more suitable for amenity beaches. However, timber can also contain natural flaws and the quantity of timber available in the required length is limited. Timber groynes can also be susceptible to damage by biological attack and abrasion, particularly on shingle beaches.

Timber above the beach level can be damaged by fungal decay and rot, whilst marine borers (molluscs or crustaceans which bore into and eat wood) can cause damage to timber below the beach level.

The design and detail of timber groynes affect their performance. Conventional straight timber groynes are constructed using piles and horizontal planking and occasionally vertical steel sheet piles are used to provide resistance to ground and wave forces. The spacing of timber groynes cannot easily be altered once they are constructed, since groynes need to be piled into the underlying substrate, which makes removal and adaptation of the structure more costly compared to rock groynes. The profile of most timber groynes can be modified by removing or adding planks, so improving their effects on beach levels. However, this requires frequent monitoring and intervention and since Coastal Management Authorities have limited resources for such maintenance this is no longer common practice. There are now many elderly, deteriorating and increasingly ineffectual timber groyne fields around the UK coastline

The use of rock groynes as beach control structures

In the early 1980s, the growing availability of durable rock and of plant large enough to transport and handle rock efficiently, led to an increased interest in building rock groynes. Although there are suitable UK sources, the two most popular materials used in modern rock groyne schemes have been Norwegian granite and French limestone which are very resistant to scouring by beach sediments under wave action and marine weathering.

Rock groynes are generally founded between 1.5m and 2m below the beach level (CIRIA, 2007) and their width increases the deeper they are founded, increasing the volume of rock required. The majority of the rock used should not move significantly under extreme storm conditions if the appropriate formula has been used to calculate rock size and the groyne has been constructed to industry standards.

Rock groynes have proved to be durable and, if built simply, their maintenance and any necessary adjustments to their profile should be less expensive than for timber groynes. If they eventually do need to be removed, this should also be easier, with fewer concerns about the dangers posed by any groyne remnants. Some of the rock should also be re-usable, increasing the sustainability of such groynes.

Relative performance of groyne fields

It is difficult to definitively compare the effectiveness of timber and rock groynes using field observations, since the groynes usually have different profiles and spacing even when they are installed on very similar beaches and subject to similar wave conditions.

For this reason, physical modelling was undertaken by Coates (1994) to compare the performance of rock and timber groynes on beach evolution. These tests were carried out for various groyne profiles using a variety of water levels and wave heights.

For each comparison, rock and timber groynes were built with virtually the same crest levels and lengths, only differing in that the end of the rock groynes sloped downward at 1:2 while the timber groynes ended vertically. The changes in beach widths and profiles under each wave and water level condition were then measured and compared to assess the effects of the different groyne types.

As an example of the results obtained, tests run with a (prototype) significant wave height of 2m showed that the beach profile just downdrift of the rock groynes retreated by 2m while for timber groynes the retreat was 7m. This difference was mainly attributed to the capacity of the rock groyne to absorb wave energy, so reducing turbulence and sediment transport close to it. In addition, the beach immediately updrift of each timber groyne was scoured by reflection of the large waves from its vertical face. These results supported the conclusions of an earlier modelling study (Coates and Lowe, 1993) in which it was observed that the difference in performance of rock and timber groynes became greater as wave heights increased.

Different beach plan-shapes between timber and rock groynes have also been noted during this study, though further work on comparable or adjacent frontages will be required to confirm these observations. Whilst timber groynes typically tend to produce the more classic saw-tooth beach plan shape seen in the example in Figure 1; rock groynes, perhaps due to their increased roughness, reduced reflectivity and their dissipation of wave energy, typically give rise to a different plan shape (as shown in the example in Figure 2). With rock groynes the minimum beach width tends to occur towards the middle of the groyne bay, as opposed to immediately downdrift of the groyne resulting in a curved or asymmetric bay-type beach.

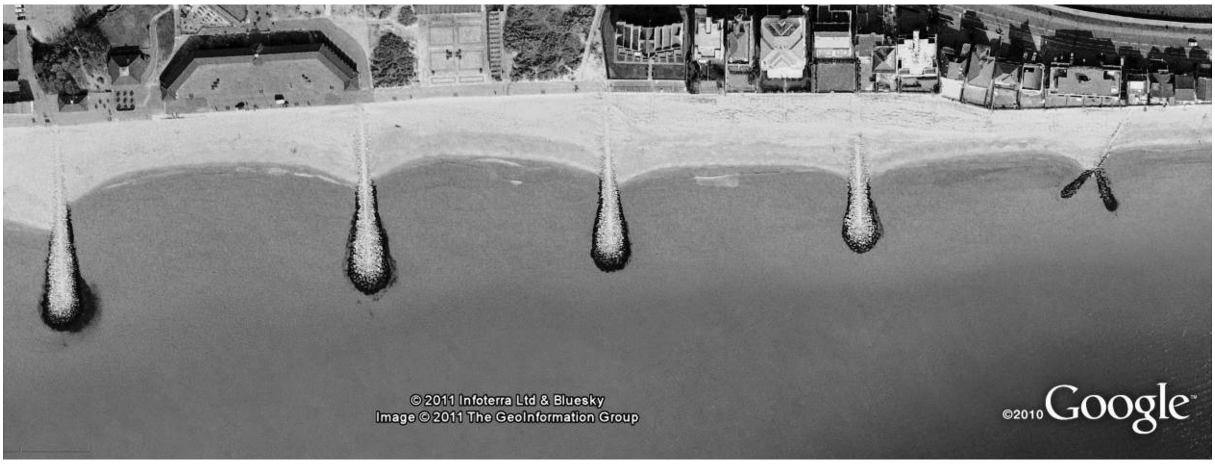

Figure 2: A plan view of a typical rock groyne field showing a curved beach plan shape

Deriving suitable beach control structures to assist in long-term coastal management at Felixstowe, Suffolk.

Felixstowe is an attractive Victorian resort on the Suffolk coast with a lively urban seafront environment, which is a key tourist attraction for East Anglia (East of England Tourism, 2009). The existing defences consist of more than fifty timber/concrete groynes from the War Memorial to Cobbold’s Point (see Figure 3), the original groynes were initially constructed over 100 years ago. Some have been repaired over the years by underpinning and/ or by placing rock on the beach adjacent to some of the groynes in order to provide lateral support. The backshore defence consists of a mass concrete wall topped with a promenade. In recent years, the dilapidated and increasingly ineffectual groynes have not prevented serious beach lowering; the subsequent loss of lateral support to the wall from the beach; and ultimately the undermining of the seawall. In some areas, as a short-term measure, rock has been placed in front of the seawall to provide extra lateral support.

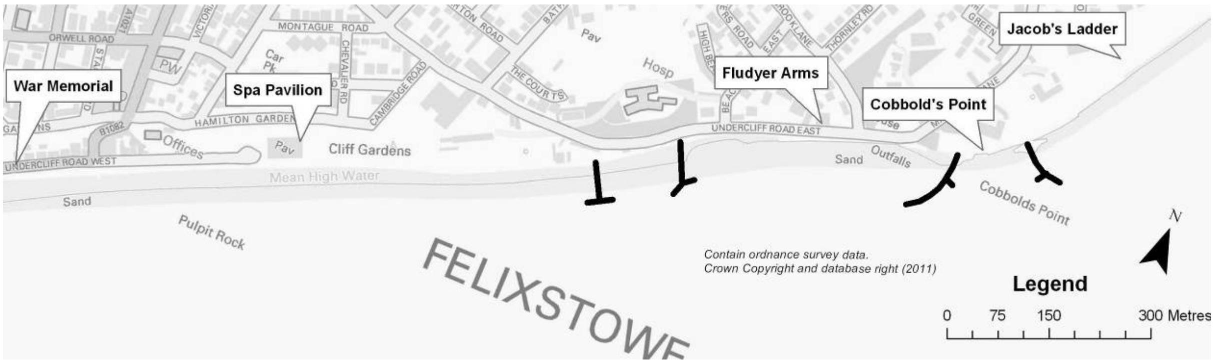

Figure 3: The Central Felixstowe frontage from the War Memorial to Jacob's Ladder

Central Felixstowe beach is a mixture of shingle and sand, with the majority of the shingle deposited on the upper beach. Owing to a drift divide around Cobbold's Point and a number of beach control structures little material now enters the site naturally. Through joint probability analyses design waves and water depths were derived: for example, a 1:100 year return period storm event has a nearshore water depth of 3.65m OD coupled with a significant wave height of 3.38m. The predominant wave direction approaches from an oblique angle, leaving a considerable angle between their crests and the seawall. To cope with this, groynes have been built close together with a typical spacing of 35m and typical length of 50m. Along the South Felixstowe frontage the beach has longer and more efficient groynes, including rock groynes only recently installed so that reducing the drift out of the Central Felixstowe frontage is likely to be less of a problem than in many cases where new groynes are being considered.

SCDC commissioned Mott MacDonald, with assistance from HR Wallingford, to produce a Project Appraisal Report identifying suitable coastal management methodologies for the next 100 years and to provide an application to the Environment Agency for funding of any initial capital works. Throughout the optioneering process for the Project Appraisal Report, Mott MacDonald undertook a costing exercise into timber groyne and rock groyne solutions for the frontage (Mott MacDonald, 2009).

The groyne design basis for the costing exercise assumes 50m long groynes at varying intervals (spacings) along the 1,300m long frontage of the existing groyne field from the War Memorial, Undercliff Road West to Cobbold's Point, Undercliff Road East.

Figure 4 shows the initial capital costs associated with timber and rock groyne fields at spacings of between 20m and 70m. Rock groynes require more expensive material, cover a larger footprint and require more labour for construction and when compared side-by-side the initial capital costs are greater. The assumptions made in preparing the costs were as follows:

- All costs are based on 2011 rates.
- The cost of the timber groynes was based on £1,714 per linear metre and for the rock groynes £3,384 per linear metre.

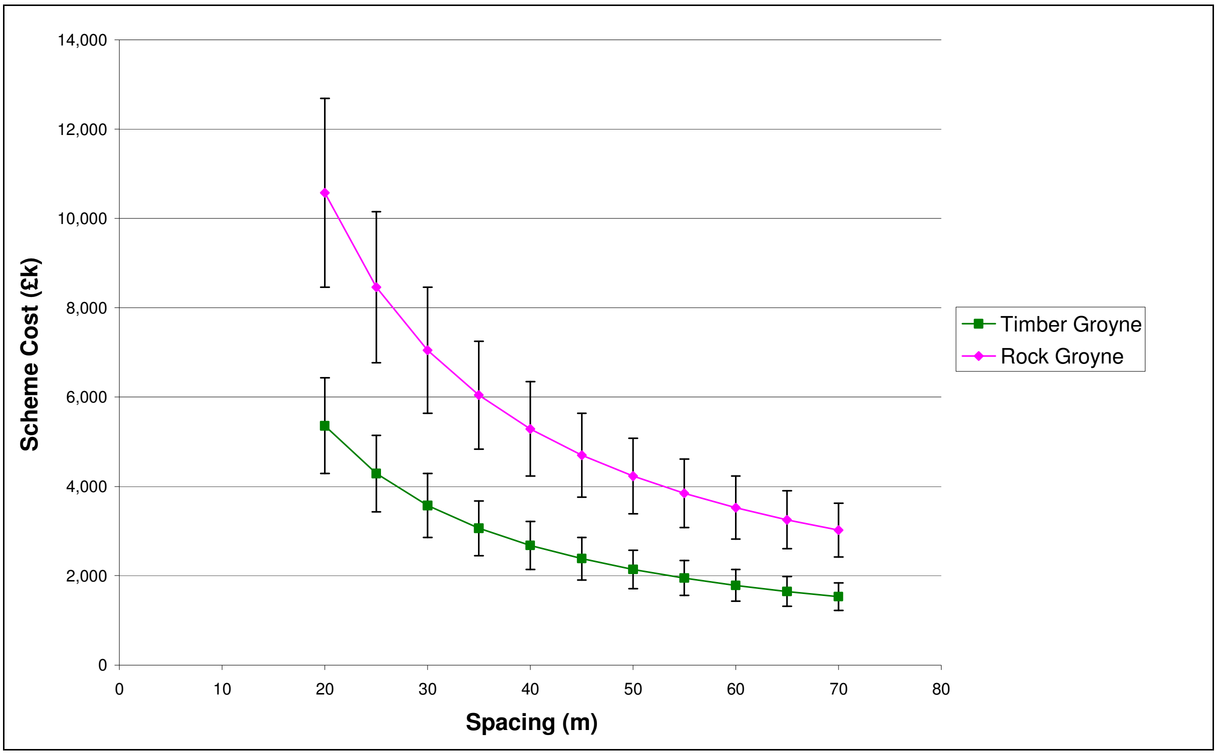

Figure 4 - Initial capital cost sensitivity of rock and timber groynes based on a 50m groyne length

Empirical review with Local Authority Coastal Managers to determine whole life costs for groyne schemes:

To improve the understanding of whole life costs of each structure type, Local Authority Coastal Managers responsible for the management of groyne fields across the south and east coasts of England were interviewed in order to obtain a first hand appreciation of timber or rock groynes on their frontages, as well as to understand typical issues, effective life and maintenance costs, which were comparable to issues likely to arise on the Central Felixstowe frontage.

Maintenance and expected lifetime

For timber groyne fields, Coastal Managers reported that annual maintenance is necessary to ensure continued effectiveness. Costs are heavily dependent upon the design of the timber groyne, the aspect of coastline, the type of beach material, meteo-oceanographic conditions and the position & spacing of the timber groynes along the beach. The average annual spend which Local Authorities reported for maintenance and repair of timber groynes varied between £500 and £2,000 per groyne. Two of the East Anglian Coastal Authorities interviewed reported that after 10 years in the intertidal environment the cost of groyne maintenance increased to between £7,000 and £8,000 per groyne, per annum. This increased cost relates to the groyne design which in both cases included sheet piling, the exposed nature of the sites and the abrasive and coarse shingle beach material at both of the frontages.

Few Authorities reported having undertaken any maintenance on rock groynes. In one instance, no maintenance had been necessary on a rock groyne field since initial construction 15 years ago. Another Authority reported undertaking repair works costing *ca.* £1,000 per groyne following a severe storm 8 years after construction.

The reported useful life of a timber groyne is significantly shorter than for a rock groyne for an exposed coastline. Rock groynes are assumed to have a 50-year design life and at the end of this period much of the material used in the initial installation can be re-used in a renovated scheme. Timber groynes for an aggressive wave environment and predominantly shingle beach are likely to have a maximum design life of 25 years, even when coupled with annual maintenance, to ensure continued effectiveness.

Sustainability

The predominant sustainability issue for both timber and rock groynes relates to the source of the materials. Whilst hardwood used for timber groynes can originate from certified plantations, Local Authority managers reported some uneasiness associated with the acceptability of using such a valuable and sensitive resource. The removal and disposal of obsolete timber groynes can prove problematic when the scheme reaches the end of its useful life. Though rock is not considered as scarce a material as a tropical hardwood, rock also has some sustainability issues associated with transport distances and extraction methods. However, in general, rock groynes were considered more sustainable than tropical hardwood timber groynes and the rocks have the added benefit of being more easily re-usable in any future re-configuration or renovation of the existing scheme, or for re-deployment in any future coastal protection scheme.

Attractiveness and amenity considerations

Both groyne types have different visual and amenity considerations, though such an appraisal can be rather subjective. The footprints of timber groynes are smaller, which means that more beach surface remains available for use by holiday makers (termed 'carrying capacity' in Spain). Timber groynes are often perceived as part of the traditional image associated with UK beaches. Rock groynes, however, have proved attractive to visitors, especially children investigating the marine plants and animals that the groynes host. Rock groynes have the added benefit of allowing the construction of a walkway along the top of the groyne thus allowing access along the groyne to less-abled people.

Health and Safety

Health and safety concerns have been reported for both rock and timber groynes. From the information provided by a number of Local Authorities, rock groynes appear to have a number of risks associated with them, but this is a general perception and is often anecdotal. However, appropriate signs and walkways along the top of rock groynes can reduce the risk of accidents. In one case study, particular care was taken with the construction of the rock groynes to reduce the number of large voids between individual large rocks which has proven successful in reducing health and safety concerns.

Costs

Whole life costs for a groyne field in Central Felixstowe were derived from the observations made by Local Authority Coastal Managers. The whole life cost of rock and timber groynes is presented in Figure 5. The assumptions made in preparing the costs were as follows:

- Timber groynes are considered to require full replacement every 25 years, whilst rock groynes have been considered with 25% replacement at year 50. These are both conservative estimates and with due maintenance both groyne fields could last longer.
- The costs include annual maintenance for timber groynes at a rate of £1,000 per groyne. This value was based on a low average maintenance cost of a variety of Local Authorities participating in the research.

- The maintenance for rock groynes was based on £5,000 per groyne every 10 years (i.e. £500 per groyne per annum).

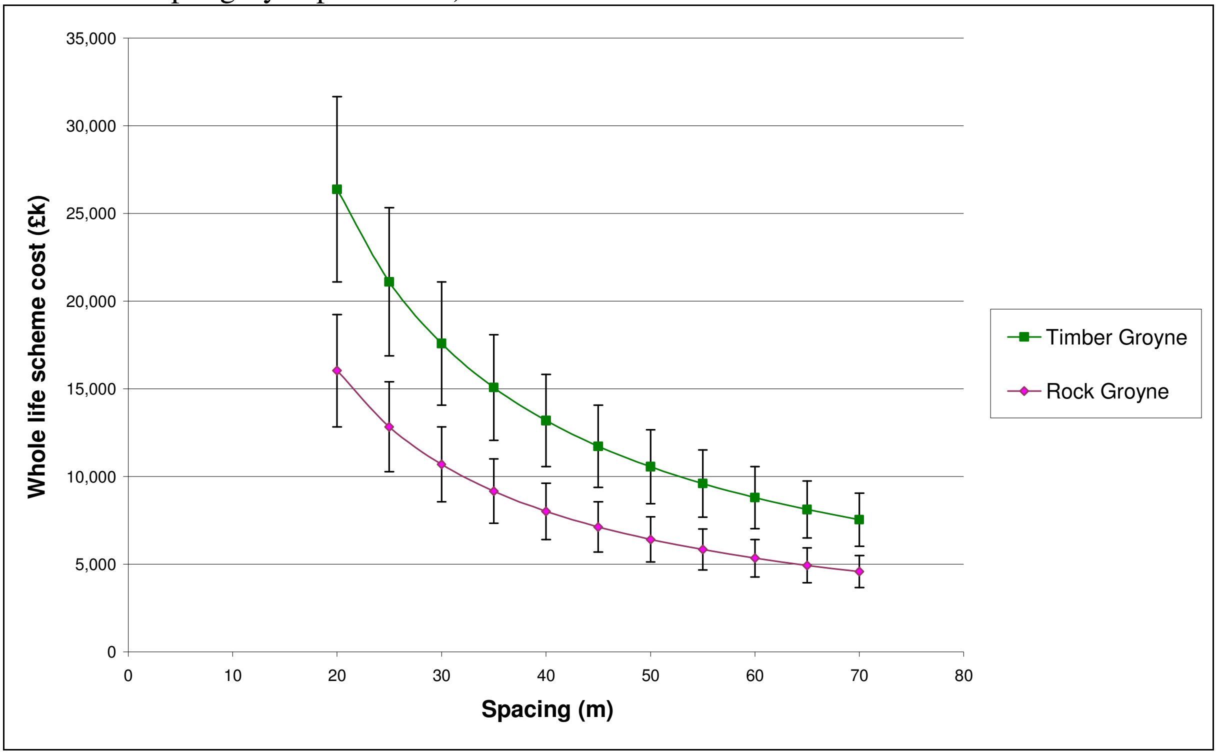

Figure 5 - Whole life costs of rock and timber groynes over 100 years for the Central Felixstowe frontage

Under these assumptions, Figure 5 clearly demonstrates that rock groynes have a reduced whole life cost when compared to equivalent timber structures at equivalent spacings. In addition to the whole life costing undertaken on a like-for-like basis, it was noted from the review that rock groynes are generally more widely spaced than timber groynes on the same frontage. The footprint of rock groynes reduces the size of the internal bay between groynes and additionally, anecdotal evidence has demonstrated that dissipative groyne structures such as rock groynes may be spaced further apart due to the lower reflection of wave energy within the groyne bays.

Areas identified for future research

Throughout this investigation and optioneering process it has become evident that there are significant gaps in scientific understanding of groyne behaviour, which could better inform the design, management and use of groynes. Two areas of further research were identified from this review:

- Empirical data collection and analysis of existing groyne systems and laboratory-based physical modelling observations, comparing different groyne construction materials. This will allow improvements in understanding behaviours/efficiencies obtained using different construction materials and to provide information for improving representation of groyne systems in numerical models.
- Anecdotal evidence has identified that dissipative groyne structures (such as rock groynes) can be more widely spaced when compared to timber groynes. However further scientific investigations and design guidance still need to be developed.

Dynamic systems require sustainable solutions to allow for adaptable management

During design of the beach management works for Central Felixstowe the Project Team used the data collated from the empirical review of Coastal Management Authorities to set out likely management actions required for the scheme over the next 100 years. However, there remains considerable uncertainty about future wave conditions e.g. as a result of climate change, particularly in mean wave directions and in the occurrence of storms. A changed wave climate will result in a change in beach behaviour. There is also considerable uncertainty regarding the amount and timing of maintenance that might be needed, relating not only to future wave and current climate, but also to future labour and material costs and likely future availability of funding.

The team concluded that a preferred scheme should be resilient to uncertainties in both the meteorological and financial climates in the coming decades.

Coastal protection based on the concept of maintaining a healthy beach is often the most economical, sustainable and environmentally acceptable way of reducing flooding and erosion risks to acceptable levels. A combination of groynes and beach recharge is therefore often preferable to building inflexible structures such as seawalls (and particularly so for a resort such as Felixstowe). In the longer term beach management through beach material recycling may be considered to counter the effects of long-term net drift or localised beach lowering problems, e.g. in individual groyne bays. Groyne scheme design, however carefully undertaken, may not prove optimal against climatic changes and could be improved by adjustments guided by long-term monitoring and experience, thus an adaptable solution was considered preferable.

Conclusions: the proposed coastal management solution for Felixstowe

On the basis of the whole life costing information, coupled with extensive public exhibitions and stakeholder engagement events, the Project Team put forward a Project Appraisal Report proposing a series of 18 straight rock groynes and 80,000m^3 beach recharge for the Felixstowe frontage. SCDC recognised that rock groynes would be more appropriate for the aggressive wave climate experienced here and valued the opportunity to be able to manage/alter the rock groynes, as required, over the 100-year life of the scheme. Through model testing and scheme refinement, the groynes designed for the frontage vary in length between 35m and 65m.

The Project Team at SCDC were keen to implement a groyne solution that physically met with the seawall at the back of the beach, as any gap between the end of the groyne and a hard backshore defence could result in outflanking and severe scour during extreme storms (as highlighted in CIRIA, 2010 & Coates, 1994). However, it was also necessary to ensure plant access between each groyne bay to allow for long-term management of the beach, since the promenade was not suitable for carrying heavy plant. In order to meet both of these objectives the Project Team derived a rock groyne design incorporating a 7m section of timber groyne towards the landward end of the structure. This allows for a 5m wide plant access bay when the timber planks are removed but when cross-planks are securely in place prevents outflanking and reduces potential for scour at the landward end of the groyne under storm conditions. An example sketch is presented in Figure 6.

The scheme will provide the people of Felixstowe with the ability to sustainably adapt and easily manage their coastline to 2110 and beyond.

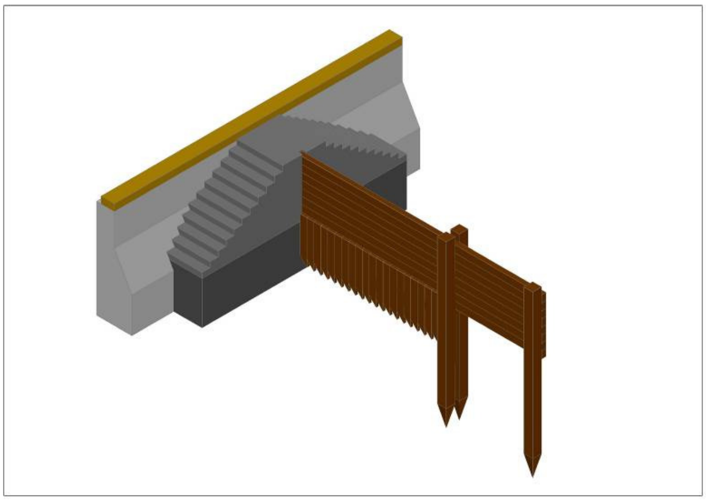

Figure 6 – An example visualisation showing a timber groyne root to close any gap between a rock groyne and the promenade. Steps are included to allow access.

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