Application of timber groynes in coastal engineering

M.Sc. Thesis
U.H. Perdok
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HR Wallingford

TU Delft
Delft University of Technology

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Cover picture:
Severely abraded timber groyne at
Bexhill, East Sussex, UK (April 2002)

Preface

This thesis presents the results of my graduation project and will lead to the completion of the Masters of Science degree in Civil Engineering at the Faculty of Civil Engineering and Geosciences, Delft University of Technology (The Netherlands). With this thesis I hope to provide with guidance on the use of timber groynes in coastal engineering and to promote the appropriate use of available timber.

I was privileged to execute the major part of this research project at Hydraulics Research Wallingford (United Kingdom) during a six-month placement period. While working on the “Manual on the use of timber in coastal and fluvial engineering”, I had the opportunity to learn from the experience of contractors, consultants, local authorities and timber specialists.

As this report is largely based on their experience, I would like to thank the following people for their cooperation: Simon Howard and John Andrews (Posford-Haskoning), Andrew Bradbury (New Forest District Council), Brian Holland (Arun District Council), David Harlow (Bournemouth Borough Council), Stephen McFarland (Canterbury City Council) and John Williams (TRADA).

Finally, I would like to thank Matt Crossman and Jonathan Simm for inviting me to Hydraulics Research Wallingford where I was able to carry out my thesis program.

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Delft, December 2002

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Summary

Beaches constantly change as they respond to natural processes including waves, currents and the wind. These processes can result in material being transported from the beach, which, if not replaced by material from adjacent areas, will result in erosion.

Groynes are structures constructed more or less perpendicular to the shoreline to restrict the movement of sediment along the shore. They usually work in two ways, by providing a physical barrier to the movement of the beach material, which enables the beach to re-orientate approximately perpendicular to the incident wave direction, and by diverting longshore currents (which may be caused by tides or waves) away from the beach. However, groynes cannot prevent cross-shore transport of sediment and because they only interrupt the longshore drift, the erosion problem is simply moved to a location downdrift of the groyne field.

Timber groynes (see Figure 1 below) can provide substantial advantages over other forms of groynes or alternative beach control structures. These include the relative ease with which the level and profile of the groyne may be adapted (by adding or removing planks) or maintained, and their appearance and small footprint are particularly advantageous on amenity beaches. The use of timber may also offer lower whole life costs and environmental advantages over alternative materials.

Figure 1. Timber groyne (Eastbourne)

The performance and durability of timber groynes is highly dependent on the design and detailing of the structure. In the past, groyne design was often limited to the slightly improved replacement of existing structures, partly because there has been little formalised documentation of best practice.

There are many types of groynes, varying in length, height, shape, spacing, alignment and permeability. The “conventional” straight groyne is constructed with piles and planking and often making use of sheet piles to provide passive resistance to ground and wave forces. Alternative groyne types include permeable pile screens, consisting of single or double rows of timber piles, with a spacing of

approximately their diameter. They reduce longshore currents but provide much less of a barrier to the movement of beach material. As a result permeable pile screens are normally less effective at retaining beaches, but do not create such severe erosion downdrift.

Different concepts may provide appropriate solutions for particular locations. In a low wave-energy environment, a combination of recycled and local timber can be used to construct groynes. Although these structures have a limited lifetime and high maintenance commitments, their low capital cost makes them an attractive option in some situations.

Functional design
When designing a groyne system it is important to have an understanding of the coastal processes responsible for erosion along a beach section. When designing effectively for a specific situation and location, an optimal functioning and thus performance can be obtained.

Structure and overall stability
The starting point for most timber groyne structures is the use of single cantilever piles. Depending on the operating conditions it is sometimes necessary to modify or supplement this approach with other techniques such as planting the posts in concrete or the use of ties or props.

Members and connections
All fixings are exposed to severe wear and oxidation. Therefore as few bolts or coach screws, as possible should be used, these never being placed in the same grain line of the timber. Galvanised steel fixings are commonly used but stainless steel fixings have the advantage that the groyne can be dismantled or refurbished more easily and the fixings can be reused.

Finishes and fittings
When driving timber piles, the end fibres have the tendency to separate (broom) at both the head and toe of the pile, resulting in a loss of structural strength. Pile rings and shoes can be fitted to protect the head and toe of the piles.

Health and safety
The role of the designer is to design in such a way as to eliminate or reduce risks to the health and safety of those who are going to construct, maintain, repair, demolish, or clean any type of structure. The remaining risks should be as few and as small as possible. Contractors must be aware of the hazardous environment they are working in, often operating with heavy machinery on unstable beaches within the tidal range.

Natural environment
To protect piles from abrasion, softwood or recycled timber rubbing pieces can be attached to the piles at critical levels. Extending planks beyond piles may also reduce wear, increasing the life of the pile. Members should be sized with an allowance for wear and the connections carefully chosen. On some sand beaches ply panels have been fixed to the groynes preventing sand being transported between the planks, thus minimising abrasion, which increases dramatically with the size of the gap. Reuse and recycling of timber can substantially reduce the need for new timber, and should be incorporated in the design and maintenance of structures.

Construction
Constructing a groyne scheme involves great expertise of the contractor, as the precise work is carried out under harsh circumstances allowing minimal tolerances. Prefabrication of elements such as panels of sheet piles, fixed near or below low water, can increase safety and improve the quality of construction. Prefabrication may also enable the use of preservative treated timbers and minimise waste.

Maintenance
Groynes should be adjusted to the optimal height, matching to the changing beach profile, preferably several times throughout their lifetime. In some cases extending groynes to the preferred height may be an attractive solution instead of rebuilding an entire groyne. On the other hand, when constructing a groyne, an allowance may be provided in the pile length for extra planking.

Timber groynes have proven to be an attractive solution to manage beaches in many locations throughout the world. However, they are only effective when longshore transport of beach material is the cause of erosion.

Figure 2. Old and badly maintained groyne (Norman's Bay)

Contents

1. INTRODUCTION

Hydraulics Research Wallingford is leading a research project with the purpose to prepare a manual for the use of timber in coastal and fluvial engineering. The team involved in this research project includes clients, consultants, contractors, timber specialists and suppliers. Industry and government, under the Partners in Innovation programme of the Construction Directorate of DTI, have jointly funded the project. It will lead to the publication of a guidance manual in early 2004.

This report concentrates on the use of timber groynes in coastal engineering, and has been written as part of the total project "The use of timber in coastal and fluvial engineering". Current information is brought together and case study analysis has finally resulted in guidance for the design of timber groynes in coastal engineering.

1.1. General

Timber has traditionally been used for the construction of a wide variety of coastal and fluvial structures including groynes, jetties, lock gates and riverbank protection throughout the UK. As a renewable resource it has the potential to be an environmentally responsible material option, if recycled or obtained from sustainable managed forests. However, negative publicity surrounding logging (particularly of tropical forests) and an increasing reliance on alternative materials has led to a belief that the practical, environmental and aesthetic advantages of timber are not being fully exploited.

There are a number of characteristics that make timber an attractive choice of construction material:

- Potential to be an environmentally responsible material as it is a renewable resource, which can be sustainable if managed properly.
- Relatively lightweight, with a good strength / weight ratio and easily handled because of its weight.
- Good workability allowing on site repairs and recycling.
- High tolerance of short duration loads.
- Attractive appearance and (to a greater or lesser extent) natural durability.

However, there are also a number of potential drawbacks associated with the use of timber:

- Timber is a natural material with inherent flaws and variability in properties.
- Timber with particular properties (very large section sizes, long lengths or high durability) required for some engineering purposes is only available in limited quantities from particular species.
- Local species of timber are only moderately resistant to the marine environment and are susceptible to biological hazards.
- Most species of timber used in engineering applications are only renewable over a relatively long timescale, making it difficult to demonstrate sustainability.
- Few sources of tropical hardwoods are currently certified.

Much of the marine work traditionally requiring timber for wharves, piers, sheet piling and cofferdams is now undertaken using concrete or steel products, or both. There are several reasons for this, including the increasing scarcity and cost of good-quality timber of the types traditionally used, such as Oak, Ekki or Greenheart. Nevertheless, there are many applications where it is still an economic preposition to use timber for marine construction purposes. Timber groynes are a good example of this. These are fence-like structures, built perpendicular to the coast with the aim to trap and retain beach material.

Because beach profiles continuously change, groynes should be continuously adjusted too. In the Netherlands groynes have mostly been constructed of rock. It is self-evident that repositioning, repairing or adjusting timber groynes is less costly than rock groynes. This however does not mean that the Dutch would be better off constructing timber groynes, as choosing the appropriate structure depends on many factors, including the location's erosion problem and beach material.

Many other coastal management structures using timber can be found around the world, such as placing rows of timber piles on top of a rock groyne. More common are one or more rows of timber piles driven directly into the beach, a solution of which its success may be questionable. An impermeable structure may be constructed using a combination of materials. A double row of timber sheet piling can be filled with sand, gravel, earth or stone with the top layer consisting of rock or rubble preventing washing out of the smaller material.

Throughout the UK, traditionally impermeable timber groynes are constructed, but little is known about best practice design or structure detailing. The tuning of groynes (length and mutual spacing ratio) is another difficult problem. As different authorities are responsible for the coastal defence structures along the UK coast, seldom any exchange of ideas has taken place. By combining the experience of several schemes, the guidance on designing durable timber groynes can be optimised.

1.2. Objectives

Due to natural processes like tide and waves, coastal areas are continuously subject to change. Longshore currents cause erosion to sand or shingle beaches, and sometimes a retreating coastline is a fact. The purpose of groynes is to trap sediment that moves through the littoral drift system, thereby maintaining beach in areas that would otherwise experience erosion. Given the proper length, elevation and spacing, groynes will permit sediment to accumulate until the groyne field is buried. Sediment will then bypass the buried groyne without causing significant downdrift erosion, with the exception of some temporary erosion caused by major storms.

The purpose of this research project is to provide with guidance on the optimal design of durable timber groynes, which perform successful within a groyne field.

Therefore this thesis is aimed at the following objectives:

- To document best practice
- To provide guidance on the use of timber groynes, from a functional and technical point of view
- To promote appropriate use of available timber

1.3. Scope of this report

C*hapter 2* discusses coastal groynes, starting with their functions and the types of groynes. In order to understand how groynes work the erosion problems and sediment transport processes are briefly described. Further this chapter deals with the morphological processes that take place once a groyne field is constructed, the loading on a groyne and current guidance for the design of a timber groyne.

Chapter 3 provides details on timber and its use as a construction material.

Chapter 4 presents six case studies, giving examples of different groyne fields along the UK coast and briefly describing good and bad practice for each of the schemes.

Chapter 5 brings together the best practice of the case studies and may serve as a guidance on the structural design of timber groynes in coastal engineering.

Finally *chapter 6* gives conclusions and recommendations for the application of timber groynes in coastal engineering and summarises the issues mentioned in the previous chapter in a decision tree.

2. GROYNES AS A SHORE PROTECTION STRUCTURE

2.1. Coastal groynes – a brief introduction

Beaches constantly change as they respond to natural processes including waves, currents and the wind. These processes can result in material being transported from the beach, which if not replaced by material from neighbouring areas, will result in erosion. Groynes are constructed more or less perpendicular to the shoreline to restrict the movement of sediment along the shore. An advantage of groynes over other hard methods is that they provide protection to the coast without fundamentally altering the characteristics of the surf zone. Wave height and length remain the same before and after construction, leaving this aspect of coastal dynamics unaltered. Methods such as offshore breakwaters protect the coast by reducing wave energy, thereby causing additional changes in coastal dynamics.

A groyne system is made up of a number of individual groyne structures, usually of similar length and spaced at regular intervals along the shoreline. Groynes usually work in two ways, diverting or intercepting longshore currents (which may be caused by tides or waves) and often also providing a physical barrier to the movement of the beach material. The shore between the groynes will orient itself more or less parallel to the approaching wave crests. Beaches already nearly parallel to the approaching wave crests can be adequately protected by rather widely spaced groynes, if a longshore transport of sediment is the problem at all. Sometimes groynes must be placed at intervals along the shore about equal to their length, occurring when the predominant waves run ashore under an angle. Since the construction of groynes is expensive, it is important that they are properly spaced.

Groynes only interrupt the longshore drift and cannot prevent cross-shore transport. Often the erosion problem is simply moved to a location downdrift of the groyne field. By stabilising a portion of a beach the erosion problem can be concentrated elsewhere in a (smaller) beach segment where, possibly, it will not be harmful. Groynes can be designed to allow some sand to spill around or through the structure to minimise downstream erosion.

Generally groynes have been constructed with a straight body, although zigzag shapes as well as straight ones with Y-, T- and L-shaped heads have been used. Rock, concrete and timber are the most common used materials. Timber groynes are fence-like structures, and can often provide substantial advantages over other forms of groynes. These include the ease with which the level and profile of the groyne may be adapted (by adding or removing planks), ease of maintenance and their appearance.

Traditionally, the design of groynes has been based on simple rules derived from experience of successful schemes, on lessons learned from failures and on relatively unsophisticated assessment of littoral drift.

The Dutch have been protecting their sand coasts for centuries, using various types of coastal structures. The majority of the groynes were impermeable timber structures, but impermeable groynes have been constructed using timber piles, placed in a single or double row. By the end of the 18th century rock structures were built replacing the timber ones, as most timber was destroyed by the shipworm.

In the southern part of The Netherlands "pile row groynes" are still used, consisting of a row of timber piles, with a spacing of approximately their diameter. Permeable pile screens deserve serious consideration as a first flexible and cheap phase in combating coastal erosion (Bakker, 1984), however it may be questionable whether permeable groynes function well in exposed coastal locations. In some cases a pile groyne is constructed on top of a rock structure, combining effective aspects of both structures.

In the UK, fishing quays and harbour breakwaters acted as coastal groynes long ago. Other early examples are the discharge of stone ballast from sailing ships or the dumping of waste on the shore. Since the sixteenth century groynes have been indicated on charts in England. General rules governing the construction can be found from documents available since the very early nineteenth century.

2.2. Types of timber coastal groynes

The overall configuration of a groyne field is mainly determined by the characteristics of the beach they are intended to control. Beach characteristics include its profile, material, and its likely change in plan shape under storm conditions. There are many types of groynes, varying in length, height, shape, spacing, alignment and permeability.

Impermeable groynes

The "conventional" straight groyne is constructed with piles and planking and often making use of sheet piles to provide passive resistance to ground and wave forces. In order to retain its impermeability regular maintenance is required, to for example repair any gaps between planks. Composite structures using steel sheet piling or concrete at lower levels and timber for the upper part have been used successfully too.

Figure 3. Conventional impermeable timber groyne (Bournemouth, UK)

Permeable groynes

Permeable groynes may be used on beaches that have adequate supply of sediment. Common structures are pile groynes, consisting of single or double rows of timber piles, with a spacing of approximately their diameter. The spacing between the piles is dependent on the volume of littoral drift and the size of the beach material. They reduce longshore currents but provide much less of a barrier to the movement of beach material, so the beach shape is more uniform. As a result permeable pile screens are normally less effective at retaining beaches, but on the other hand do not create such severe erosion downdrift.

Figure 4. Pile row groyne (Ameland, The Netherlands)

Low cost groyne

There is a wide range of different timber groyne concepts, which provide appropriate solutions in particular locations. At Calshot (UK), along the Solent in the lee of the Isle of Wight, a combination of recycled and local timber have been used to construct zigzag shaped groynes. Although these structures have a limited lifetime and high maintenance commitment, their low capital cost makes them an attractive option in some situations.

Composite structure

Another groyne type using timber, sometimes used as breakwater, consists of two sheet pile walls. The space between the sheet piles is filled with sand, gravel, earth or stone. To avoid the finer material to wash out, rubble or rock is placed as a top layer.

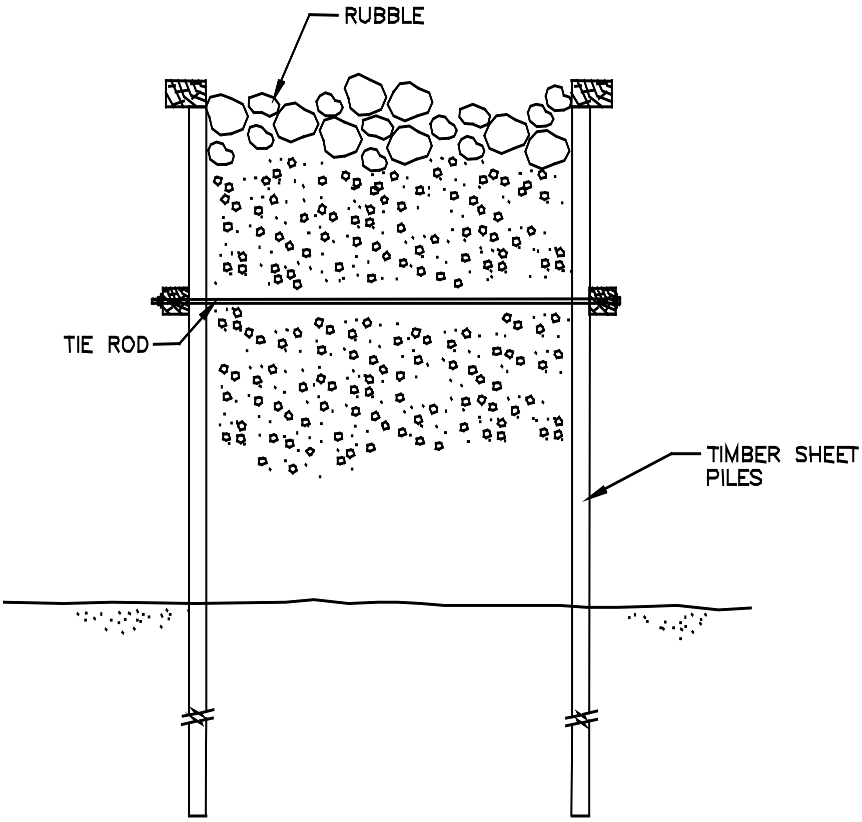


Figure 5. Filled sheet pile groyne

Pile row structures and timber groynes usually have a relatively low initial cost since the volume of materials required is small, materials are often readily available, and construction is usually faster than for comparable rock structures. However, the service lifetime of these structures is often shorter, and therefore the life cycle cost may be comparable.

On the Dutch Wadden shallows in the northern part of The Netherlands another concept is used, encouraging the deposition of sand, mud and silt. Using locally grown material, such as willow, "accumulating faggots" are constructed, trapping sediment by their filtering action. These faggot structures are briefly discussed in Appendix 3.

2.3. Functions of coastal groynes

Groynes are used to manage or control beaches. If successfully controlled, a good beach is the best form of coastal defence because it combines optimum hydraulic performance in terms of dissipating wave energy with an environmentally attractive amenity. Beach material close inshore is continuously being moved around by wind, wave and current action. This littoral transport is classified separately as longshore and cross-shore movement and is discussed in Section 2.4. Constructing a groyne field along the shore may retain coasts suffering from erosion due to longshore sediment transport. Groynes primarily influence the morphological development of a beach, and are not the coastal defence itself. The objective of a groyne system is to stabilise a stretch of beach against erosion.

The main function of a groyne system is to:

- Prevent or slow down the alongshore drift of material
- Build-up material in the groyne bays

They achieve this by:

- Intercepting wave induced currents
- Deflecting strong tidal currents away from the shoreline
- Serving as a barrier, to enable a beach section to reorientate itself

In some specific situations groynes may also be used to:

- Hold artificially nourished material on a beach that has no natural supply
- Control seasonal shifts of material alongshore and hence swings in shoreline within a bay
- Accumulate beach material in front of hard beachheads such as sea walls, revetments, bulkheads and cliffs
- Improve the extent and quality of an amenity beach
- Increase the depth of beach material cover to an otherwise erodible seabed soil

The Shore Protection Manual (1984) summarises the functional design of groynes with the following eleven rules:

Rule 1 If cross-shore sediment transport processes are dominant, consider nearshore breakwater systems first. Groynes can only trap longshore transport, and have hardly any effect on the onshore-offshore transport of sediment.

Rule 2 Conservation of mass for transport of sediment alongshore and cross-shore means groynes neither create nor destroy sediment. Because groynes trap beach material at a specific location, it will not be added to the adjacent shoreline, usually causing erosion at that location.

Rule 3 To avoid erosion of adjacent beaches, always include a beach fill in the design. If the groyne bays are filled directly after construction littoral transport will bypass the system.

Rule 4 Agree on the minimum, dry beach width for upland protection during storm events as a measure to judge success. Beach profiles continuously change, and a summer profile will give a too optimistic impression of the effectiveness of the groynes.

Rule 5 Begin with X_g/Y_g=2-3 where X_g is the longshore spacing and Y_g is the effective length of the groyne from its seaward tip to the design shoreline for beach fill at time of construction.

Rule 6 Use a modern, numerical simulation model to estimate shoreline change around single groynes and groyne fields.

Rule 7	Use a cross-shore, sediment transport model to estimate the minimum, dry beach width, Y_{min} during storm events.
Rule 8	Bypassing, structure permeability and the balance between net and gross longshore transport rates are the three key factors in the functional design. Use the model simulation to iterate a final design to meet the Y_{min} criterion.
Rule 9	Consider tapered ends, alternate plan forms and cross sections to minimise impacts on adjacent beaches.
Rule 10	Establish a field monitoring effort to determine if the project is successful and adjacent beach impacts.
Rule 11	Establish a “trigger” mechanism for decisions to provide modification (or removal) if adjacent beach impacts are found non-acceptable.

These eleven rules give a good first impression of the uncertainty of designing a successful coastal management system. In Section 2.7 more currently documented functional design is discussed, after which in Chapter 5, after having studied six schemes at various locations in the UK, it will be reviewed and supplemented.

2.4. Erosion problems

2.4.1. Erosion assessment

Coastal erosion is becoming an increasing problem all over the world. Before grasping to solutions trying to stop the erosion in a specific location, the cause of erosion must be found for that location. Therefore it is important to understand how sediment is moved. This section gives an introduction to some fundamental concepts.

The different types of erosion may be split up into two groups:

- Erosion having natural causes
- Erosion resulting from human interference

Natural causes of erosion may include the natural change in sediment supply, environmental forces (including climatic changes) and relative sea level rise. The various natural causes have different time scales. Storms may occur seasonally, sand spits may grow in a few decades and the time scale at which sea level rise occurs involves centuries. Human caused erosion may include the removal of beach material, stopping or changing direction of sediment movement and damage to dune vegetation due to recreational activities.

It must be remembered that erosion is only a problem when it interferes with human activities along a coast. The process of coastal erosion will at a certain time find an equilibrium stage by redistributing sediment along the shorelines. The “do-nothing” strategy must therefore be considered first of all.

To identify the cause of erosion at a certain location, not only the problem area itself must be investigated, but also a much larger area along the neighbouring coasts. Secondly this snapshot study of an eroding coastal section must be placed in its historical context, again involving a large area, by a historical survey.

Snapshot survey

For the snapshot survey measuring and viewing a coastal section together with understanding the coastal processes may possibly find the erosion causes. Looking at the beach and dune profiles can give indications of what the problem might be. Investigating coastal forces such as currents, winds and waves will help understand the processes.

Historical survey
This survey gives a comprehensive view of the historical movement of the coastline. Using maps, aerial photographs and all other possible historical information, the evolution of the coast can be determined to ultimately understand why erosion occurs. To avoid inaccuracies, vegetation lines should be used rather than the waterlines on maps and photos. As the time scales involved with some erosion cycles may well exceed a number of decades, the historical survey may not give the true picture of an erosion trend. In some cases a further detailed analysis will be necessary. Measurements including beach cross-section profiles, the bathymetry of the nearshore zone and grain sizes are needed.

Only after possible causes have been found for coastal erosion, the possible solutions should be considered. Erosion takes place when sediment is removed from an area, transported by the wind or by the water. Transport by water is usually the main cause of coastal erosion, and is discussed in the following section. Beach or dune erosion caused by the wind, sometimes may necessitate measures to be taken. In Appendix 2 the use of dune fencing, constructed with natural materials such as timber, is briefly described.

2.4.2. Sediment transport

Sediment transport plays an important role in many coastal engineering problems. If the volume of sand that enters an area is smaller than the volume that leaves the area, erosion will take place. On the other hand, accretion will occur if more sediment is brought into the area than leaves the area. In a coastal zone both waves and current are of importance for the sediment transport.

The total transport in a certain direction is found by adding up the transport at each level in the water. As the transport largely differs at each level, it is difficult to measure the precise amount of sediment transport.

In general the sediment transport processes can be divided into three stages:

- The stirring-up or the loosening of bottom material
- The horizontal displacement of these particles by the water
- The re-sedimentation of these particles again

Each stage depends on the water movement and the sediment characteristics. The water movement is basically different for currents only, for waves only, or for both waves and currents together. Important factors in sediment transport are the sediment characteristics. The main characteristics are the diameter and the mass density. When water flows over a beach, the currents will cause horizontal and vertical forces on the particles. In order to initiate a sediment transport, the fluid stresses have to overcome the particles' threshold of movement. Obviously shingle has a larger threshold of movement than sand.

Modes of transport

The horizontal displacement may be divided into three modes of transport:

- Bed load
  In this case, the material rolls and jumps along the bottom, its weight being carried by the bed. The moving particles collide with those still on the bottom, often initiating movement of those particles again. The layer, in which bed load transport takes place, is only a few times the particles' diameter thick.
- Suspended load
  In this mode the water carries the weight of the particles. The friction between the fluid and the particle is entirely responsible for the transport.

- Sheet flow
  If the water motions, and thus the resulting stresses on the particles exceed a certain value then the ripples on the seabed may be washed away. A thin layer with a high concentration of particles will result in a considerable amount of transport.

Which mode of transport takes place is primarily dependent on the intensity of water movement. Generally at first there will only be bed load, and small ripples will start to form. If the velocity of the water increases, the ripples will increase in size and particles will be brought into suspension. If the current increases even more, the ripples will be washed away, resulting in sheet flow. The difference between the various modes of transport is difficult to define, and often both the lower, or higher modes take place simultaneously.

Transport by waves
Water particles describe a circular orbit with the passing of waves in deep water. With the depth below water surface, this orbital movement decreases exponentially until there is no movement at all, at a certain depth. As waves propagate towards the shore the seabed influences the orbital movement and the water particles describe an elliptical orbit. Just above the seabed the movement of the water particles has reduced to a horizontal oscillatory motion. This back and forth movement of the water is directly related to the wave height and wave period. If these oscillating currents at the seabed are large enough they will initiate sediment movement. The sediment will travel as bed load, or possibly higher modes of transport, until the current velocity drops below a certain level again, depending on the grain size of the sediment. However if the waves are symmetrical, no net sediment transport will take place as the sediment is moved over the same distance in one direction as in the other. When the waves are not symmetrical, a net sediment transport will occur in one direction, not necessarily being in the same direction of wave movement. The difference between the water particle movements due to waves in deep or shallow water is illustrated in Figure 6 below.

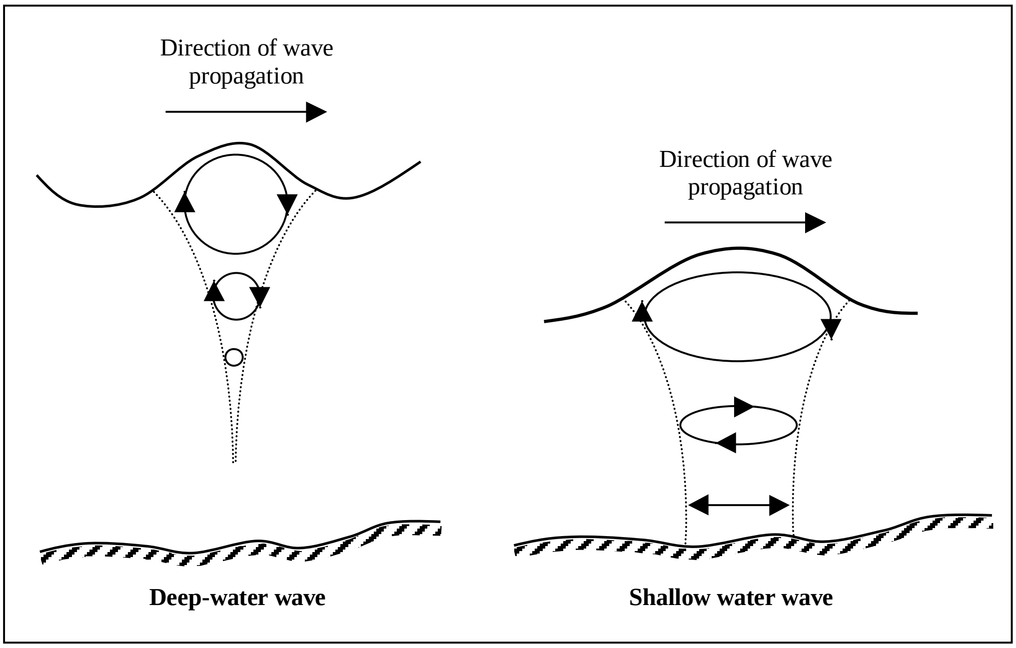


Figure 6. Water particle motion in waves

Transport by currents
Currents that are most common in coastal engineering may be divided into tidal- and wave-induced currents. Other causes of currents are wind-induced stresses or river flows.

Tidal induced currents are the result of a gradient in mean sea water level. As the water rises and falls with the tides it produces flood- and ebb tidal currents. The maximum velocity occurs at flood and ebb tide midpoints, and at high and low water the currents reduce to zero, after which the current reverses. The sediment carried by the tidal current will therefore be deposited at high or low water.

Waves running ashore cause currents. When waves approach the shore at an angle, water is forced along and onto the shore. The wave-induced contribution of horizontal momentum to the mean balance of momentum is referred to as the radiation stress. Within a given volume of water, the wave-induced momentum has to be counterbalanced by another force, such as a pressure gradient or a flow velocity. So changes in radiation stress will lead to changes in water level or result in a current. Therefore a water surface slope from the breaker line towards the shore exists, known as wave set-up, and results in a horizontal pressure gradient counteracting the wave induced radiation stress resultant.

In addition to this wave set-up, breaking waves may also generate a circulation current. As can be seen in Figure 6, the momentum flux is larger at the top of a wave than at the bottom. This initiates a current at the water surface towards the shore. The water that is forced onto the shore has to be balanced by an offshore flow, which occurs near the bottom. Often this seaward flow takes place as concentrated zones of offshore flow, and are known as rip currents. A symmetrical longshore movement of water feeds the flow from both sides of the rip. Together with a longshore current, the rip currents are fed from the updrift direction only.

When waves approach the shore under an angle, radiation stress changes will result in a current along the shore too. The velocity of this wave-induced current is dependent of the angle of wave attack, the height of the waves and the beach slope. The direction of sediment transport along a shore depends on the incoming wave direction. Figure 7 illustrates the velocity distribution of the longshore wave-induced current, for two wave angles.

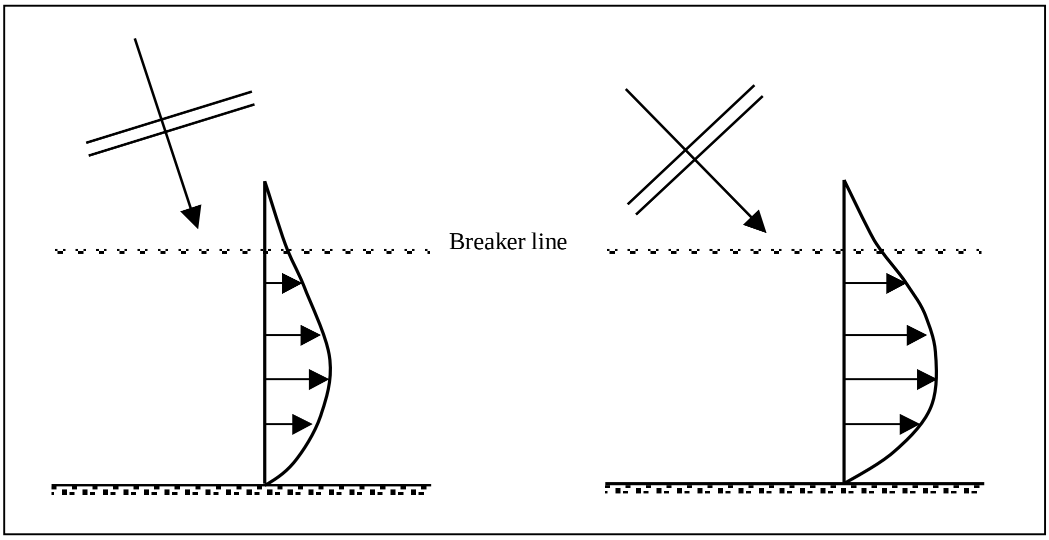


Figure 7. Velocity profiles of wave induced currents

Longshore sediment transport

Longshore sediment transport is the movement of sediment by waves and current along the coastline. Most of the longshore transport takes place in the surf zone.

It is important to make a distinction between gross and net longshore sediment transport. Seldom does a transport only take place in one direction, as wind and waves vary in direction. Tidal currents sometimes result in large gross sediment transports, but the net transport is usually low, because of the change of drift direction. The morphological changes of a beach are mostly controlled by the net longshore transport.

Indicators that a net longshore sediment transport occurs:

- Beach material is accreting up-drift of barriers such as piers or groynes.
- The predominant wave direction forms an angle to the beach.
- Development of a spit at one end of the beach.
- Graded alignment of a beach, as the finer material moves along a beach and leaves the coarser material behind. The updrift beach is narrow and steep, whereas the downdrift section is wider and flatter.

Cross-shore sediment transport

The onshore-offshore transport of sediment mainly takes place as a result of changing wave conditions. Long period swell waves with small heights move sediment shoreward, rebuilding the beach. Larger and steeper waves, such as storm waves erode material from the beach and move it to bars just off the shore.

When a wave runs ashore, water travels up the beach as far up the beach as the wave's energy will allow, and then the water returns to sea under gravity. Under calm conditions, during the summer, the backwash will return to sea before the next wave runs ashore, so it doesn't interfere with the swash of the following wave. As the swash energy is larger than the backwash energy, more sediment will be transported up the beach than down it. Gradually a beach will be built up due to this process. However, when the backwash of a previous wave reduces the swash of a wave, the ability to transport sediment up the beach is withheld. In this case sediment is transported towards the sea, instead of up the beach. The latter occurs under storm conditions, and will eventually lead to a gentle beach profile, known as the winter profile. The gentler slope of the winter profile has the advantage to dissipate wave energy over a greater beach surface. The sediment that is transported offshore usually forms a bar below the low water line. This bar will gradually move landwards under calm weather, to eventually form the summer profile. The profile for a specific beach depends on, both sediment sizes, and deep-water wave characteristics, such as wave height and length.

2.5. Morphological response to groynes

2.5.1. General

After constructing a groyne, or a groyne field, a large section of coast on either side of the groyne is affected. As groynes are constructed into the sea, they interfere with the transport of sediment along the shore. As stated in Section 2.3, groynes achieve there functions with the following processes:

- Intercepting wave induced currents
- Deflecting strong tidal currents away from the shoreline
- Serving as a barrier, to enable a beach section to reorientate itself

If groynes are constructed into the surf zone, they will interfere with the process of waves inducing currents along the shore. The wave-induced momentum of an incoming wave has to be counterbalanced by another force, which in this case can be done by the groyne. In its turn, the groyne passes the force on to the ground in which it is founded. Nevertheless, not all wave-induced currents are stopped because groynes lie far apart, and don't reach sufficiently far out into sea.

The remaining current, together with tidal currents are deflected away from the shoreline. In contrary to wave-induced currents, it is impossible to stop tidal currents. At the updrift groyne of a groyne system, the alongshore current is diverted offshore, and combines with currents at the groyne head, to run along the line of heads. After passing the terminal groyne, the flow returns to the shore. At the heads of the groynes the current strength is increased, and may result in scour. Between the groynes the currents are less strong, but the flow field is more complex. The permeability, length and height of the groynes are the most important parameters in terms of effects of a groyne system on current flow patterns. Impermeable and surface-piercing groynes will result in stronger currents within the groyne bays and at the groyne heads. These high local currents may cause erosion

2.5.2. Beach alignment

Beaches tend to adjust their orientation to a position where the net longshore transport is minimised. This orientation is with the face of the beach into the predominant wave direction, thus decreasing the longshore transport to zero. In small bays, or between two groynes, beaches can reach this state of equilibrium relatively quickly, but open coastlines will perhaps never reach this point. A shingle beach responds much quicker to a wave activity than a sand beach. Figure 8 illustrates the accretion and erosion process on either side of a groyne. When a volume of water, with a certain concentration of sediment, reaches a groyne, some of the sediment will accumulate at the updrift end. Therefore the same volume of water will continue with a lower concentration of sediment. Because of this decrease in sediment concentration, erosion will take place downdrift of a groyne. For this reason extra attention should be given to the terminal groyne of a groyne field, as the downdrift erosion can be significant. After a certain distance, which can be considerable, the volume of water will reach its initial concentration again, provided the flow is not disturbed again. To minimise the degree of downdrift erosion, several measures can be taken, including beach nourishment, bypassing of material, constructing permeable groynes or minimising the height of the groyne.

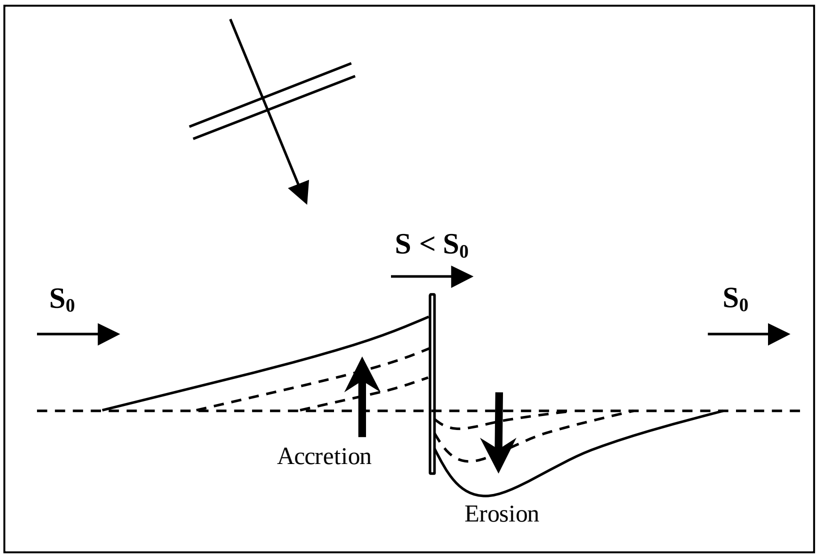


Figure 8. Shoreline development after groyne construction

The flow field between groynes is influenced by a number of processes. When waves approach a groyne they will diffract around the groyne, spreading the energy of the wave over a greater area, resulting in smaller waves progressing beyond the tip of the groyne. Therefore the wave set-up in the lee vicinity of the groyne is lower than outside its wave reducing effective area. Due to the difference in water levels currents around and behind the groyne will occur (see Figure 9), and may have a scouring effect at the tip of the groyne. The circulating flows within the groyne bays are a result of this wave set-up, flowing seawards downdrift of a groyne and towards the shore on the updrift side.

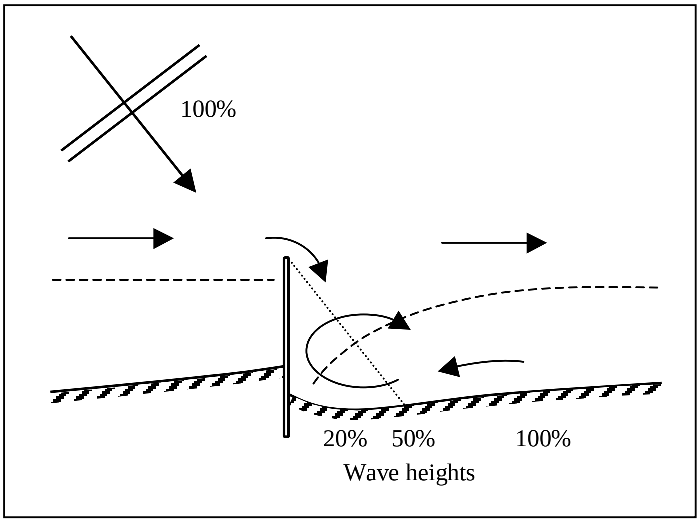


Figure 9. Currents due to wave set-up

2.5.3. Beach profile

After having discussed the effect on the beach alignment, the beach shape as seen from above, this section discusses the beach profile, which is the cross-section shape of a beach. The cross section of a beach is largely determined by the onshore-offshore transport of beach material, which mainly takes place as a result of changing wave conditions. The steep summer profile of a beach is generally built by the long period swell waves with small heights. The mild winter profile is the result of the larger and steeper waves, which usually run ashore in the winter, and erode material from the beach and move it to bars just off the shore.

The slope of a beach profile depends on what beach material is present on the beach. Figure 10 summarises the typical features of the four most common beach types. Shingle beaches respond quicker to changing wave conditions and their slopes are steeper than sand beaches. As the threshold of motion of sand particles is smaller than that of shingle, a sand beach will erode easier than a shingle beach. A groyne on a sand beach therefore requires more precise dimensioning; as for example a small over height will result in extra currents and will lead to scour. Sometimes rip currents may concentrate along the length of a groyne, and can remove great quantities of material out to sea. Additionally, the groyne will partly be undermined threatening the stability of the structure. The stability may be in danger since the height of the beach on either side of the structure may greatly differ. The typical beach profile will have its own location, either further near the end of the groyne, or closer to the shore.

The different beach types will require different groyne profiles too. It is important to make the distinction between a mixed beach, and a shingle upper and a sand lower beach. In the latter case, shorter closely spaced groynes may be constructed between the longer groynes, required for the sand beach. Because the characteristics of a beach are so dependent on the type of beach material, it is essential that when beach nourishment takes place the material brought ashore is the same as present on the beach.

Shingle beach
Typical features: Slope 1:6 ~ 1:10
D_{50} 10 – 40 mm

Shingle upper/sand lower beach
Typical features: Slope shingle 1:10
Slope sand 1:40
D_{50} shingle 10 – 40 mm
D_{50} sand 0.3 mm

Sand/shingle mixed beach
Typical features: Slope 1:30
D_{50} 2.0 mm

Sand beach
Typical features: Slope 1:100+
D_{50} 0.3 mm

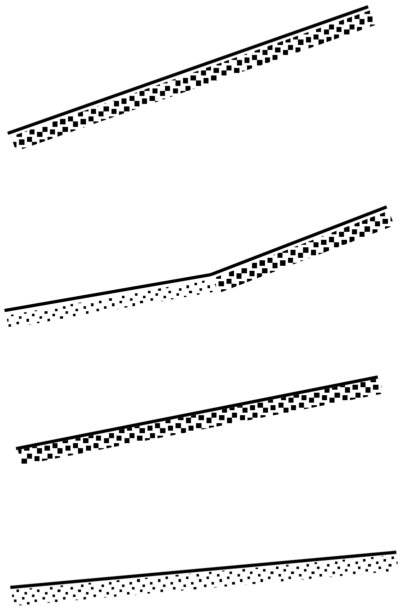


Figure 10. Beach classification (based on CIRIA Report 119)

2.6. Loads on groynes

2.6.1. Wave forces

Waves and the longshore currents they cause are the dominant sediment moving forces in the nearshore zone. Waves often also cause the critical forces that act on coastal structures. Thus, wave data are needed to establish cause and effect relationships involved in the performance of beach erosion control projects.

Waves can be divided into wind waves and swell waves. Wind waves are generated by winds blowing over the sea and are of greatest interest in coastal engineering. The size of the waves is dependent on the fetch, duration of the wind blowing over the surface and the speed of the wind. Swell waves are waves that don’t receive energy from the wind anymore and just propagate away from the area in which they were generated. Only the large period waves can travel great distances, as their rate of decay is small. The swell waves reaching the shore thus have larger periods than the wind waves.

As the waves reach the shore they will undergo transformations as they dissipate their energy. When the waves travel into shallower water, the friction with the seabed reduces their velocity (see also sediment transport by currents in Chapter 2.4). The decelerating of the wave transforms kinetic energy into potential energy, thus leading to an increase of the wave height (and a decrease of wavelength). This process of modification of the waveform is known as shoaling. The height of the wave cannot increase to infinity as there are two limitations, the wave steepness and the wave height to water depth ratio. Waves will break at a certain depth, dissipating some of its energy in turbulence. Remaining energy is reflected back or generates currents, other waves, sound and heat. Depending on the beach slope and nature and the wave characteristics the waves will break in a different way.

Because groynes are generally oriented nearly perpendicular to the shoreline, waves propagate along the groyne’s axis so that their crests almost make a 90-degree angle with the groyne. For a conventional timber groyne, lateral wave forces arise because a wave crest acts on one side of the groyne whereas a lower water level acts on the other, either the still-water level or a wave trough. Wave reflection occurs for directions of wave approach that make an angle with the groyne axis. The incoming wave crest aligns itself perpendicular to the groyne's axis, and the resulting wave height is higher than, but not twice as high as, the incoming wave. Wave heights on the leeward side of the groyne may be lower. However, the groyne should be designed for waves approaching from either direction. The maximum lateral force acts only over a portion of the structure at once, and forces are distributed longitudinally along the groyne by the horizontal waling.

When breaking or broken waves strike the vertical face of a structure at an oblique angle, the dynamic component will be less than for breaking or broken waves that strike perpendicular to the structure face. Waves breaking directly against vertical-face structures exert high, short duration, dynamic pressures on the structure. The moment of impact only lasts for an extreme short period, so the pressure can't be very representative for the stability of the structure but certainly is important for it's strength. Minikin developed a design procedure based on observations of full-scale breakwaters and the results of Bagnold's study. The method is described in the Shore Protection Manual (1984). The maximum dynamic pressure acts at the still water line and decreases parabolically to zero at a distance of half the breaking wave height above and below the still water line (see Figure 11). When the top of a structure is lower than the crest of the design breaker, the dynamic and hydrostatic components of wave force and overturning moment are obviously reduced.

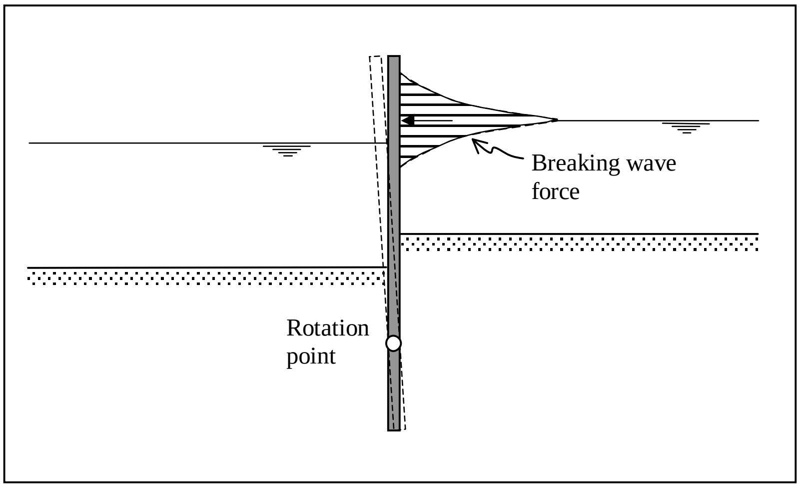


Figure 11. *Minikin wave pressure diagram*

2.6.2. Earth forces

In addition to wave forces, forces due to the build-up of sediment and difference in sand elevation from one side of a timber groyne to the other are important. The resulting earth forces coupled with wave forces establish maximum lateral forces and maximum bending stresses in cantilevered groynes. Generally, the maximum sand elevation difference results in the maximum lateral force per unit groyne length. The lateral earth force is a combination of both active and passive earth pressures acting on the updrift and downdrift sides of a groyne. Active earth pressure acts in the direction of the deflection. Passive earth pressure develops to resist deflection of the groyne and acts opposite to the direction of the deflection. Earth retaining walls experience similar forces.

Figure 12 illustrates these forces. The two triangular shaped forces closest to the groyne (cross-section view) are the hydrostatic loads. Although the water may have slight level differences on either side, they remain approximately hydrostatic, whether any other forces work on the groyne or not. The outer two forces represent the soil pressures. At the level of the rotation point, these shapes show a sharp bend, as this is the point where active and passive forces change side. On the right hand side in the figure, the force is active above the rotation point, and passive below this point.

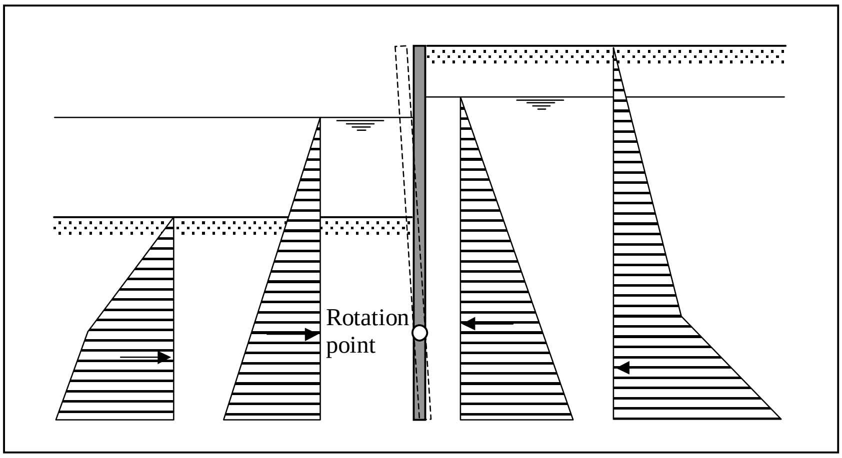


Figure 12. Loads and reactions on cantilevered groyne

When some kind of anchoring system is used to stabilise the structure, the rotation point will change location, and thus has effect on how the active and passive forces are devided. In the situation sketched in Figure 13, the rotation point is all the way at the top, so all the active forces are on the right hand side, and the passive forces are on the left. In reality anchored groyne shall be constructed with a tie or prop, connecting to the main piles lower than shown here.

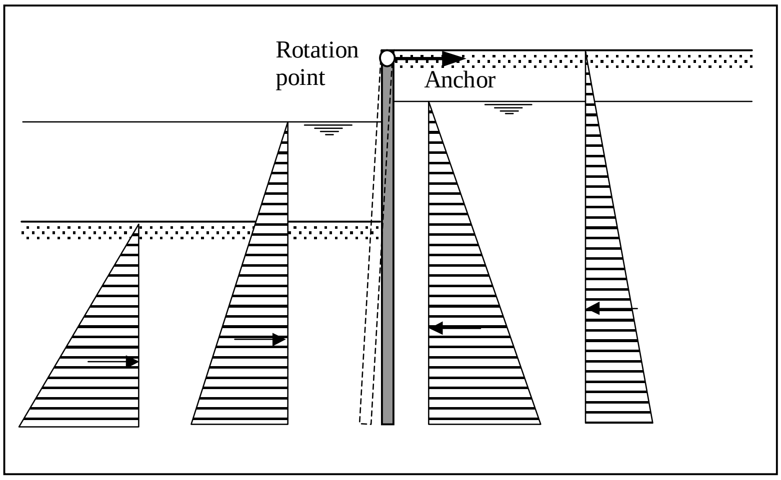


Figure 13. Loads and reactions on anchored groyne

Appendix 1 shows some calculations made on a groyne, with varying sand elevations and with varying groyne height (i.e. depth of groyne into beach). Using a computer program, graphs have been made presenting bending moments, shear force and resultant soil pressures. Although it seems attractive to design a groyne with the optimal stresses, in order to reduce the section sizes of the piles, the decisive factor for section sizes is usually the expected degree of abrasion. Nevertheless the graphs give a good understanding of the loads, and can be used for specific design details.

2.6.3. Current forces

Current caused forces are usually small when compared with the forces due to waves. Rip currents can cause an additional lateral force (along the axis of the groyne), but are of no significance. However currents are a major factor to consider when designing a coastal structure, as they can undermine the structure's foundation. The same is the case for currents along the structures head, or currents induced by the difference in wave set-up on either side of a groyne. When scour occurs, the stability of the structure is at risk because the resistance against rotating has been reduced.

2.6.4. Impact forces

A groyne might experience impact forces due to wave-carried debris or vessel collisions. The size of these forces is difficult to predict because the cause of the impact and mass of the impacting body are not known beforehand. If debris is expected to be a problem, appropriate levels of conservatism should be included in the design. Experience has learnt that groynes are often damaged by loose parts of the groyne itself, as loose planking or waling will act as a battering ram. Therefore regular maintenance is an important issue, to ensure a long service life of the structure. Other measures that can be taken may include improving the visibility of the groyne for vessels, by placing marker beacons at the outer end of the groyne.

2.6.5. Other forces

A groyne may have to be designed to withstand forces that might occur only during construction, such as driving piles into the ground. Groynes may have to carry construction equipment or there may be extra loads due to temporary fill. These forces may be critical and exceed forces due to other more usual causes such as waves and currents.

2.7. Functional design of timber groynes

In this section current guidance on the functional design of groynes is summarised. After discussing the case studies in Chapter 4, the functional design will be reviewed in Chapter 5.

2.7.1. Length

Most longshore transport takes place in the surf zone, between the breaker line and the shoreline. The length of a groyne determines the trapping effectiveness of the system, depending on how far across the surf zone it reaches. The location of the breaker line, and thus the width of the surf zone, varies with wave height and tidal stage, therefore the relative groyne length also changes.

The length of a groyne should be based on the expected surf zone width with the shoreline at its desired post-construction location. Groynes that initially reach through the surf zone will trap more sand and the shoreline will accrete until sand eventually begins to pass around its seaward end. Shorter groynes will allow sediment to bypass the groyne immediately after construction, which may be desirable to minimise erosion along downdrift beaches. Although self-evident, it may be useful to state that the mild slope of a sandy beach requires a much longer groyne than a steep shingle beach. And secondly, a large tidal range leads to a longer groyne than a small tidal range.

2.7.2. Height

The height of a groyne controls the sand movement over the groyne and determines the amount of sheltering from waves to the nearby beach. Factors such as the amount of construction material to be used and wave reflections from the groyne are influenced by the height. The height of a groyne, above beach level, may vary over the groyne's length, and differs for the summer and winter beach profiles. The groyne profile is built to approximately the desired post-project beach profile, generally such as shown in Figure 14. High groynes are likely to create rip currents, and flows at the head of the structure, sometimes leading to erosion channels, which will transport beach material out of the groyne bays. Deep channels might even threaten the stability of the groyne structure. The importance of the height on the effectiveness of a groyne differs for different beach types because the amount of scour depends on the size of beach material. Sand beaches are most sensitive to the height of a groyne and can best be adjusted to protrude only 0.5 m or two plank widths above the seasonal beach profile. However, this requires a considerable degree of maintenance. On shingle beaches, greater groyne heights are permissible and practical.

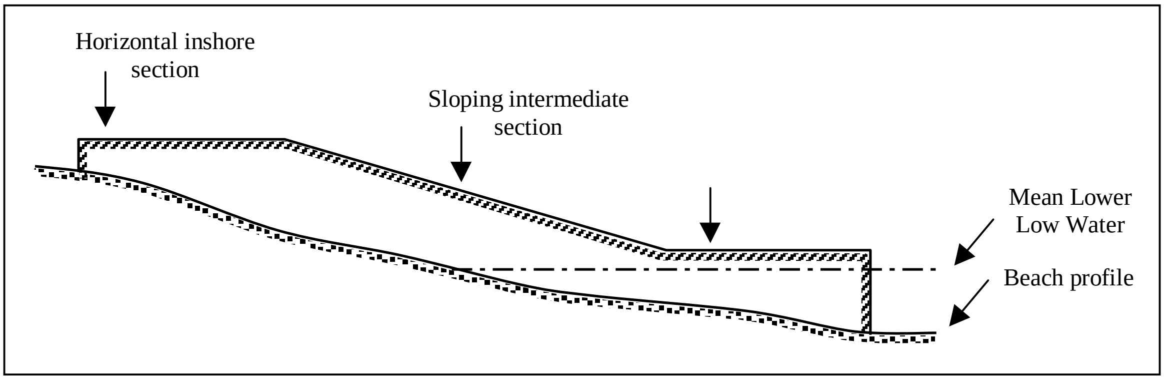


Figure 14. Typical groyne profile

2.7.3. Spacing

The spacing of groynes is usually given in terms relative to the length of individual groynes, generally in the order of two to three groyne lengths. The groyne length is specified as the distance from the beach berm crest to the groyne's seaward end. Steeper beaches or a small tidal range require shorter groynes and therefore the spacing is smaller too. When designing a groyne system, the spacing is determined by an analysis of the shoreline alignment that is expected to result following groyne construction. This alignment will approximately correspond to the crest of the dominant incoming waves. The shoreline alignment is a function of the wave-, and longshore transport environment at a site. When waves approach the shore nearly under a right angle, larger groyne spacing can be used. When the waves make an angle with the shoreline, closer groyne spacing is required. In case of varying wave direction and transport rates, the shoreline alignment near groynes will also vary, and the spacing is generally chosen to be relatively small.

2.7.4. Permeability

Groynes are either permeable or impermeable, depending on whether sediment can be transported through the groyne. To obtain an absolute barrier for sediment, a groyne must be constructed completely impermeable, requiring very precise assembling.

The idea of permeable groynes is that they reduce alongshore currents, and thus reduce sediment transport. Permeable groynes have several advantages such as their relatively low cost and a smaller tendency to produce rip currents and currents round the end of the groyne. Another advantage is that permeable pile screens don't create such severe erosion downdrift, as sediment is transported through the groyne. Several studies have been carried out for permeable groynes, however opinions about their functioning differ. Bakker (1984) believes permeable pile screens deserve serious consideration as a first flexible and cheap phase in combating coastal erosion. They reduce longshore currents but provide much less of a barrier to the movement of beach material, and therefore are less effective at retaining beaches.

2.7.5. Orientation

Generally groynes are constructed perpendicular to the coastline. To minimise wave impacts, groynes could be aligned into the predominant wave direction. However, to provide the most effective control of littoral movement they should be angled slightly downdrift. Because wave and drift directions may vary, the most practical solution is chosen: aligning groynes transverse to the coastline.

3. TIMBER AS A CONSTRUCTION MATERIAL

3.1. Timber – a brief introduction

As a natural material, the efficient utilisation of timber is dependent on some form of selection and grading. An understanding of the characteristics and properties of timber as a raw material will enable the designer or user to ensure that timber is used to best effect.

One advantage which timber has over almost all other materials is that trees are a living, renewable resource. Good land management and thoughtful felling regimes are recognised as essential issues of the timber trade that will help to secure the long-term availability of certain timbers.

3.1.1. The structure of timber

Wood is made of organic matter. The basic building block of timber is the wood microfibril, which may be described as a fibre composite, where the fibre element provides strength to the composite while the matrix provides stiffness and transfers stress from fibre to fibre. The microfibril is made up of cellulose, which provides strength, and the hemicellulose and lignin act as the matrix that stiffens and bonds the cellulose fibres.

Cellulose and hemicellulose are sugar-based building blocks. Cellulose consists of building blocks of glucose that are linked up longitudinally to form long, thin fibres that lie parallel to each other in a particular pattern, giving the cellulose component a high degree of crystallinity. A single molecule of cellulose is made up of a chain of approximately 8000 glucose units. It is this arrangement of the glucose building blocks that gives strength to cellulose. Hemicellulose is similar to cellulose in that it is made up of various carbohydrate units (sugars) such as mannose and galactose but is not as ordered in its structure and is described as having a low degree of crystallinity. A typical hemicellulose molecule may contain a chain of 150-200 sugar units. Lignin is a complex non-crystalline compound consisting of many different organic compounds that may be best summarised as a matrix of aromatic compounds.

Other chemicals may be present in the timber, which may be classified as extractives. Examples of extractives are gums, oils, tannins, latex, resins, silica and calcium deposits. Large quantities of silica may cause blunting of cutting tools but are also responsible for giving greater resistance against attack by marine borer. The make up and distribution of extractives varies from species to species and is thought to play an essential role in providing durability against biological attack.

All living organisms are composed of cells. In the living tree, different cell tissues perform different tasks. Some tissue groups will transport water and nutrients and others perform a structural function providing the tree with strength and elasticity. Most of the conducting and supporting tissue is arranged vertically and this arrangement forms the grain of the timber. Of course, water and nutrients have to be transported horizontally, across the grain as well. This is carried out by an arrangement of horizontal tissue types known as rays. The size and distribution of the ray tissue varies from species to species and is a useful diagnostic feature for identification.

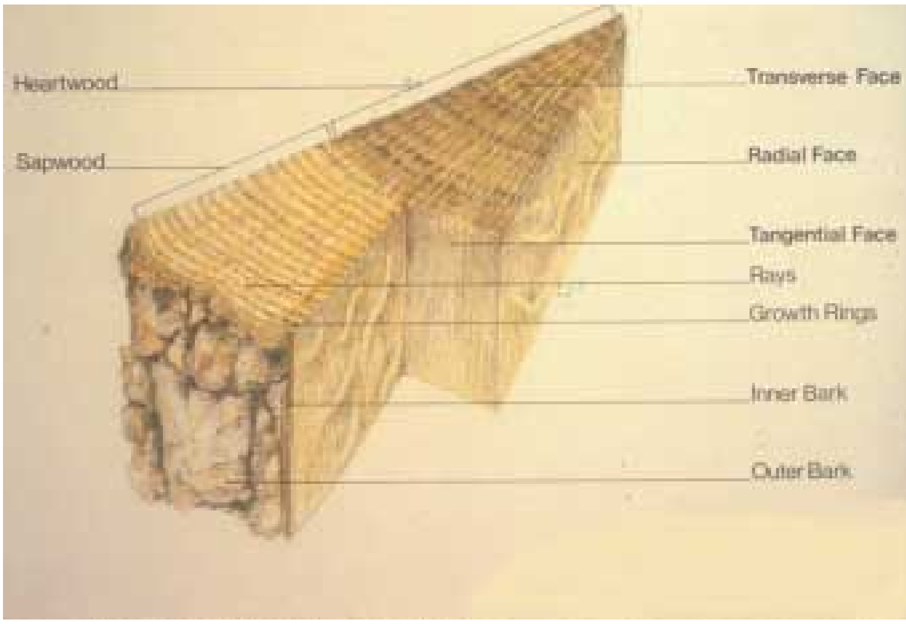


Figure 15. Gross features of timber (courtesy to TRADA)

3.1.2. Cross-sectional features

Growth rings

For every year of growth, the tree will lay down a ring of timber known as an annular ring originating from the cambium, which is the thin sheath of cells between the bark and wood. The outermost ring is the most recently formed. This ring may be further broken down into earlywood and latewood. Simply put, earlywood is laid down during the growing season where transportation of nutrients and water is of primary importance and latewood is laid down at the end of the growing season where metabolic activity is at its lowest level. The primary function of latewood is to provide support.

Sapwood

The cross section of the trunk of the tree may be divided into two zones: the sapwood and the heartwood. The sapwood is physiologically active and supports the tree's living activity. The sapwood is usually a narrow, paler band of timber around the heartwood. However, not all trees show a clear difference between sapwood and heartwood, e.g. Spruce and Greenheart. The sapwood has a low resistance to all types of biological attack.

Heartwood

Heartwood is metabolically inactive. As the tree ages, it increases in girth as a consequence of the cambium laying down a new layer of sapwood each year. The central part of the trunk begins to lose water and stored food substances. The living cells in this region undergo a slow process of conversion as they senesce and may convert food and waste materials into extractives before eventually dying. This can result in a number of changes within the developing heartwood. The colour of the timber may darken due to the deposition of extractives, which vary in composition between species. Extractives are responsible for providing the natural durability to the heartwood. In addition to the formation of extractives, outgrowths from the cell walls may develop to block the vessels, leading to the heartwood being less permeable. These outgrowths are known as tyloses and are a common feature of teak and oak and appear as balloon-like structures under the microscope.

3.1.3. Classification of timber

The commercial division of timbers into hardwoods and softwoods has evolved from long traditions when the timber trade was dealing with a limited range of species. Nowadays, this division has no relation to the softness or hardness of the timber. The terms “softwood” and “hardwood” can be confusing as some softwoods are harder than some hardwoods, e.g. Yew is considerably denser than Balsa wood. Both groups contain timbers that vary in density, strength and resistance to biological attack, i.e. natural durability. The differences between softwoods and hardwoods are briefly explained and illustrated on the following two pages.

Softwoods

- Softwood timber is produced from the gymnosperms, the coniferous or cone bearing trees, which are mostly evergreen. Examples are Douglas fir, Pitch pine, Larch and European redwood.

- One characteristic of many, although not all, softwoods is their ability to produce resin. The resin is formed in parenchyma cells and in some species is stored and transported in resin canals. These canals are not cells but cavities in the wood lined with parenchyma cells. These canals are present both horizontally and vertically and often provide the anatomist with a useful identification feature. In simple terms, the resin canals provide a means of response to wounding or mechanical damage by screening-off the affected timber with resin and isolating it from surrounding, healthy tissue.

- In softwoods only two cell types are present:

Tracheids

The “woody” tissue is made up of cells known as tracheids, which are arranged vertically and comprise 95% of the wood volume. These cells are hollow, needle-shaped and generally 2.5 mm – 5 mm in length. The length to width ratio is in the order of 100:1. The tracheids are packed close together and resemble a honeycomb when viewed in cross section. Liquids pass from one tracheid to another through microscopic openings known as bordered pits. The configuration and distribution of these pits affects the permeability of the timber, which in turn affects the ease with which it can be treated. The earlywood consists of comparatively thin walled, paler tracheids whose primary function is transportation of sap. The latewood tracheids are considerably thicker walled and darker. The function of the latewood tracheids is primarily support.

Parenchyma

The “non-woody” tissue is known as parenchyma. Parenchyma may be present both horizontally (rays) and vertically (axial parenchyma). These cells are soft and thin walled. The rays form narrow bands of cells radiating outwards from the pith to the cambium and are continuous. Axial parenchyma in softwoods are arranged as isolated vertical series of cells, known as strands.

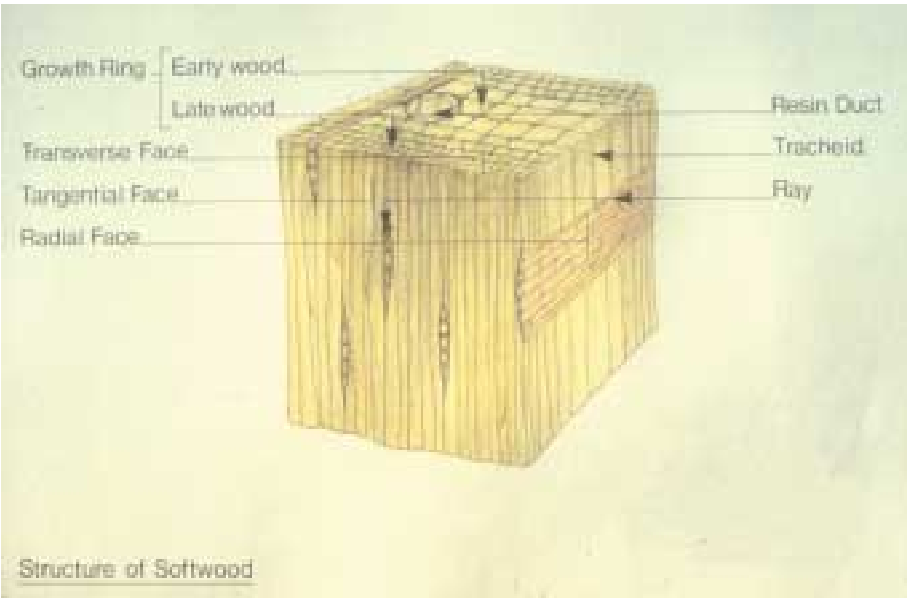


Figure 16. Typical 3-D structure of softwood (courtesy to TRADA)

Hardwoods

- Hardwood is produced from one group of the angiosperms, known as dicotyledons, which are the broad-leafed trees. Most tropical hardwoods retain their leaves all year round, while the temperate zone hardwoods are generally deciduous. Examples are: Ekki, Greenheart, Oak, Elm, Teak, Jarrah, Kapur, Balsa and Balau.

- Hardwoods have three cell types:

Fibres

The majority of hardwood tissue is made up of fibres, which have very thick walls offering strength and support to the tree. The fibres are narrow, needle-like cells similar in appearance to the latewood tracheids of the softwoods. The fibre thickness is species dependent and affects wood density. For example, Balsa fibres are comparatively thin walled in comparison to those of Greenheart. It follows that Greenheart is far denser than Balsa. Simple slit-like pits link adjacent fibres to one another.

Vessels

Water conducting tissue is made up of vessels, which are quite different from the fibres. Vessels are built of short, perforated elements arranged in axial columns and vary in length from 0.2 mm – 0.5 mm and range widely in width from 20 µm – 400 µm. When viewed in the transverse section, these vessels are known as pores. Transport between adjacent vessels and ray tissue takes place between numerous pits in the longitudinal walls of the vessels. For the vast majority of hardwood species there is very little change in the size and distribution of the vessels, except for a reduction in diameter towards the very end of the growth ring. These timbers are known as diffuse porous timbers, examples of which are Beech, Lime and South American mahogany.

When viewed in the transverse section, some species of hardwood such as Oak, Elm and Ash exhibit two markedly different sized vessels. Comparatively wider vessels are located in the earlywood band of the growth ring whereas narrower vessels are located in the latewood. Such species of timber are known as ring porous timbers.

In other species such as Hickory, Walnut and Teak the earlywood is marked by incomplete rows of large pores while the latewood appears the same as the ring porous types. These species are classified as semi-ring porous.

Parenchyma

In hardwoods the parenchyma tissue is the same as that for softwoods and provides the same function, that of sap storage and conversion. However, the principal difference between the parenchyma of softwoods and hardwoods is that the parenchyma in hardwoods is more abundant and more highly developed and varies in its distribution and arrangement.

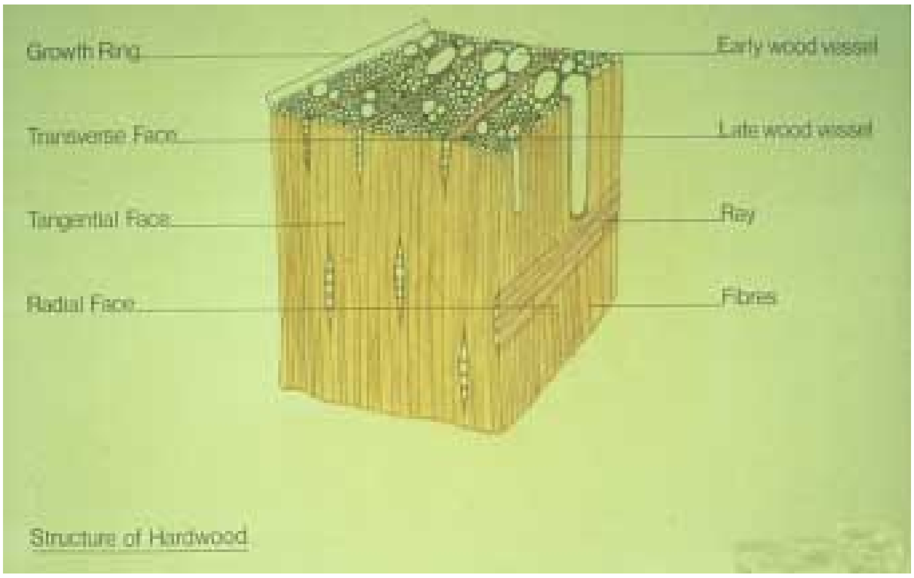


Figure 17. Typical 3-D structure of hardwood (courtesy to TRADA)

Softwoods
The quality of softwoods depends largely on the proportions of thin to thick walled tracheids and on the contrast between the wood of the early and latewood zones. Distribution of these zones is affected by the duration of the growing season and northern latitudes. For example, softwood originating from Northern Russia, e.g. European redwood will be characterised by having narrow growth rings and a high proportion of latewood within each growth ring. Softwood, such as Corsican pine originating from the Mediterranean will have wider growth rings and comparatively less latewood. Generally, in terms of strength and overall quality, softwood originating from northern latitudes is seen as superior to that originating from south-west Europe.

Hardwoods
When first formed from the cambium, the vessel members have end walls just like all other cells. However, early in the cell development, the end walls split, and are digested by enzymes to form a column of continuous vessels. The split ends of the vessels of different species may vary in their structure. The vessels of some species may be joined through simple perforation plates and in other species only part of the cell wall may have been digested to generate perforation plates. These features often provide the anatomist with a useful diagnostic tool. These plates provide a more effective means of allowing water transport in hardwood than the bordered pit arrangements found in softwood tracheids. Transport between adjacent vessels and ray tissue occurs between numerous bordered pits in the longitudinal walls of the vessels.

3.2. Moisture in timber

Water is an essential chemical constituent of timber. Living trees and freshly felled sawn timber can contain large volumes of water - up to about 200% moisture content of the timber. The moisture content figure can be more than 100% because the weight of water in timber is expressed as a percentage of the oven dry weight of the wood, which is determined by using the following formula:

$$Moisture\ Content\ (MC)\% = \frac{weight\ of\ wet\ wood - weight\ of\ dry\ wood}{weight\ of\ drywood} \times 100$$

Thus a piece of wet timber whose weight is half dry wood and half water will have a moisture content of 100%. Above the 25-30% moisture content level, water fills or partially fills the cavities of the wood fibres. When wood dries, this water is lost first. This reduces the weight of the piece but does not change its dimensions. When the cell cavities are empty but the cell walls still retain their bound water, the wood is said to be at fibre saturation point. Above fibre saturation point the timber may be described as “green”.

Further drying below fibre saturation point results in shrinkage of the wood, as the walls of the woody tissue contract. When dried wood is put into a wet or moist environment this process happens in reverse order. It is usually necessary to dry wood before it is used or treated in some way, i.e. impregnated with wood preservatives under pressure, unless it is going to be used in water or in a very wet environment.

There are two main reasons for drying timber. These are:

- The timber of many species will decay if kept at high moisture contents for long periods. Some susceptible timbers will suffer from mould, discoloration or staining even if they are kept wet for only a short time. Timber below about 20% moisture content is too dry to suffer such discoloration or decay.

- Wet timber will usually dry in service. As it loses water below the 25-30% fibre saturation point it will shrink laterally. If the grain of the piece is not absolutely straight, distortion may occur. Pre-drying the wood allows these inevitable dimensional changes to be avoided in service and enables the production of accurately shaped and sized components.

Further reasons for drying that may be important in specific cases are:

- To save weight during transportation
- To make machining easier
- To enable strong glue joints to be made
- To allow preservatives to penetrate
- To increase the loads that timber can carry

With reference to using large sections of naturally durable timber such as Ekki or Greenheart as piles, planking, sheeters and waling, the timber will almost certainly be in the green state. Components that are introduced to a permanently wet environment, for example tidal and inter-tidal zones, will maintain a high moisture content, above the fibre saturation point and will not experience movement in service as a consequence of changing moisture content.

Movement of timber

The change in dimension by timber after its initial drying shrinkage is called "movement". Shrinkage or swelling occurs in response to changing environmental conditions, such as changes in temperature and relative humidity. Distortion is caused by the difference in shrinkage in the tangential direction compared with that radially, coupled with the fact that the grain of a piece of timber rarely runs straight. Thus large changes in moisture content below fibre saturation point can result in the bowing or twisting of timber components. The response of timber to changes in temperature and humidity is quite slow and tends to average out minor changes in conditions such as diurnal fluctuations.

The outer layers of the timber respond more rapidly to changes than the inner sections of a piece. Protective or decorative coatings, such as paints, varnishes and exterior wood finishes slow down the response to a degree roughly related to the thickness of the coating but will not totally prevent the moisture content of the timber from changing. In general terms, changes in moisture content of timber, provided it is permanently out of contact with the ground or water are measurable on a seasonal basis, rather than in terms of days or weeks.

Actual movement values vary between species and can be influenced by mechanical restraint. For most practical purposes the following assumptions can be made:

- Timber does not shrink or swell lengthwise along the grain.
- Shrinkage starts as the timber dries below about 30% moisture content or the fibre saturation point.

Movement of green planking

If timber is put into service with a moisture content higher than that which it is likely to reach with time, for example green Ekki planking above water level, two interrelated problems can occur. One is shrinkage and the other is distortion. If, for example green Ekki planking at 45% moisture content is put into an environment where the expected service moisture content will vary between 12%-16% it can be expected to shrink by 1% of the board's dimensions across the grain for every 3% drop in moisture content below the fibre saturation point of 30%. Therefore a drop of 18% moisture content may lead to shrinkage across the grain by up to 6% of the dimension of the plank. Therefore, green Ekki planking of dimensions 100 mm x 400 mm may shrink to 94 mm x 376 mm.

Whilst it is unrealistic to apply high precision to matters involving moisture content, a severe mismatch between the moisture content of supply, storage or installation and the timber's eventual service moisture content will often lead to problems in service. Careful design to accommodate anticipated movement, coupled with sensible moisture content specification will avoid such problems.

Table 1 indicates the movement values of a number of common species, based on a classification system formulated by the Forest Products Research Laboratory (now part of the Building Research

Establishment). The classes are based on the sum of the tangential and radial movements corresponding to a change in humidity conditions from 90% to 60% relative humidity at a constant temperature.

Where movement tolerances are critical, a timber with small movement characteristics should be considered.

Table 1 Movement values for a range of timber species

Movement value	Small	Medium	Large
Timber species	Douglas fir, Idigbo, Iroko, Asian teak, Western hemlock, Makore, American mahogany, Purpleheart, Padauk, Western red cedar, Balau	European redwood, Oak, European elm, Radiata pine, European larch, Sapele, Utile, Jarrah	Ekki, Greenheart, Karri, Sweet chestnut

Small: 1% change in dimension requires 5% change in moisture content
Medium: 1% change in dimension requires 4% change in moisture content
Large: 1% change in dimension requires 3% change in moisture content

3.3. Degradation of timber

Over the course of time and the influence of the external environment, timber structures, like all other structures, experience a loss in performance. Degradation is both inevitable and undesirable. At best, degradation is limited to the surface layers of the timber structure. However, given the right conditions, degradation will eventually affect the whole structure, particularly in terms of mechanical performance, strength and durability. The rate of degradation is usually specific to the particular timber species and the specific conditions.

3.3.1. Mechanical damage

Abrasion

Mechanical damage can take many forms. One of the most common types of damage to timber in the marine environment is abrasion. Abrasion of coastal groynes is an important, if not the most important factor in determining their service life. The resistance of timber to abrasion is related to its density: the denser the timber, the greater its resistance to abrasion. Abrasion problems may be most apparent in areas where there is a small tidal range as the erosion will be concentrated on a relatively small section of the groyne.

Impact

A second and often destructive damage is that of impact loads. The timber members must have the ability to withstand shock loads caused by vessels or driftwood. Loose elements on the structure itself may have the effect of a battering ram, continuously being moved by the waves until its fixings collapse. Impact damage on the timber can result in compression failure of the timber fibres, leading to breaking of the member.

Creep

Timber serving in the marine and fresh water environment will suffer mechanical degradation. The most common cause of mechanical deterioration occurs when timber is stressed under load for prolonged periods of time, which is known as creep. As a result of creep one must take into account a loss in strength with time, under load. For example, for a timber element to sustain a load for 100 years, then the load must not exceed 50% of the load the timber would fail at in the short term. In all structural applications a load endurance factor should be incorporated in the design and is usually applied as one of several contributing parts to an overall safety factor.

3.3.2. Biological attack in fresh water

Timber in the marine and fluvial environment will in most cases remain permanently wet. Where those timber elements are out of contact with surrounding water, they will probably be exposed to conditions that will result in them being vulnerable to irregular attack. For fungal decay to occur, four conditions must be present: food, adequate moisture, suitable temperature and oxygen. In most circumstances, lack of moisture is the limiting factor that restricts fungal activity. However, low levels of oxygen, limited nutrients and low temperatures also decelerate or even inhibit fungal activity. The timber itself or the cell contents provide the necessary nutrients. Oxygen is usually available under service conditions except when the timber is totally under water. Practically all fungal activity ceases at or below freezing point and is very slow just above it. Optimum conditions generally occur at around 20°C to 30°C and at 30% to 50% moisture content.

The following types of biological attack may occur in fresh water:

- Bacterial, mould and sapstain attack. Mould and sapstain fungi are lower fungal organisms that are best described as "scavengers", they feed upon readily available cell contents but do not cause decay of the timber structure. Their presence however, indicates that conditions favourable for fungal decay exist.
- Soft rot attack occurs in ground contact and in marine and fluvial environments. Soft rotters are also lower organisms.
- Dry rot attack is by far the most important destructive fungus in buildings. However, with reference to structures in the marine and fluvial environment, its occurrence may be viewed as insignificant.
- Wet rot attack is by far the most important group of fungi to consider in terms of timber structures serving in the marine and fluvial environment.

If used in fresh water, the moisture content of the timber will exceed the decay threshold of 20% and it is highly probable that fungal decay will occur. Aggressive fungal decay above the water level may occur, principally by wet rot type fungi. In addition, insects may also attack wet timber above water level, which is discussed in Section 3.3.4. However, below water level only fungal decay of the soft rot type may occur.

Soft rotting type fungi erode the outer layers of the timber components at a relatively slow rate. The outer surfaces are typically dark and soft in texture. The depth and rate of penetration of the fungi is largely regulated by the timber's density. However, the affected timber may also be exposed to currents. The combined effects of the soft rot fungi and faster erosion of the decayed outer layers of timber may accelerate the deterioration of the component.

3.3.3. Biological attack in the marine environment

Salt water can act as a timber preservative and heavy salt deposition in wood may offer some protection against fungal decay. For timber out of contact with sea water it is important to realise that salt deposition may not be permanent. Horizontal faces of timber or joints are at risk of fungal and insect attack if the moisture content of the components rises above the decay threshold of 20% for prolonged periods. Wood that is exposed in the sea below the high tide mark may be subject to attack by marine bacteria, fungi and marine boring animals.

Survey local authorities

A small survey has been carried out among 33 local authorities along the UK coastline. The questionnaire referred to which timber structures are found along the coast, which species have been used and if any form of marine borer attack has been identified on the structures. Fifteen local authorities responded to the survey, of which only three claimed to suspect some form of marine borer attack. Probably attack by marine borers occurs at more locations, but is not recognised as such by the authorities. Appendix 4 presents the responses to the questionnaire. The significance of attack is probably not very great, as the commonly used hardwood species are quite resistant against attack

The principal causes of biodeterioration of timber in the marine environment are marine borers, which can cause severe damage in relatively short periods of time. In UK and other temperate waters, only two types of borer are of significance, the mollusc *Teredo spp*. (shipworm) and the crustacean *Limnoria spp.* (gribble).

On the following two pages the marine borers shipworm and gribble are described:

Shipworm

There are two types of molluscan bi-valve borer: the teredinids (*Teredinidae*) (otherwise know as the shipworm) and pholads. The teredinids are the largest and widely distributed group. The pholads are more restricted to warm temperate and tropical waters. In terms of assessing the risk of molluscan degradation of timber around UK waters, only the teredinids have been identified.

The teredinids possess a soft-worm like body with two shells at the head of the animal, which allows the animal to bore into the timber element usually along the grain. The back end of the animal remains in contact with seawater via a small hole of 1-2 mm in diameter. Two siphons, scarcely visible to the human eye, protrude into the surrounding water to enable water to be drawn in to provide oxygen and micro-organisms on which the animal may feed through the inhalant siphon. The exhalant siphon releases waste and reproductive larvae.

The precise mode of settlement of juveniles on to wood is unclear. One thought is that colonisation is associated with softened regions of wood, which have suffered fungal and bacterial attack. Another view is that teredinids will colonise timber irrespective of biological pre-conditioning.

The grinding action of the shells produces fine fragments of wood, which are ingested, and the cellulose component digested. The animal remains in the same tunnel throughout its life and lines it with a calcareous deposit. The animals avoid intruding into neighbouring tunnels. In warmer waters some species can grow up to 2 m in length.

Teredinids are confined to marine and estuary areas with a good water-quality, -temperature (warmer than 5°C) and a salinity exceeding 7‰ (DWW 1998). Their occurrence in the UK is sporadic and in some cases seasonal.

Figure 18. Shipworm/Terinidid (courtesy to TRADA)
Figure 19. Shipworm attack (courtesy to TRADA)

Gribble
The crustaceans are very different from molluscan borers. The principal difference is that crustaceans may move to fresh wood whereas molluscs remain in their burrows for life.

In UK waters, the principal crustacean marine borer is *Limnoria spp*. otherwise known as the gribble. Attack by the gribble is superficial and results in the creation of a network of tunnels varying in 1-3 mm in diameter at or just below the surface of the wood. These tunnels are characterised by regularly spaced respiration holes at the wood surface.

The adult gribble has a segmented body and seven pairs of legs and varies in size from 2-4 mm in length and is whitish-grey in colour. The ecological factors such as sea temperature and salinity have a significant impact on the distribution and vigour of the gribble. Extensive attack by the gribble weakens the wood to such an extent that the surface layers are eroded away by tidal action. The rate of erosion may be further accelerated by the action of soft rot type fungi. Gribble are more resistant to changes in salinity and higher levels of pollution than shipworm, but are commonly found in water warmer than 5°C and salinity exceeding 10‰ (DWW 1998).

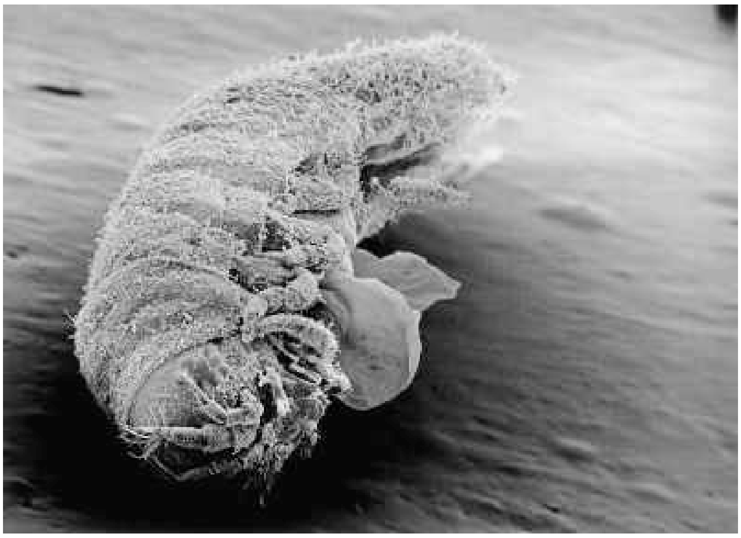


Figure 20. *Scanning Electron Micrograph of a gribble/Limnoria spp (courtesy to Natmus, Denmark)*
Figure 21. *Gribble attack on a timber pile (courtesy to TRADA)*

Knowledge of the incidence of marine borers around the UK, and European coastline is an important consideration for the engineer when specifying timber. Unfortunately, the last comprehensive survey for marine borers in the UK was carried out by TRADA during the 1960's. This survey showed that gribble and shipworm were present at various locations, around the entire UK coastline. With reference to both types of borer, the research demonstrated that geographical features such as changing water temperatures influences overall distribution of the organisms. Other factors within harbours and river estuaries such as tidal range, sea and air temperatures, salinity, oxygen levels and pollutants may also be significant. These factors may alter widely over a short space of coastline. One factor of importance to consider is the influence of marine borer infested wrecks in and around harbours and also the effects of borer-infested driftwood entering harbour areas. The risks of introducing borers through wrecks and driftwood may be minimised by good harbour hygiene.

3.3.4. Other degradation processes

Insect attack

In general, timber structures serving in the marine and fresh water environment are not vulnerable to insect attack in the UK. However, there are exceptions to this statement and it should be qualified by the fact that sapwood regions that may exist in some timber elements will be vulnerable. Untreated sapwood, ideally, should not be present on these types of timber structure. However, where sapwood band exist, they will deteriorate rapidly. This may have consequences if fixings have been located within sapwood areas.

Where insect attack is noted over the timber structure, i.e. it is not limited to sapwood, it will usually be the evidence of “weevil” attack. The wood-boring weevil only occurs on decayed timber. Therefore, the presence of weevil serves as a warning that more hazardous organisms are at work degrading the structure.

Chemical degradation

The most important characteristics relating to chemical resistance are impermeability and density. Chemical attack is restricted to the surface of the timber and can be caused by acid or alkaline chemicals. Degraded wood surfaces have a “fluffy” appearance and are quickly eroded. The attack is superficial. In the marine environment, sea spray results in salt deposit forming on the wood surface, which can result in defibrillation of the fibres. One positive side effect of these salt deposits is that they act as a natural preservative and discourage many species of fungi from degrading the timber.

Photochemical degradation

On exposure to ultra-violet light, the coloration of the heartwood of most species, for example, Teak, Mahogany and Iroko will lighten although a few species such as Douglas fir will actually darken. Colour change is part of the photochemical degradation process. The effects of wind and rain also cause degradation of the timber surface. Weathering results in the loss of surface integrity of the timber and affects its appearance. Generally, weathering does not the affect the long-term performance and strength of timber elements. There is one exception and that is the breakdown of surface finishes and can result in premature failure of joinery products as water penetrates through the paint film and raises the moisture content of the component to levels which can support fungal decay.

The rate of photochemical degradation and weathering results in slow erosion of the timber surface and can act as an indication of fungal decay. With reference to maritime and fresh water structures comprising dense, large sections of timber, weathering is insignificant.

Thermal degradation

Very low temperatures have no effect on the strength properties of timber. High value softwoods originate from well within the Arctic Circle where for many months of the year the tree is standing in permafrost. Thermal degradation only occurs in timbers that are exposed to high levels of radiant heat where the surface can attain a temperature above 100^{o}C. The surface of the timber will darken.

Degradation by fire

Timber is an organic material, and as such, in the dry state it is flammable. The thermal energy required to ignite and sustain the burning of timber is considerable. Timber has the ability to form a char layer, which is a good insulate and slows down burning. The behaviour of timber in fire is predictable in relation to the section size of the component and its density.

Fire degradation in marine structures may be viewed as uncommon and can occur by accident or by vandalism. Where fire degradation has occurred, very often it is possible to predict the residual strength of the structure by considering the reduced sections of timber, which have been protected by the char layer.

3.4. Durability and preservation

Wood is naturally a durable material, which is resistant to most biological attack, provided it remains dry. However, prolonged wetting leads to a risk of decay by wood rotting fungi, though susceptibility varies according to the wood species. This varying susceptibility is categorised by the timbers' natural durability classification.

There are significant differences to the European Standards approach to durability and preservation compared with the approach in existing British Standards. The following sections will discuss the fundamental issues regarding durability and preservation that are common to both European and British Standards. Section 3.6 gives a brief overview of the differences between British Standards and the European Standards.

Durability may be a natural feature of the timber or it may be imparted by the use of preservative treatments. However, before discussing the technical factors, critical to the successful preservation of timber, it is important to gain an understanding of natural durability.

3.4.1. Natural durability

Timber is a variable material and its natural durability to various forms of biological attack is affected by many factors. Natural durability may be defined as the resistance of the timber to biological attack. It is important to recognise that the term natural durability only refers to the heartwood of timber species. The sapwood of all timber species has no natural durability.

Timber species differ distinctly in their resistance to biological attack. The heartwood of some species, e.g. Greenheart, will last for decades in ground or marine contact whereas that of European redwood will suffer destruction in a comparatively short period of time. Historically, natural durability was recognised through experience of working with various species. However, in the nineteenth century field tests provided specifiers more reliable test data.

In more recent times natural durability ratings have been determined by one of two methods. These ratings are based on field tests where 50 x 50 mm stakes of heartwood have been exposed in ground contact and assessed at regular intervals. Larger section sizes will last longer in ground contact. For example if a 50 x 50 mm heartwood stake of oak lasts 15-25 years in ground contact, it follows that a 100 x 100 mm stake can be expected to last 30-50 years. The drawbacks of this test method are that it is time consuming, location dependant and subject to human error.

A faster more objective method to assess durability is to carry out weight loss tests with specific laboratory organisms as detailed in *BS EN 350 Durability of wood and wood based products – Natural durability of solid wood Part 1: 1994 "Guide to the principles of testing and classification of the naturally durability and treatability of selected wood species of importance in Europe"*. Part 2 of BS EN 350 presents a list of 20 softwoods, 107 hardwoods and 7 commercial species groupings.

BS EN 350 identifies five natural durability ratings, which are detailed below. The equivalent British Standard BS 5589: 1989 "*Preservation of timber*" also classifies timber into five durability ratings but does not assign them a numerical classification. The durability ratings are summarised in Table 2. For a wider range of species the reader should refer to BS EN 350-2 and BS 5589.

Table 2 Classification of natural durability

BS EN 350		BS 5589	Approximate life in ground contact	Examples
Class 1	Very durable	Very durable	>25 years	Jarrah, Greenheart, iroko, and ekki.
Class 2	Durable	Durable	15-25 years	European oak, sweet chestnut, robinia and yellow balau
Class 3	Moderately durable	Moderately durable	10-15 years	Caribbean pitch pine, Douglas fir, sapele and European larch
Class 4	Slightly durable	Non – durable	5-10 years	European redwood/whitewood
Class 5	Not durable	Perishable	< 5years	Beech, sycamore and ash

The natural durability ratings defined in BS 5589 and BS EN 350 do not consider the resistance of the timber to marine borer attack. It is important to recognise that resistance to marine borer does not necessarily parallel resistance to fungal decay. In addition, natural durability in any climatic or geographical region may vary according to the force of wood destroying flora and fauna. It is therefore important to carry out a risk assessment based on local information about the performance of wood species and the presence of wood destroying organisms.

Natural durability may also vary within the tree itself, especially for those timbers that are classified as being very durable. In some species such as Ekki, some anatomists have described a layer of timber between the sapwood and heartwood as “transition wood” which is not as durable as fully formed heartwood. Transition wood is generally slightly paler than the fully formed heartwood.

As previously stated, it is important to recognise that natural durability against fungi does not necessarily indicate durability against marine borer attack. The majority of timber species are susceptible to marine borers but a limited number of species are recognised as being resistant, i.e. naturally durable in the marine environment. It is also important to recognise that local site conditions will also affect the longevity of timber structures. For example, a timber that is naturally resistant in temperate waters may be more vulnerable in tropical waters. In addition, brackish sites support a greater hazard of shipworm than saline waters.

High silica content of 0.5% or greater is thought to impart resistance against marine borer attack. It is thought that a silica aggregate deposited in certain timber species has a blunting effect on the boring apparatus of marine borers. Resistance may also be imparted by toxic extractives present in the timber. The natural defence mechanisms against marine borers are presented in Table 3.

Table 3 Natural defence mechanisms against marine borer attack (based on DWW wijzer 91)

Defence mechanism	How	Disadvantages	Examples of resistant species
Silica	Silica aggregate form a mechanical resistance	- Difficult processing of timber - Silica content has to exceed 0.5%	- Basralocus - Manbarklak
Alkaloids	Natural toxic extractives	- Alkaloids can leach out after several years - Eco-toxicity of leaching out of alkaloids is not known	- Greenheart
Density and hardness	Great strength and coherence form a mechanical resistance	- Difficult processing of timber - Performs best in combination with other defence mechanism	- Manbarklak - Ekki

3.4.2. Preservation of timber

Historically wood has been treated with a wide range of wood preservatives prolonging the service life of timber. However, some of these compounds have been banned from use whereas others are being restricted. The principal reason for the banning and restriction of certain compounds is their reported eco-toxicity. Greater environmental awareness and the need to develop environmentally friendly preservatives has driven preservation research and, since the 1970's, many new chemicals and products have been tested for their effectiveness. Some commercially available treatments are still being appraised for their long-term performance.

At the time of writing the use of creosote based wood preservatives in the European Union is expected to be restricted in the near future owing to concerns that benzo-a-pyrene, one of the active compounds in creosote is thought to be more responsible to trigger cancer than was previously thought.

The primary objective of the pre-treatment, or pressure treatment of timber with preservatives is to ensure that even when timber is serving in a hazardous environment it remains in good condition throughout the design life of the component. Therefore, where naturally durable timber species are not available it is possible to use non-durable preservative treated timber species in their place. However, the specifier must be aware of a number of limitations governing the use of preservative treated timbers in the marine and fresh water environment, for example, preservative effectiveness and timber permeability. In simple terms pressure treatment encapsulates the timber component with a preservative envelope. The treatability of the timber regulates the depth of this preservative envelope and the end use of the component. Pressure treatment is the most effective method of application for the majority of wood preservatives, although by itself pressure treatment is absolutely not a universal solution to increase the durability of non-durable timber species in hazardous environments.

Three types of preservative treatment may be considered appropriate for non-durable timber that is expected to serve in a marine or fluvial environment. These are water borne salts/oxides, tar-oil preservatives and light organic solvent preservatives (LOSP's). It is also important to specify a timber that is permeable to wood preservatives, especially if preservative treated timber is introduced to the marine environment.

Water borne preservatives

There are two types of water borne preservatives. In one type, the active ingredient remains soluble in water and can be leached from the timber if service conditions involve prolonged exposure to water and (wet) soil. This mobility is not desirable in timber serving in a marine or fluvial environment. Typical mobile water borne wood preservatives are boron-containing salts. These types of preservatives are not suitable in hazardous environments.

The other types of water borne preservative are mixtures of inorganic oxides. Water delivers the active ingredients into the timber under pressure. The actives react with surrounding timber and are chemically fixed to the timber to give a highly effective preservative treatment. In other words the preservative is permanently incorporated in the timber and does not leach.

These types of inorganic salts usually contain copper, chromium and arsenic (CCA) commonly known throughout the UK industry as “Tanalith”. Despite their excellent track record, the use of CCA type preservatives in some countries is being restricted because of the arsenic and chromium content. However, in the UK the use of CCA type preservatives are not restricted at time of writing.

Light organic solvent preservatives

Light organic solvent preservatives (LOSP's) may be used to treat timber but these preservative systems must be used in conjunction with a protective coat over the timber such as a paint layer. This type of wood preservative would only be appropriate in situations where regular maintenance of the structure is carried out. One feature of many of the LOSP's is that once the protective (paint) film fails the preservative leaches out of the wood. Timber treated with these types of preservative may only be used out of ground contact. LOSP's are also coming under closer inspection as during treatment volatiles are emitted as a by-product. New technologies have led to the use of emulsion type carrier systems, dispersed in water, which results in lower emissions of volatile organic compounds into the atmosphere.

Tar-oil preservatives

Tar-oil or creosote-based preservatives have been used extensively in marine and fluvial environments and at one point were the pre-eminent preservatives used worldwide. In the UK, to date, there are no current regulatory controls governing the use of creosote treated timber in these environments. However the marketing and use of creosote and all products treated with it are to be banned throughout the European Union. Industrial applications of the wood preservative will also be restricted. The ban and restrictions come into effect throughout Europe from June 2003.

The principal technical disadvantages of creosote are that it is not possible to apply paint or stain systems to creosote treated timber. The wood is greasy to the touch and is vulnerable to "bleeding". This is when creosote migrates to the surface of the timber, which can be deposited on exposed skin, clothing and animals. In many recreational applications, this is undesirable and has led to its restriction. In such situations, water borne CCA type preservatives tend to be favoured.

The table below gives an overview of the artificial defence mechanisms against marine borers, among which preservative treatment.

Table 4 Overview artificial defence mechanisms against marine borer attack (based on DWW wijzer 91)

Defence	Method	Advantages	Disadvantages
Preservative treatment	Applying preservatives under pressure	- Protection against marine borer attack - Permeable timber species are easy to treat	- Possibly leaching out of preservatives - Timber has to be treated before construction
External treatment	Applying a protective coat over the timber	- Protection against marine borer attack	- Protective coat may be damaged (regular maintenance) - Timber has to be treated before construction - Protective coat may be environmental-unfriendly product
Sealing	Wrapping the timber with some kind of synthetic	- Protection against marine borer attack - Kills marine borers present in the structure - Timber can be sealed after construction	- Expensive - Synthetic wrapping may be damaged - Structure isn't strengthened
Detailing and constructive aspects	- Reduce number of piles in contact with water - Use appropriate timber species (resistant timbers in water, non-resistant above water)	- Environment-familiar materials used	- Restricted construction possibilities
Use of alternative materials		- No marine borer attack	- Inappropriate use of venerable materials - Non-renewable materials - Often lower ecological value

Treatability of timber

The life expectancy of non-durable or perishable timber components may be enhanced by pressure treatment with an appropriate wood preservative. The effectiveness of the pressure treatment and the service applications of the timber will also be dependent on the permeability or treatability of the timber to the preservative. BS 5589 and BS EN 350-2 describe four categories of permeability or treatability, i.e. the ease with which a timber species can be pressure treated, which are listed in Table 5. Where high preservative loadings are required to protect timber, only those species that are permeable or moderately permeable should be used. Deeper and more uniform preservative penetration into timber may be achieved by incising the wood. Incising is a process whereby the surface of the timber is cut with sharp blades at regular intervals. For example, Douglas fir, although classified as being moderately durable against bio-deterioration, has been used extensively in the marine environment. However, the sapwood of Douglas fir is moderately resistant to treatment and the heartwood is classified as resistant.

Table 5 Classification of permeability classes

Treatability class		Description	Explanation	Examples
BS 5589	**BS EN 350**			
Permeable	1	Easy to treat	Easy to treat; sawn timber can be penetrated completely by pressure treatment without difficulty	European beech, pine (sapwood)
Moderately resistant	2	Moderately easy to treat	Fairly easy to treat; usually complete penetration is not possible, but after 2 –3 hours pressure treatment, more than 6mm lateral penetration (depth) can be reached in softwoods and a large proportion of hardwood vessels will be penetrated.	European elm, pine (heartwood), sitka spruce (sapwood)
Resistant	3	Difficult to treat	Difficult to treat; 3 – 4 hours pressure treatment may not result in more than 3 – 6mm lateral penetration	Douglas fir, European larch, obeche, spruce (heartwood)
Extremely resistant	4	Extremely difficult to treat	Virtually impervious to treatment; little preservative absorbed even after 3-4 hours pressure treatment	Basralocus, Greenheart, jarrah, European oak, teak

3.4.3. Durability by design

No construction is capable of lasting forever. Nevertheless, structures built of timber are capable of achieving long and excellent design working lives, provided that the correct principles are considered. With time, moisture and dirt can become trapped at member junctions, unless good details are provided to minimise the risk at such locations. Trapping points lead to premature decay and insect attack, which then spreads to other parts of the structure. Careful detailing provides conditions for moisture drainage and air circulation at such points. By understanding the relationship between moisture content and fungal decay, it is possible to improve and prolong the service life of timber structures by following a few basic principles.

The following principles illustrate the key points for improving the durability of timber structures:

- Provide effective drainage from timber
- Protect exposed end grain
- Protect the top of horizontal members
- Avoid direct contact with other absorbent materials
- Avoid water traps and capillary paths
- Ensure surfaces are well ventilated
- Control vapour diffusion
- Be aware of moisture movement of timber

Good drainage details minimise the volume of water that can accumulate on horizontal surfaces. Furthermore, by using the effects of surface tension, design details can be improved to so that the risks of fungal decay are minimised (see Figure 22). Sharp corners tend to break surface tension whereas radiused corners maintain surface tension. When combined with a slope of 1:8, water is drained away from the horizontal surface. The water on the vertical face pulls the water off the horizontal face. The radiused surface should be a minimum of 3 mm.

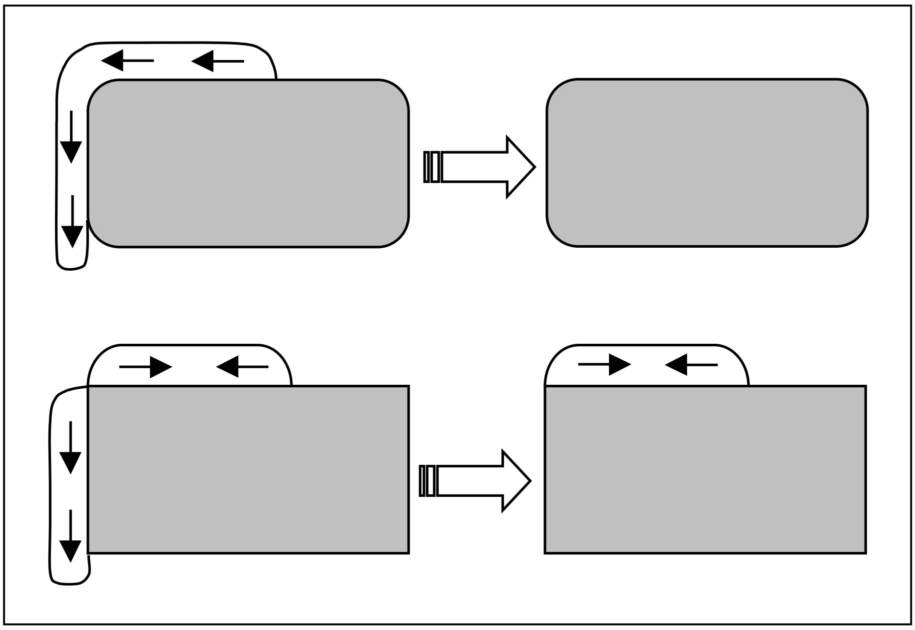


Figure 22. The advantages of incorporating a radiused corner to horizontal surface

One of the most common causes for premature failure in external timber structures is the lack of a capping detail. The microscopic structure of timber may be simply described as a bundle of "drinking straws". Therefore water can penetrate down exposed end grain faces with the result that the consequent increase in moisture content can support fungal decay. By capping the end grain of exposed elements, the risks of fungal decay penetrating along the wetted end grain are significantly reduced.

Sometimes it may not be possible to fully protect joints in timber structures and it is inevitable that moisture will remain trapped and localised areas of high moisture content may occur. For example, the joint where a supporting beam connects with a piling in a bridge may be particularly at risk. It may not be structurally practicable to introduce ventilation around the joint. Therefore, a drainage channel could be drilled into the ventral sector of the joint. Additionally, boron rods could be added to the joints to provide preservative protection against fungal decay. Very briefly, boron rods are highly concentrated reservoirs of boron based wood preservative. The preservative is activated and mobilised by moisture; in other words, the preservative is only activated when conditions are conducive for fungal decay. Boron rods should not be used in marine and fluvial engineering, as boron is highly toxic to fish.

3.5. Environmental considerations

3.5.1. Sustainable procured timber

The Forest Stewardship Council's Trademark is a label on timber and wood products, which indicates that the wood comes from a well-managed forest. The FSC is an independent, non-profit, non-governmental organisation. It is an association of members founded by a diverse group of representatives from environmental and social groups, the timber trade and the forestry profession, indigenous peoples' organisations, community forestry groups and forest product certification organisations from around the world. FSC certified timber guarantees that the forest of origin has been independently inspected and evaluated to comply with an internationally agreed set of strict environmental, social and economic standards. The FSC Trademark enables designers and specifiers to choose timber with the confidence that they are not contributing to the destruction of the world's forests.

There are now a wide variety of FSC certified timber species available in the UK: European hard- and softwoods, North American hard- and softwoods and tropical hardwoods. However, there are a few species not yet available carrying the FSC label. There are many lesser-known species, which can be substituted - woods that have the same or similar properties as their better-known counterparts.

Many organisations are now implementing timber specification policies. Such a policy would ideally cover all projects where timber is specified. Having a policy about timber specification is a good way of ensuring that everyone working on a project is clear about what timber is acceptable for use.

Table 7. Overview what to check when ordering or supplying FSC certified timber (based on DWW wijzer 92)

a) Specification at tender stage	Specify that FSC-certified timber should be supplied
b) Direct delivery	• Check delivery note • Stamp or sticker on timber (not obligatory) • Certificate (not obligatory) • Afterwards: check invoice of the supplier
c) Delivery via contractor	• Add witness point to quality plan • Check waybill • Stamp or sticker on timber (not obligatory) • Certificate (not obligatory) • Afterwards: check invoice of the supplier
d) Delivery note	• Reference made to FSC • Relevant certification scheme/organisation mentioned • Code number referring to the chain of custody certificate number • Timber specie, quantity and sizes of timber
e) Timber	Label, stamp or sticker on timber (not obligatory)
f) Certificate	Supply of a certificate is not obligatory and only a certificate is certainly **not** sufficient proof of certification
g) Invoice of the supplier	• Reference made to FSC • Relevant certification scheme/organisation mentioned • Code number referring to the chain of custody certificate number • Timber specie, quantity and sizes of timber
When in doubt:	**Contact the mentioned certification organisation or FSC**

3.5.2. Recycled timber

Recycled timber can provide a valuable source of material. Re-claimed timber should be set apart from "new" timber and certain guidelines should be followed. It is critical that the right species for the job is selected. By identifying the species, the salvager can judge whether it is worth recycling the timber and what markets the recycled material should be aimed at. Generally, the timbers should be machined so that worn, weathered and damaged surfaces are removed to expose the underlying timber. This will inevitably result in a loss of section. The freshly exposed surfaces are now in a presentable condition to enable the timber to be graded to the appropriate visual or machine-grading standard.

In addition to naturally occurring strength reducing features such as knots and slope of grain, the timber may have been significantly affected by man-made defects such as holes for fixings and notches. In practical terms, where high volumes of timber are being recycled, heavily notched timbers should be machined so that these areas are removed. The timbers should be assessed for any signs of bio-deterioration such as fungal decay and marine borer attack. Survey techniques typically include decay detection drilling and hammer soundings.

Mechanical damage may significantly affect the strength of recycled timber. If there are visible signs of impact, there may be a risk of compression failure within the timber. If compression failure is suspected the timber should be rejected and cross cut to exclude the impact area.

Large section timbers such as Balau, for example, may have been cut in such a manner that the member contains “boxed heart”. Boxed heart is when the weaker, less durable timber comprising the pith in the centre of the tree is protected by stronger durable material. Examining the end grain usually identifies timbers that exhibit boxed heart. Provided that the boxed heart is still armoured by older mature timber after cleaning, the reduced section may be used. However, it may not be advisable to place the recycled member in a critical part of any structure. If the reduction of the section results in exposure of the pith along the length of the member then it should be rejected.

There are other factors to consider. Large section timbers that have been serving in dry conditions will be well seasoned and, as such, will be dimensionally stable. In situations where little timber movement is expected, recycled timbers may have significant advantage over large sections of green timber.

3.6. Design standards for timber structures

All timber structures have to be designed with certain regulations. In the UK the British Standards have been used, and still are used for this. Currently European standards are being introduced, which will replace the Britsh Standards in the near future. The regulations for the design of timber structures are given in Eurocode 5. The major difference between Eurocode 5 and the currently used BS 5268 is that Eurocode 5 is based on a limit state approach to design and the British Standards are based on a permissible stress approach.

British Standards

In permissible stress design the permanent loads and the characteristic values of the variable loads on a structure are used directly to derive the stresses in it’s various components. The designer then ensures that these stresses do not exceed the permissible values for the materials, which are computed from their characteristic values, reduced by appropriate safety factors and tabulated in the code. Applied stresses are compared with permissible stresses.

Eurocode 5

In limit state design, partial factors are applied to both loads and materials. These factors are of four kinds:

- Permanent loads
- Variable loads
- Accidental loads
- Material factors

Comparison is made between the design values of the effects of actions and the design strengths of materials.

4. CASE STUDIES

When starting the case studies, at first calculations have been made of which a few are presented in Appendix 1. Before long was discovered that the design of timber groynes has evolved in time and largely differ from a calculated groyne. As the size of the timber members is highly related to, for example the desired life time, level of abrasion and impact loading the best dimensions have been discovered by replacing and repairing groynes over the past few centuries.

Hardly any design for timber groynes has ever been documented, leading to different designs along the UK coast. Often one local authority makes design “mistakes” that other authorities may have made in the past. A lack of documentation and communication between the authorities is the main cause. Therefore these case studies have resulted in combining the best practice designs and experience to provide guidance on the use of timber groynes. It has been revealed that durability by using certain design details is the most advantageous improvement for timber groynes. And pointing out the importance of waste-minimisation, reuse of old timber and procurement of certified timber can lead to the sustainable use of suitable timber species.

At the start of this research project a number of schemes along the south coast of the UK were visited. This chapter summarises information about six of these schemes. When visiting a certain scheme, a representative of a local authority or consultant provided with explanation and information about the scheme. 0 presents a map with the locations of the visited schemes along the southern UK coastline.

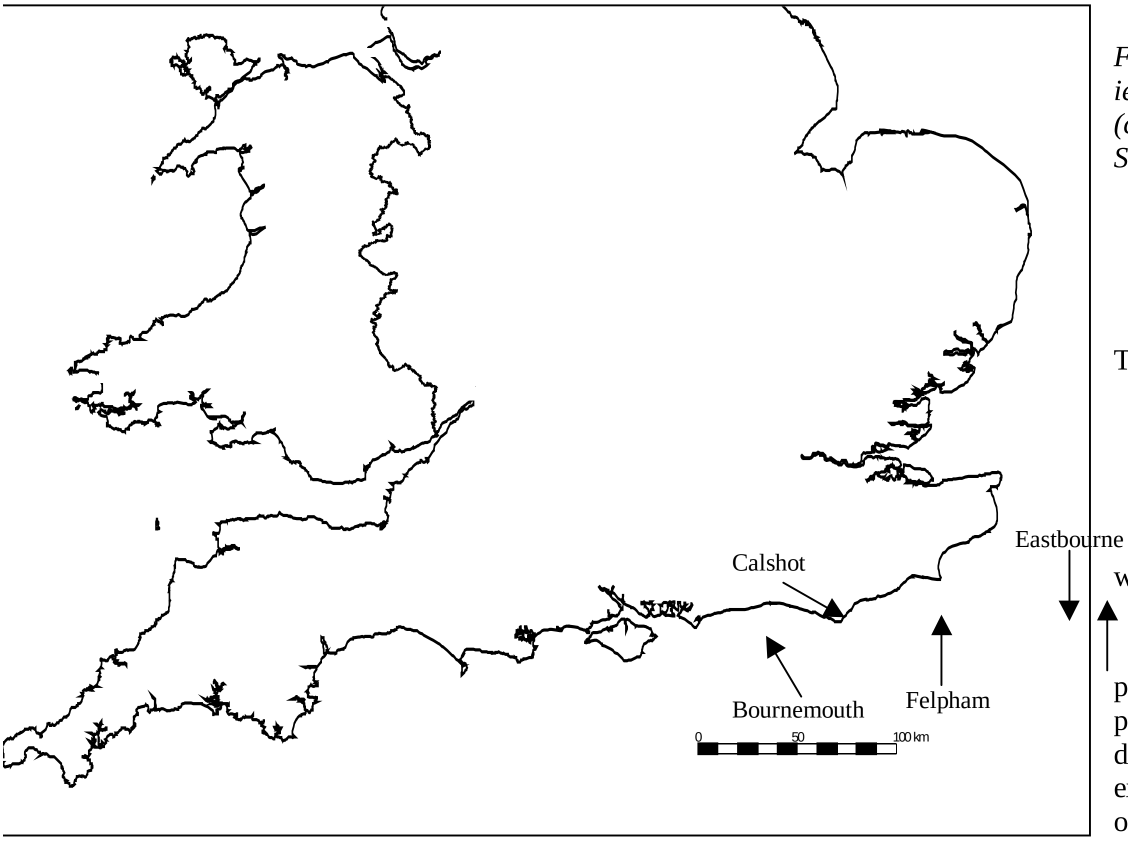


Figure 23. Overview map site locations (courtesy to Ordnance Survey)

The responsibility for a certain scheme depends on whether the scheme is part of a coast protection or sea defence. An explanation for the often confused distinction between coast protection and sea defence is that coast protection protects relatively higher land from erosion, whereas sea defences protect lower lying land from flooding. In case of a sea defence the responsibility lies at the Environment Agency, otherwise at the local authority. The UK is divided into counties, which again are divided into the local authorities (see map in Appendix 5). Table 8 below names the studied schemes with the local authorities and counties in which they lie.

Table 8 Local authorities and counties

Scheme	Local authority district	County
Bexhill	Rother District Council	East Sussex
Bournemouth	Bournemouth Borough Council	Dorset
Calshot	New Forest District Council	Hampshire
Eastbourne	Eastbourne Borough Council	East Sussex
Felpham	Arun District Council	West Sussex
Tankerton	Canterbury City Council	Kent

As the site visits took place in April 2002, most of the beach levels were relatively low because of their winter profile. This gave the opportunity to get a better viewing of the structures, but made it more difficult to determine their performance. However, discussions with responsible authorities or maintainers revealed how the coastline evolved after construction of the scheme. This gave an excellent understanding of the performance in a larger time scale, which obviously is of greatest interest.

After the site visits, information was obtained through designers, consultants, maintainers, contractors, local authorities and timber merchants, such as drawings, engineering reports, photographs and costs. Remarkably not a single strength or stability calculation was found in all the gained information. Some consultants declared that some stability calculations had been made in the past, and current designs were made using their experience. The information on each of the schemes is summarised and presented together with aerial photographs in Appendix 5. Together with the experience of consulted organisations, understanding and analysing the schemes have resulted in guidance on best practice and is discussed in Chapter 5.

4.1. Bexhill

The Bexhill coast protection scheme lies within the Rother District Council's boundaries. The groynes at Beaulieu Road (Bexhill) have been constructed in 1977 and are still in a good condition. The beach consists of mixed sand and shingle, which lies on top of a siltstone bed. At the time of construction of the groynes, no beach material was present at all. The old groynes were founded in the beach and were washed away together with the sand and shingle. Prior to the works in 1977, the grass slope behind the beach was rapidly eroding and thus endangering the urban development at the top of these dunes. Posford-Duvivier recommended groynes to be constructed on the siltstone bed, together with a beach renourishment program.

Figure 24. *Groyne at Bexhill with underlying bedrock showing at low tide*
Figure 25. *Detail of rubbing piece protecting the main pile*

At the bottom of the grass slope a concrete working platform was built, with a six-meter drop down to the bedrock beside it. The slope of the siltstone bed is approximately 1:29, and still can be seen in front of the beach at low tide. An estimation of the beach profile was made and resulted in the design of 85 m long groynes with a slope of 1:13 (with 6 steps in the planking). In order to construct a stable groyne, triangular frames were constructed to work as props and ties. These frames were prefabricated off-site and reassembled on site. A trench was excavated into the siltstone bed, in which the posts were planted, and backfilled with concrete. Two steel U-profiles acted as ties between the main piles and the braces. Throughout the scheme two hardwood timber species have been used: Balau for the piles and Kapur for the planking. As the lengths of the piles vary from nearly 7 m to 2.2 m, the section sizes vary too. Even planking and waling sizes vary over the length of the groyne, minimising the quantity of timber used, but resulting in a more complex construction plan.

After completion of the groynes, mixed sand and shingle was brought ashore, to protect the dunes and to minimise downdrift erosion. The groynes were designed for a 30 to 40 year lifespan and seem to be in a good condition after 25 years. This scheme may be called quite successful, as it clearly shows that the groynes hold the beach in its place. Just beyond the end of the groyne heads the siltstone bedrock, with no loose material on it at all, shows at low tide. The estimated beach profile corresponds with the actual profile, resulting in the good functioning of the groyne. Additionally, regular maintenance has prevented major damage on the structure, which would make washing away of beach material possible. On critical levels, rubbing pieces, as shown in Figure 25, have been attached to the main piles, ensuring the latter to withstand their design-lifetime.

Figure 26. Planting posts in trench (courtesy to Posford Haskoning)

This case study is based on information provided by Posford Haskoning and site visit observations in April 2002 together with John Andrews, responsible for the design of the scheme.

4.2. Bournemouth

The Bournemouth Borough Council's coastline is composed of sand, gravel, clay and rock. At Hengistbury Head low grade iron ore boulders served as an excellent shore protection in the past. However in 1948 the iron ore was removed from the foreshore as part of a mining excavation, which led to the rapid erosion of the beaches at Hengistbury. At Bournemouth the beaches consist mainly of fine sand, this changes at Southbourne (eastwards) to coarser material. The last part of the beach up to the Long Groyne at Hengistbury consists of gravel and cobble size material. Most areas of cliff have been protected from sea erosion by seawalls and groynes for over 90 years and have been re-graded to a more stable angle.

Longshore drift is considered to be the main cause of sediment depletion in Bournemouth. Sediment accumulations at Studland, Hengistbury Head Long Groyne, Mudeford Spit and Hurst Spit are results of the predominantly eastwards direction. Drift to the west is less common but does occur and is the causation of Sandbanks spit and the Sand Hills.

The beach near Hengistbury Head Long Groyne is mostly unprotected from long fetch Atlantic waves. The longest fetch English Channel waves come from a south-easterly direction with exposure increasing to the east therefore, wave height is slightly higher at Southbourne than Boscombe. Winds from the west or south-west are more frequent and stronger than winds from the east so, Southbourne also receives the most powerful winds. The (small) tidal range hasn't caused any problems except when at spring tide combined with the channel surge in extreme conditions.

Figure 27. High quality groyne at Bournemouth

From 1915 until 1969, 45 concrete groynes, three steel groynes and one timber groyne protected the Bournemouth coastline in combination with a seawall. In 1970, when the existing groynes were in a dangerous condition, a review of the coast protection policy was done by Halcrow and led to the new policy of beach replenishment with timber groynes to hold the fill in place. A change to timber was made because of the difficulty of maintaining concrete in the aggressive marine environment. In 1991 the "Groyne building programme" was completed, with in total 51 new timber groynes. Now Bournemouth has a field of 52 timber, 3 concrete and 10 rock groynes.

The earliest of the 51 new groynes were built with a high profile at the outer end. Later groynes were built with the planks at a lower level as an economy measure to reduce costs. The Greenheart piles were placed to the same level leaving the possibility of raising the groynes at a later date. Either horizontal planking or vertical sheeters were used. Five different experimental designs had been used between 1971 and 1975, including a permeable type of groyne. This design was not repeated as they suffered severe abrasion and members were lost. Additionally an aerial survey was done and identified these permeable groynes as being ineffective. Another type was introduced with a low profile, thinner planking (75 mm) and joints in planks at the piles to increase strength. By 1996 all five types of groynes had been demolished and replaced by the type proven to be best, with some additional improvements.

In 1987 an experiment was done using 5 different timber species for the planking on several adjacent groynes. All groynes had Greenheart piles, which showed gribble attack when inspected in 2000. The Greenheart planking showed the worst wear and Ekki planking least.

Monitoring beach levels within the groyne bays assesses the performance of the groynes. This has led to several improvements in both the profiles and positions of the groynes. The improved and currently used design consists of 300 x 100 mm sheeters and planking attached to 305 x 305 mm piles with stainless steel bolts. At the upper end lower end of the 9 m long piles 300 x 200 mm waling supports the structure. The profile was made steeper to match better with the beach profile. At the seaward end the level is low to reduce turbulence. A higher level at the seawall avoids transport of sand over the groyne. Plywood panels have been fixed to the downdrift side of the groynes to prevent the gaps between the planking from opening up, which led to considerable problems on earlier designs. The panels have to be replaced with time, but are efficient in that they reduce damage to the planks. Joints and fixings have also been reviewed. Planks are joined with butt joints at the piles (having previously been between the piles to make best use of the lengths of planking available), which are easy to construct and provide the groyne with greater strength.

Figure 28. *Stainless steel fixings and pile rings*
Figure 29. *Plywood panels avoid transport of sand between planking*

The Bournemouth Borough Council maintains and replaces the 51 timber groynes along their coast in a rolling programme. The groynes have a life expectancy of 25 years so two groynes are replaced each year. The present construction cost of each groyne is approximately £195,000, which is in part due to the small tidal range and the large length of the groynes, which necessitates considerable temporary works (a steel platform is constructed to provide access for a crane). The hard underlying strata necessitate pre-boring for the piles with high-pressure water lances.

The Bournemouth scheme seems to perform satisfactory, which requires extreme precision, as a sand beach is vulnerable to scour, if the groyne is not designed and maintained properly. However the negative aspect of this sublime high quality timber groyne is its price. The design of the groyne has timber planking till the top of each pile, requiring exact estimation of the expected beach level. Scour on the piles is minimised in this way, but raising the height of the groyne will be an expensive matter. As one of the few sites along the UK coastline, the Bournemouth Borough Council had identified marine borer attack by gribble.

This case study is based on information provided by David Harlow of Bournemouth Borough Council and site visit observations in April 2002. Further the document “Environmental appraisal of the Bournemouth artificial reef proposals” by S. Harris has been used.

4.3. Calshot

New Forest District Council has renewed mixed softwood and recycled hardwood groynes and revetments over the last five years along the Calshot coastline. Calshot is situated along the Solent on a natural shingle spit with a large shoal area just offshore. The Isle of Wight protects the shore against large waves. This allows the existence of low-lying marshy areas along the Solent's shorelines, sometimes with a small shingle beach.

The New Forest District Council uses a maintenance-based approach for their shore protection structures at Calshot. Short zigzag shaped groynes have been constructed using reused hardwood king piles with 2 meter long treated softwood piles between them. The neighbouring privately owned coastline of Lepe uses entirely Douglas fir groynes. The locally grown Douglas fir softwood erodes fairly rapidly and needs regular maintenance, and replacement after approximately 10 to 12 years. At the landward end the Calshot groynes connect to a timber breastwork, constructed with the same timbers and a geotextile to hold fine material in place. At the time of the site visit a contractor was reconstructing the breastwork, progressing about 20 meters a day with two workers.

Figure 30. Low cost groyne at Calshot, UK

On either side of the king piles Greenheart waling is attached, leaving enough space for the round softwood piles to be placed between them. Pins are driven in a hole through the waling into the Douglas fir. The hardwood piles and waling are left in place when the softwood needs replacing.

Due to the eastward alongshore drift the shingle spit grows into the Southampton Water on the east. Regularly shingle is removed from the spit and transported updrift of the Calshot groynes. The small shingle beach is in a healthy condition, and its maintenance and replacement is relatively cheap. For these gentle wave and current conditions, this proves to be an excellent alternative to hold the coastline in place.

This case study is based on site visit observations in April 2002 and discussions with the maintaining contractor and New Forest District Council local authority.

4.4. Eastbourne

More than a century ago a concrete seawall was constructed along Eastbourne's coastline. Additionally oak groynes were installed in order to bring the dropping beach levels to a halt. Until the late 1980's these groynes were reconstructed and maintained when necessary.

In the late 1980's and early 1990's several storms caused permanent damage to Eastbourne's sea defences, leaving the town at risk of serious flooding. The sea front consists of a shingle upper beach with a flat sandy area uncovered at low tide. By the end of 1991 some areas were scoured out to bare rock and the beaches failed to recover. The exposed sea wall was regularly under attack of storm waves, and the groyne field in front of it severely damaged because of the extreme conditions. Broken timbers, high wave loadings and marine borer attack mainly caused damage. With the increased levels of attack and waves reflecting from the sea wall, the shingle beach had no chance of recovering at all.

Figure 31. Overview of Eastbourne coast protection scheme

Posford-Duvivier carried out investigations for the Eastbourne Borough Council and came up with a strategy for the future management of their coastline. In the mean while emergency works were done to prevent the seawall from collapsing. The reports showed that because of updrift control of the coastline the natural west to east littoral drift was intercepted, resulting in an insufficient recharge of the Eastbourne shore. It was calculated that 229,000 m^3 of beach material had been lost between 1973 and 1990, including 41,000 m^3 of beach nourishment added between 1983 and 1989. The studies indicated further that waves were the dominating factor of the longshore transport of shingle and that a seafront without groynes would have resulted in an extra 19,000 m^3 loss of shingle per year.

After having evaluated numerous options, Posford-Duvivier recommended a closely spaced hardwood timber groyne field to be constructed, controlling a new and wider beach. To determine the minimum beach volume required and the beach profile response to storm conditions, HR Wallingford carried out a flume study. The results were used for a wave basin physical model, to determine the optimal spacing and configuration. Finally the most advantageous design consisted of a replenished beach controlled by 94 groynes and further specific extra works on three locations.

The construction of the coast protection scheme was launched in 1995 and completed in 1999. The £30 million scheme included the construction of 94 new timber groynes, rock revetments at particularly vulnerable areas of the beach and extensive beach nourishment. The average cost of one timber groyne was about £95,000. The sea wall was refurbished and on top a promenade, separated from the highway by a splash wall, was installed. The splash wall should prevent shingle from being thrown on the highway in case of any future extreme events. Massive groynes were constructed, being designed to retain a 3 meter differential across them. In order to realise a beach width of 20 meter and a slope of 1:9, in total over 780,000 m^3 of shingle was pumped ashore after completion of the groyne field.

Figure 32. Groyne with plant access bay

Each groyne was constructed with ties, consisting of entire Oak logs, attached to every fourth pile. The 230 x 75 mm planking and single 230 x 230 walings have been attached to the king piles (305 x 305 mm) using hot dipped galvanised coach-screws and bolts. The hard pile driving meant in some cases that the piles were stopped high and driven to the required depth after two to three tidal cycles. A gate was used to ensure that piles were square on the planking. In areas where the chalk platform made pile driving impossible, the posts were planted in a concrete filled trench. Sheeters below the planking were used where ground conditions allowed them to be driven.

In order to justify the decision to use Greenheart timber, the consultant and council investigated its sustainability. The whole procedure, including finding the appropriate supplier, led to a significant delay of the scheme.

The Eastbourne groyne profiles runs under a slope, and protrudes only about a plank's width above the beach at the head. This has a positive effect on the sandy lower beach, as currents will remain limited and cause no significant scour. At the upper end of the beach, plant access bays have been constructed, consisting of doubled piles at a wide spacing with extra thick planking spanning the entire width of the bay. When necessary the planking can be removed and plants can pass through the groyne. Especially in case of low beach levels, such as during construction this may come in handy to provide an exit for equipment operating on the beach. The high planking level over the entire length of the groyne provides no possibility to add planking. At some locations along the groyne's length it seems as if some planking may be better to be removed, to match the beach profile.

This case study is based on information provided by Simon Howard and John Andrews of Posford-Haskoning and site visit observations in April 2002. Further the paper "Eastbourne coast protection, 1991-2000" by B.E. Waters (2002) has been used.

4.5. Felpham

The Arun District Council has responsibility for approximately 18 kilometres of coastline along the south coast of England in West Sussex. Their defences generally consist of a shingle and sand beaches backed in critical locations, particularly where major urban development is close to the defences, by concrete sea walls. The sea walls, although constructed in the past as the primary defence, are now seen as a secondary form of defence protected in part by shingle beaches retained in front of them. Groynes have been present in various forms on the frontage for over a hundred years.

Figure 33. Groynes at Felpham with rock toe in front of seawall (courtesy to Posford Haskoning)

A littoral drift along the majority of the frontage has been used to gradually retain shingle and progress towards the designed beach profile over a number of years without the requirement for beach nourishment. Monitoring of sediment movement and gradual adjustment of planking levels has ensured that sufficient material is allowed to pass through the system to avoid problems in downdrift areas.

The western part the frontage has a chalk bed underlying the beach whereas in other areas the substrate is a blue clay. The chalk, if exposed, will weather very gradually without substantial erosion, the clay however when exposed can erode fairly quickly. This variance of substrate has led to the development of two types of groyne. The general design for both types is based on main timber piles driven into the substrate with horizontal planking to form the barrier to hold the shingle. On the frontage with chalk substrate the bottom plank is carefully let into a narrow trench excavated in the chalk surface hence avoiding under runs with minimal disturbance of the chalk. Where clay exists a lower waling is fixed above the clay level and vertical timber sheeters are driven into the clay to a nominal depth of 1.0 -1.5 meters before the top of the sheeters are fixed to the lower waling with coach screws.

All timber used in Felpham scheme, which was carried out from November 1998 to July 1999, is sawn Greenheart with nominal cross sections of 230 x 230 mm for piles, 230 x 150 mm for walings, and 230 x

75 mm for planks and sheeters. Walings generally span two full bays plus two half bays with scarf joints in mid-bay, whereas planks cover three or four bays and are fixed with coach screws.

Timber is purchased by the Council on a forward shipment basis for main schemes to ensure, as far as possible, supply from sustainable sources and also to reduce lead in times for the contract. Timber is then “free issue” to contractors. The Council’s ability to ensure that timbers are supplied from sustainable resources is limited by the reliability of information that can be obtained with regard to forestry practices in distant countries. The extension of such schemes as the Forest Stewardship Council certification scheme and the chain of custody certification will enable to purchase with a greater level of certainty. At the moment no quantity of suitable timber is covered by the FSC scheme according to the Council.

Standardisation in the groyne designs allows for accurate cutting schedules to be prepared to minimise waste. A minimum extra length of 100 mm on each piece should be allowed to compensate for tolerances in piling accuracy and to ensure tight butt joints in the planking where ends are trimmed parallel to piles and not perpendicular to the planking line.

General maintenance is carried out with biannual inspections, which leads to an annual maintenance contract, with the works normally carried out by the in-house works section. The inspections are supplemented by ad-hoc inspections carried out during other works and by information from the public. Local residents realise that early replacement of a lost or broken plank is generally in their interests. With a predominantly shingle beach, abrasion is the main problem. The two main areas of abrasion are on the piles, at beach level on the down drift side caused by the wave run up and back wash, and immediately above planking level where shingle is moved over the groyne by the wave action. There has been no indication of problems with marine borers. Timber rotting in situ has also been very limited and has been restricted to some of the Douglas fir timber, generally in areas at ground contact level after normally a minimum of 20 years. None of the timber used is treated in any way. Beach levels are allowed to settle for approximately two years following installation of the groyne and then an assessment is made of the need and location for “pile rubbing strips”. Maintenance generally consists of replacement of missing or broken planks, fixing of additional planks as the beach profile is improved and the fixing of pile rubbing strips.

There are approximately 300 timber groynes on the Arun District Council frontage and the maintenance budget is in the region of £70,000 per annum. This budget is provided to cover salary costs, timber supply and execution of the works. Of that budget annually approximately £40,000 will be utilised on timber purchase and timber groyne repairs and maintenance.

When end of life groynes are removed, timber is salvaged where possible for either re-use on future maintenance works or into the new scheme. Where the timber is not suitable for utilising in a groyne structure but is suitable for other purposes, it is either made available for use by other departments of the Council or sold off to recycling companies. The timbers re-used are generally main piles, cut in shorter lengths for the short piles at the tail end of new groynes; planking, which can be used for rubbing strips; and timber sheet piles which can be re-used either as rubbing strips for the piles or, where they are in very good condition due to little exposure to abrasion during their use, re-used as sheet piles.

The beach and groynes are in a good condition, and make the rock toe in front of the concrete seawall unnecessary.

This case study is based on information provided by Brian Holland of Arun District Council and site visit observations in April 2002.

4.6. Tankerton

The Canterbury City Council is responsible for the 16 km of coastline between Seasalter and Reculver, along the North Kent coast. The primary defence system of Tankerton is the shingle beach, which is controlled by timber groynes. Just behind the shingle beach a seawall holds and protects a grass slope. The seawall was initially constructed in 1911 and has been refurbished several times since. In February 1996 a storm event removed a great deal of the shingle beach and undermined the seawall partially. An extensive survey was carried out for the beach level and wall condition.

The full length of Tankerton's coastline is densely populated and at some locations permanent beach huts are constructed at the toe of the grass slope. The old timber groynes were constructed between the 1950's and mid eighties and their lengths, spacing and state varied considerably. The net littoral transport along the coastline is from east to west, with an estimated annual loss of shingle of 15,000 m^3. Until 1991 every two to three years the beach was recharged, allowing a five-year beach drop till the 1996 storm event took place.

Figure 34. Ekki groyne (courtesy to HR Wallingford)

The eroded beach exposed the underlying clay and the toe of the seawall in some areas, but in other areas the beach reached till the top of the seawall. Emergency works were carried out, filling the space beneath the toe with concrete and placing temporary fencing along the top of the wall.

The survey compared a number of alternatives for the Tankerton coastline and finally recommended the scheme with a beach and timber groynes. From mid 1998 works were carried out along the Tankerton frontage. A groyne field consisting of 36 timber groynes was constructed, and other groynes were refurbished. Additionally in total 122,000 m^3 of shingle was supplied to the beach.

The groynes are constructed with Ekki piles (230 x 230 mm) and planking (76 x 230). Some hardwood (Greenheart or Balau) was re-used from the demolition of the existing groynes, for sheeters, piles and struts. Both cantilevered as strutted piles have been used in the design, using Y-shaped raking struts as shown in Figure 35. The bottom planking acts as a waling with bolts countersunk in order to attach the sheet piles to them. At the landward end of the groynes, steel plates are attached to the top planking for plant access, together with cutting one pile flush with the planking. Other piles reach 300 to 530 mm beyond the highest planking, leaving the possibility to add one plank.

Figure 35. *Y-shaped raking struts (courtesy to HR Wallingford)*

This case study is based on information provided by Canterbury City Council and site visit observations. Further the following documents have been used:
Proposed coast protection works at Tankerton, Kent – Engineer's report, August 1996
Tankerton coast protection works – Phases 1 & 2, Timber supply contract, July 1997
Tankerton coast protection works, March 1998

5. GUIDANCE ON THE DESIGN OF TIMBER GROYNES

5.1. Effective functional design

The performance of a coastal protection scheme may be defined as to what extent the scheme's objectives are achieved. For timber groynes the objective is to reduce the net sediment transport along a shore, in order to retain a reserve of beach material. At a higher level, the objective is to reduce the risk of flooding and coastal erosion. Often a cost - benefit analysis will determine the maximum permissible risk, for a specific location and therefore the "performance" of a scheme is related to the "benefits" of its hinterland. So optimising a scheme's performance is obtaining the best results with as little investment as possible

In order to achieve the highest possible performance a review of the functional design is done in this section. The best functional design is only described in this section, giving a better understanding how to design effectively. Exact numbers won't be given and may be obtained using, constantly improving, computer models or flume tests. With an effective functional design, an optimal performance can be obtained. More constructional issues, achieving optimal performance at a lower level, are discussed later in this chapter.

5.1.1. Length

Groynes extending through the surf zone will trap more sand and the bays will fill up until sand passes around the groyne. When the widening of a beach is desired, the groynes can be constructed with a length matching the future breaker line. As the long groynes will catch nearly all of the longshore sediment transport, downdrift erosion will take place, unless sufficient beach nourishment is carried out. Short groynes, not extending across the surf zone, have the advantage that they don't intercept all the sediment transport along a shore, and thus cause less downdrift erosion. However part of the function of the groyne is lost, as the wave driven currents are only partly cut off. A shorter length has effect on the spacing of the groynes too, leading to a smaller spacing.

From an economic viewpoint, a groyne is preferably constructed above the mean low water mark, as building in the water is a costly matter. However for the functional design of a groyne system, they are only effective if they reach far enough into the surf zone. An important issue, for the length of a groyne, is the connection to the shore at the upper end of the beach. If the groyne is too short at the landward end, outflanking may occur. To avoid this, the groyne should run sufficiently far back into the beach to allow an occasional beach drop (and retreat of the beach head), without it harming the groyne. Alternatively the groyne can adjoin to a revetment or seawall, preventing the outflanking of the groyne.

As the length of the groyne is largely dependent on the beach material, in some cases a combination of long and short groynes can be useful. With an upper shingle and a lower sand beach, short groynes can be constructed between longer ones.

Generally the optimal length of a groyne is from the berm of the beach till approximately the breaker line. However, for tidal situations the breaker line changes with the tide level, for a given wave height. In practice it has proven to be effective to construct groynes beyond the breaker line of a summer wave climate at mean high water tide level. The reason for choosing the summer wave climate is because this is the wave climate when beaches are built up again.

5.1.2. Height

The height of a groyne, i.e. the height above beach level, is of great importance to currents around the groyne and to the degree of wave reflection. Therefore a groyne preferably only protrudes just above the beach level, adjusting it as the beach levels change. Especially the head of the groyne is of importance; a lower seaward section will allow currents to carry some sediment over the structure and will reduce wave reflections from the groyne. Most of the sediment transport will be trapped, as the greater concentration of sediment travels along the bottom (bed load). As shown in Section 2.7.2 the seaward end is often chosen to run horizontal. This will result in higher wave reflections, increased currents and larger forces on the structure. Additionally a sloped crest profile, as shown in Figure 36, has a positive effect on the abrasion of the structure by spreading the abrasion over the length of the crest.

In practice it will be uneconomic to continuously adjust the groyne height, but attempting to keep the groyne height at a level approximately two to three plank widths above beach level will improve the functioning of the groyne. A tolerance of another two plank widths will be acceptable, keeping in mind that sand beaches are more susceptible to an over-height than shingle beaches. A groyne profile matching the beach profile will reduce near shore longshore currents (wave and tidal induced), but minimise the increase of flows around the structure by letting water pass over the structure too. For new groyne systems, where a build-up of beach material is anticipated, ideally the groyne height is increased, working from the downdrift end as the beach develops. Similarly, gradually increasing the height during the groyne's lifetime can spread concentrated abrasion on the structure.

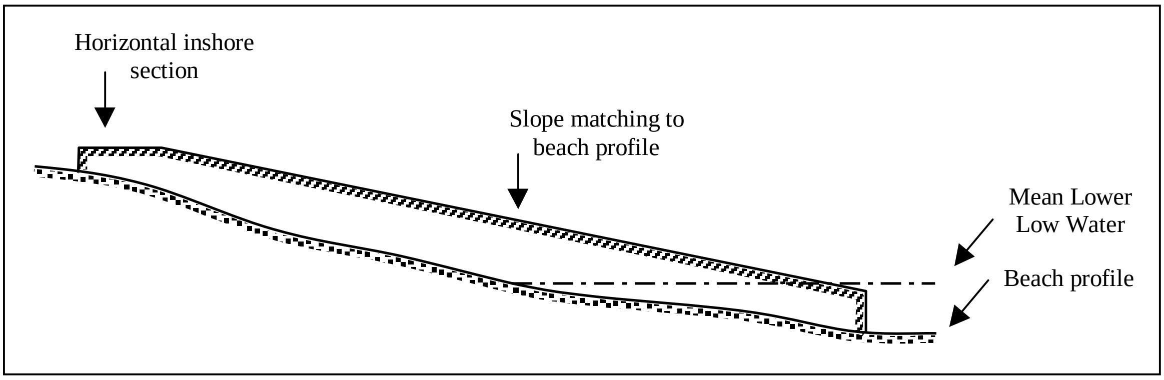


Figure 36. Groyne profile

5.1.3. Spacing

The spacing of groynes should be determined by the approach angle of incoming waves, and not just by applying a spacing of for example two time the groyne's length. As the waves run ashore, making an angle to the depth contours, refraction and diffraction will take place. The approach angle of the incoming wave will change towards the shore and will contribute to the curved shape of the shoreline. Figure 37 shows different spacing distances, with matching beach alignments. An effectively spaced groyne will result in a beach alignment running from the heel to the head of the groyne. At both ends, but especially at the heel of the groyne an extra length is required to avoid outflanking. The shore should preferably run slightly back towards the end of the groyne, as can be seen in the figure.

Obviously the length of the groyne determines the spacing of a groyne too. Shorter groynes will require a closer spacing. So when determining the spacing, at first the required groyne length should be known. Subsequently the predominant incoming wave direction is used to estimate the beach alignment near the tip of the groyne. With the parabolic shape of the shoreline the spacing can roughly be calculated. Dependent on the alignment of the beach, the groynes can be closely spaced for waves approaching at an angle or more widely spaced for a more perpendicular wave approach. When the wave direction varies widely, the longshore transport probably varies too, requiring a less close spacing than for extreme angles of wave approach.

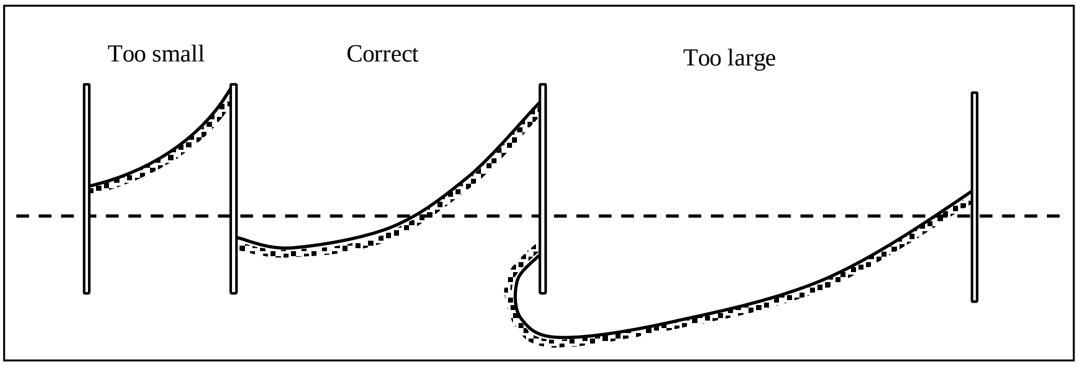


Figure 37. *Spacing of groynes*

5.1.4. Permeability

Permeable groynes have a different function than conventional impermeable groynes. They will reduce alongshore currents, such as tidal currents but will not serve as a barrier, which is necessary to build up material in a groyne bay. In some cases they might be useful, to keep such currents way from the shore with the created increase of resistance close to the shore. However when insufficient beach material is brought into the system the erosion will not be brought to a halt. The Bournemouth Borough Council has experimented with a permeable design between 1971 and 1975. This design was not repeated as they suffered severe abrasion and members were lost. Additionally an aerial survey was done and identified these permeable groynes as being ineffective.

Additionally, with an impermeable groyne, abrasion is concentrated on a few predictable locations, and the structure obtains its strength and stability by spreading forces over a certain length (and height) of the structure. For permeable groynes, members or piles each have to resist forces individually. Figure 38 illustrates how a permeable groyne does reduce close inshore currents but doesn't serve as a barrier to make reorientation of a beach section possible.

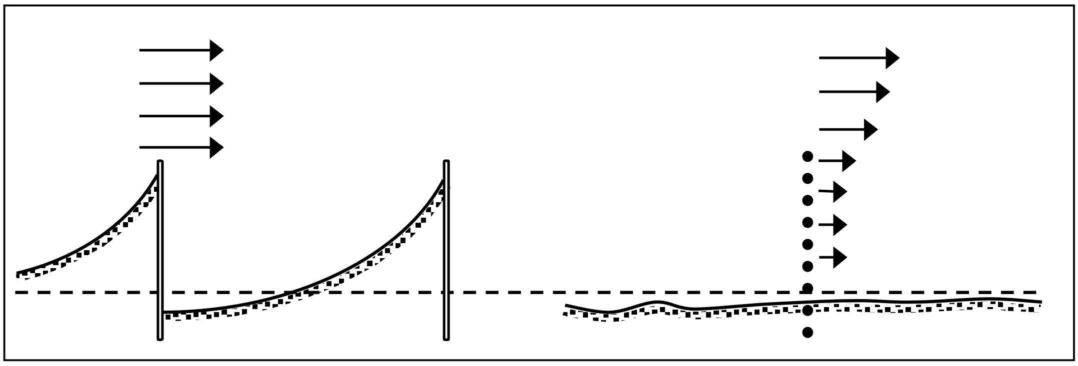


Figure 38. *Permeability*

5.1.5. Orientation.

At locations where the wave and littoral drift direction vary frequently, groynes have to be aligned at right angles to the coastline, to prevent destructive effects of a wrongly oriented groyne to occur. However when the littoral drift and wave directions are consistent, a more effective angle can be chosen. Figure 39 illustrates the alignment possibilities of groynes. When groynes are aligned into the predominant wave direction they will suffer least from wave impacts but will be less effective at retaining a beach. Figure 39B shows that the groynes are easier outflanked than when they are aligned in a different direction. When aligning groynes in a downdrift angle as presented in Figure 39C, the parabolic shaped beach will be most effective against outflanking. The groyne provides maximum shelter for the beach, and additionally rip currents will be directed under an angle away from the shore, decreasing their offshore transporting action. Figure 39D shows the complete parabolic shaped beach, held in place by a T-shaped groyne. In some cases this shape, requiring more construction material, may be an attractive solution as it functions as a breakwater too, reducing cross-shore transport.

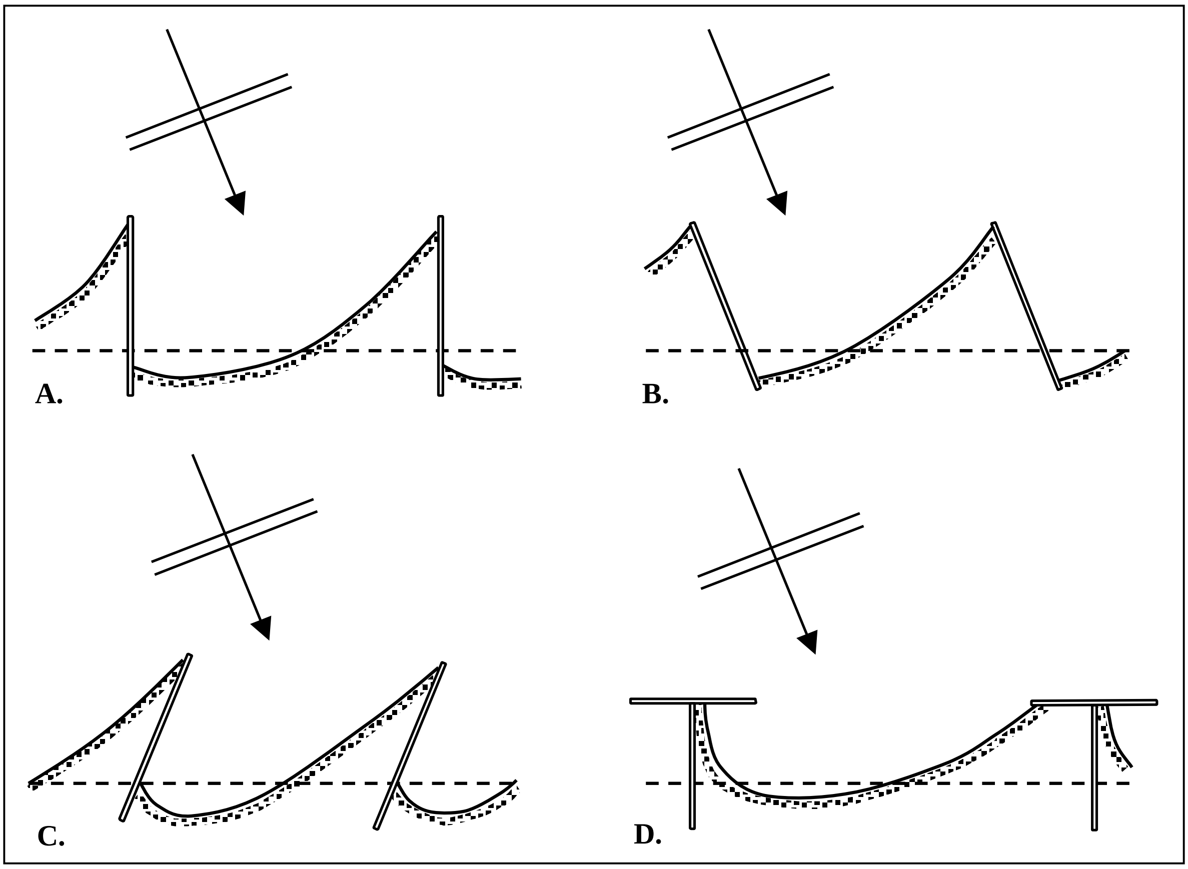


Figure 39. Alignment of groynes

Choosing an alignment other than transverse to the coastline should only be done when the littoral drift and wave direction are constant from one direction. An updrift alignment can rapidly cause erosion and thus cause serious problems.

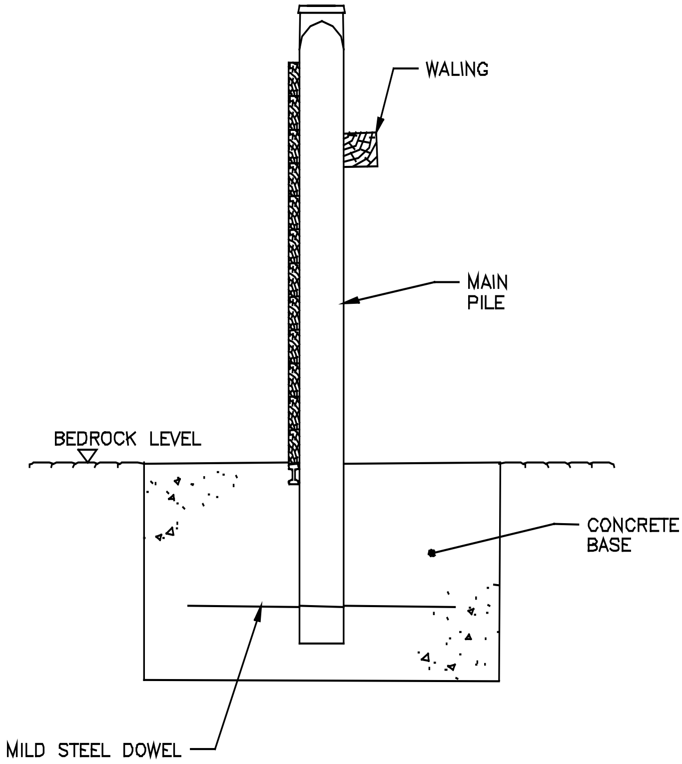
5.2. Overall stability of structure

The stability of a groyne structure is determined by its ability to withstand loads exerting a moment on the structure. Usually evenly spaced cantilevered main piles with buried in-fill panels of vertical sheet piles or horizontal planks achieve overall stability. The stability of a groyne can be affected by scour and undermining of the foundations. The means of attaining sufficient stability is dependent on the beach type in which the groyne is to be founded.

In coastal and fluvial engineering the loadings are often dynamic and irregular. A random wave front approaching the shoreline at an angle does not exert a steady, sustained load over the full length of a groyne. Instead, at any given point in time it impacts certain lengths whilst others are left relatively unaffected. For this reason it is necessary to design structures with the ability to spread localised areas of high loading. This can then be taken into account when calculating the overall stability of a structure.

The design of a structure, including its foundation, should be kept as simple as possible. If at all possible props and ties should be avoided due to the problems of abrasion from beach movement, and extra complexity of the structure. If they are unavoidable then ties are preferable because they are located on the updrift side of the groyne where beach levels tend to remain higher for longer periods, thereby reducing abrasion.

Planted posts
The simplest way of constructing a groyne is by placing (either planting or driving) posts in the ground, with planking between the piles. Where the ground conditions are too hard for the piles to be driven sufficiently far into the ground, holes or trenches can be excavated after which timber posts inserted and the excavations backfilled with the beach material or imported fill such as concrete. Posts planted in concrete can also be used in situations where piling would otherwise be possible but the required lengths of timber are unavailable. Shorter lengths of timber set in a concrete base can potentially match the performance of longer driven piles. However, to use a concrete foundation the substrate must be able to carry such heavy loads, to avoid cracking of the concrete or even instability in its whole. At the Bexhill scheme trenches were excavated into the siltstone bed and backfilled with concrete, such as shown in Figure 40. A more usual situation is shown in Figure 41, excavating into the beach and backfilling with the same material. In this case the planking level must lie well under beach level, to provide extra resistance against rotating and to avoid seepage under the structure, as piping may form a threat.



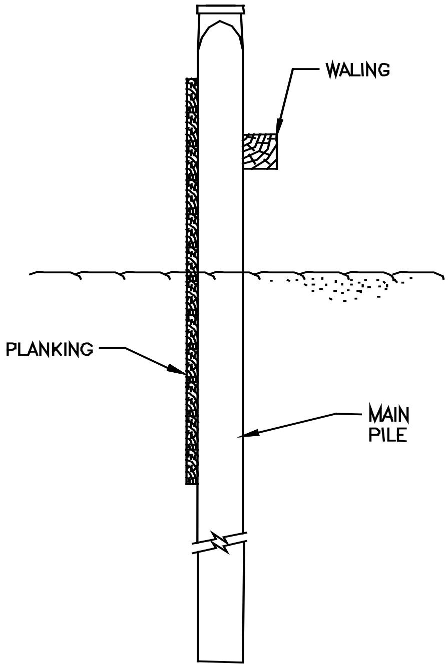


Figure 40. Planted post in concrete foundation (Bexhill)
Figure 41. Planted post in beach

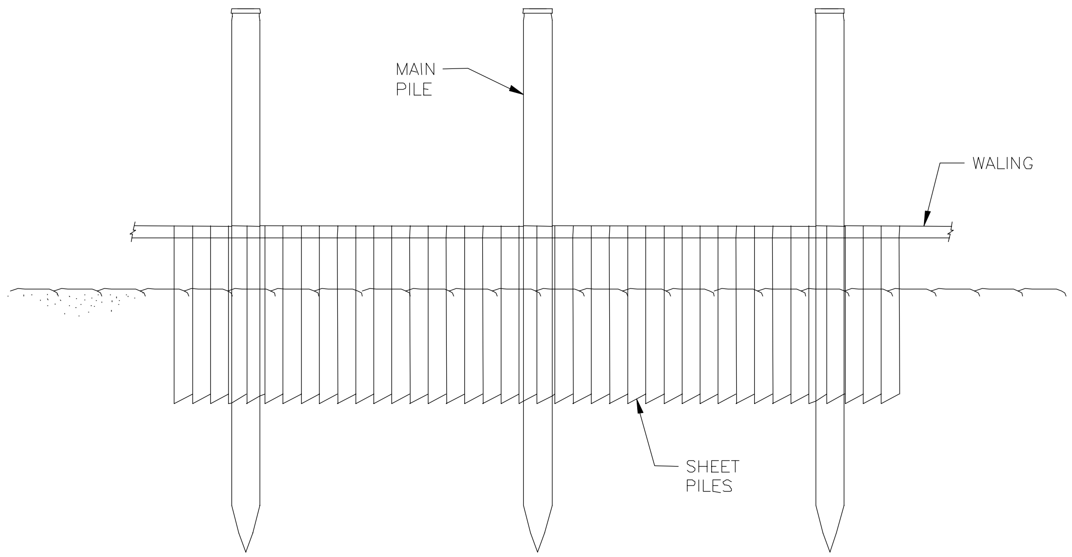
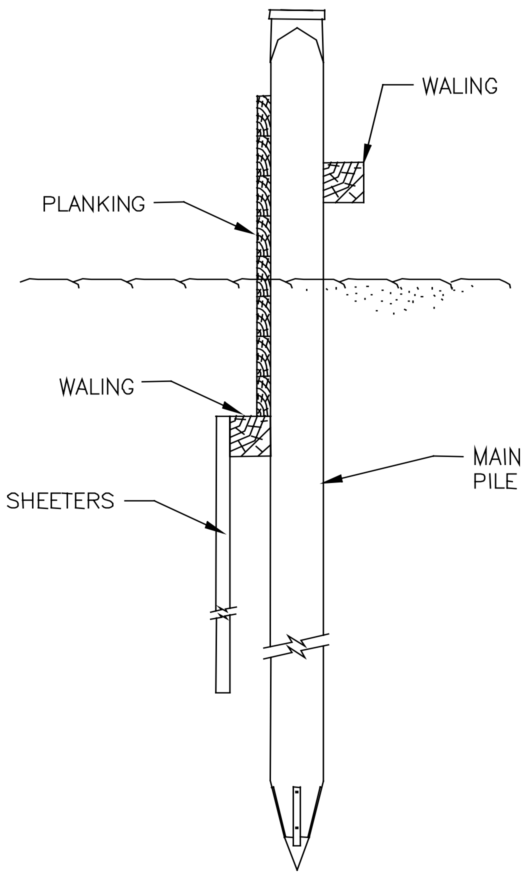


Figure 42. Contiguous panels



Contiguous piles

A different method, to help support the main piles is to drive sheet piles in the ground close to the posts and attaching them to a waling. In soft ground conditions the sheeters will the help the piles to resist rotation. In-fill panels of smaller section piles, such as sheet piles, can be installed between the main piles as shown in Figure 42. The sheet piles are bolted or coach screwed to the waling, which can be seen in Figure 43, after which the sheet piles can be cut flush to the waling. Directly above the waling planking will be placed till the appropriate level. Under normal conditions the vertical sheeters won't be visible, as they will remain under beach level. This method can only be used in relatively soft ground, to make driving of sheeters and piles possible.

In order to make driving of the sheeters easy, the bottom end is cut at an angle to ensure that the driven sheeter is forced against the previously placed. A tongue and groove in the sheet piles will keep the piles in line and make the panel impermeable. Without tongue and groove the sheeters can be fixed to a top and bottom waling, keeping them in the correct place or by using accurate machinery.

Figure 43. Contiguous piles

Buried panels

An alternative arrangement to the contiguous piles described above is to excavate between the main piles, as explained for the planted posts, and fix horizontal in-fill panels, such as planking. The planking extends below the lowest anticipated beach level. Buried panels are often used instead of contiguous piles when most of the necessary excavation is in a non-cohesive material, such as shingle or sand. With a clay substrate, the contiguous pile system has preference.

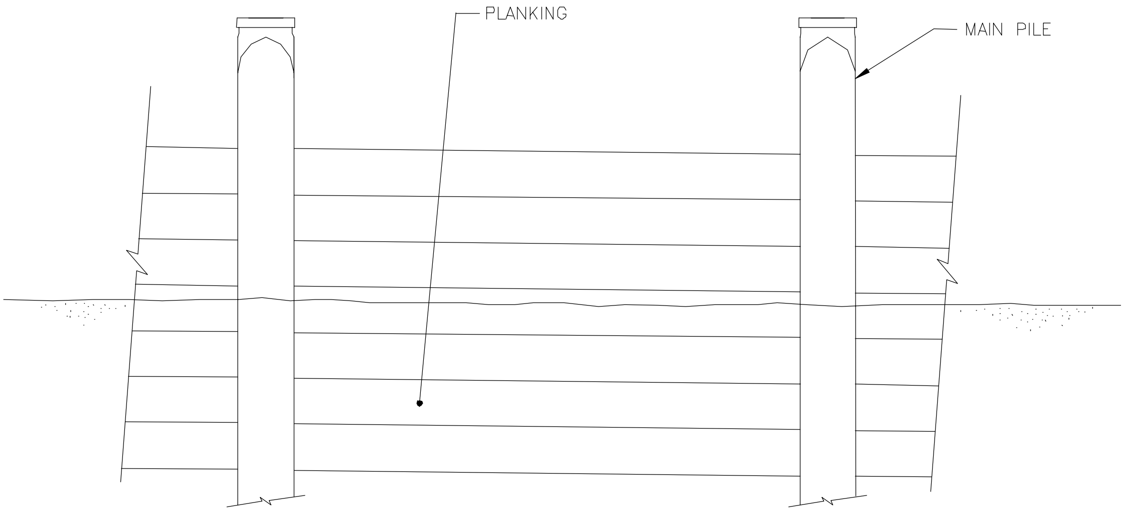


Figure 44. Buried panels

Figure 45. Excavating in order to attach planking (courtesy to Posford Haskoning)

Props
Where the main piles are unable to resist rotation on their own, props (working in compression) can be used. They will require their own anchorage arrangement. In Figure 46 a prop arrangement is illustrated as used at the Bexhill scheme. In this case the whole structure is founded in a concrete filled trench, in the siltstone bed.

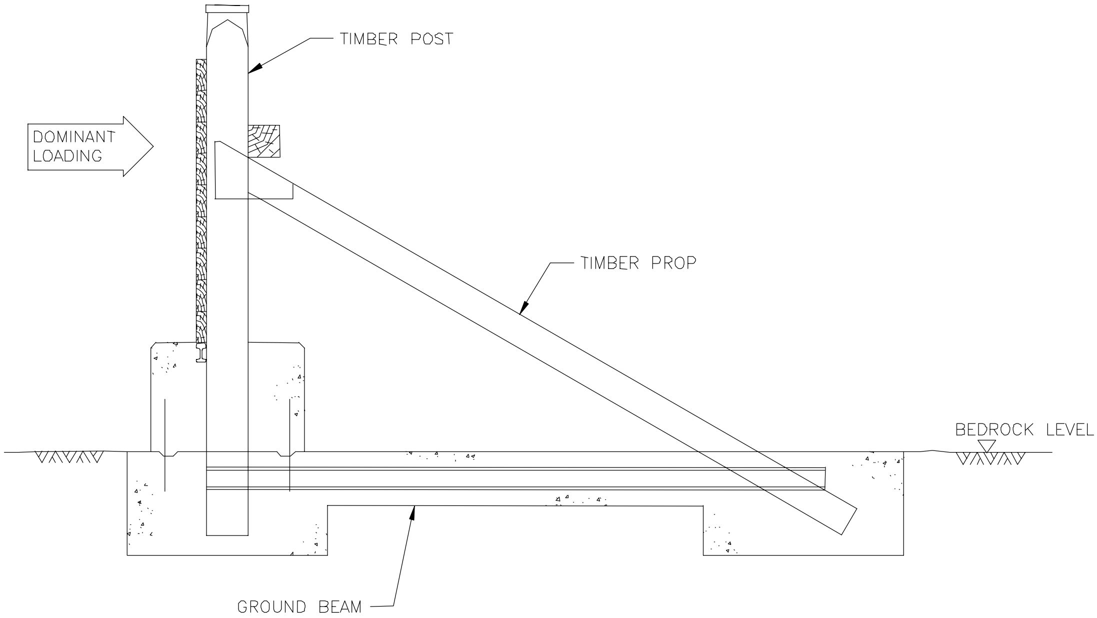


Figure 46.   Prop arrangement (Bexhill)

Ties
Instead of, or in addition to (as at the Bexhill scheme), the prop structure, ties (working in tension) can be used to support the main piles. This system is superior to the prop structure, because lee side erosion will uncover the prop, exposing it to abrasion and possibly undermining the prop. Ties or props can be made of whole logs and will require an anchorage system such as secondary piling, illustrated below. Ideally the whole tie will permanently remain under beach level.

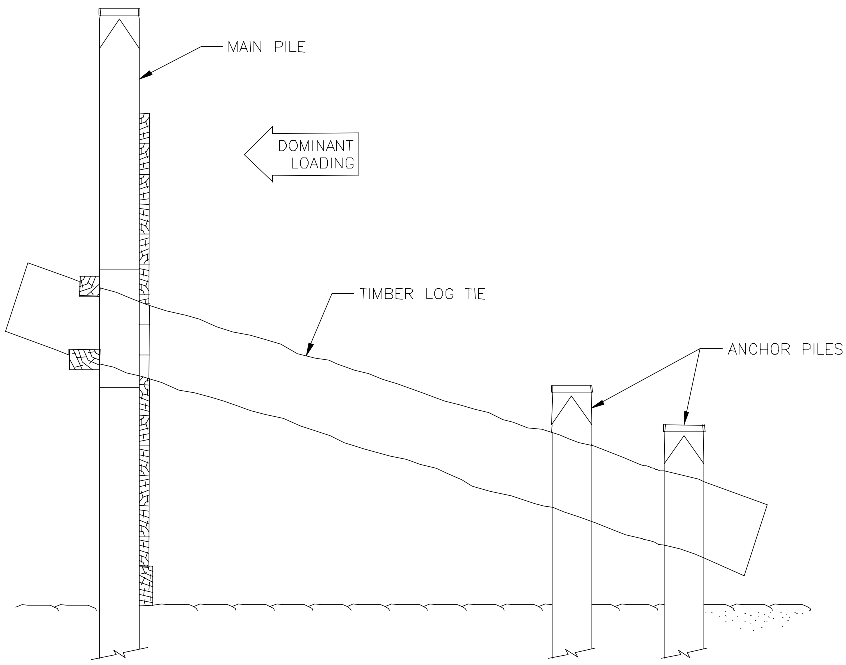


Figure 47.   Timber log tie

5.3. Members and connections

The key issue for members and connections is keeping the structure arrangement uncomplicated with as few connections as possible. Members and their connections should be designed and developed together. Connection details will often influence the design of the members, and vice versa. The number of connections should be kept to a minimum and in relation to this, individual members should be kept as long as possible. The arrangement of members and connections should be designed to allow for the distribution of localised loads, such as wave impacts, into the structure. Permissible stresses can generally be increased for short-term loading conditions.

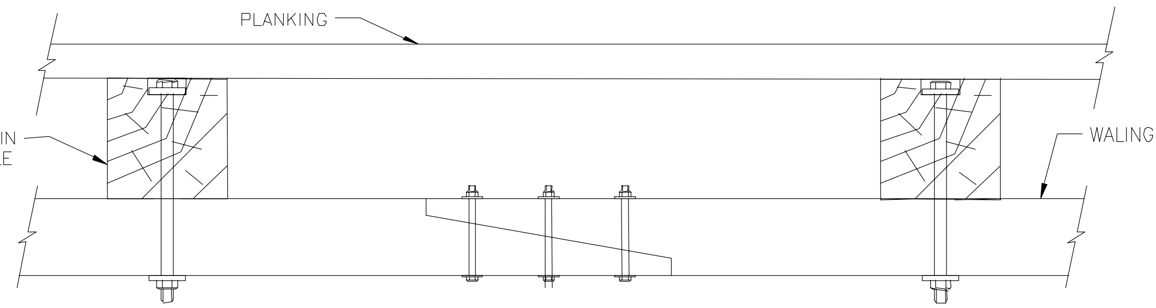


Figure 48. Connections typically used in a groyne

Members

From a design perspective, members typically fall into one of three3 categories:

1. Primary members responsible for the main stability of the structure (e.g. piles, props and ties)
2. Secondary members accountable for the main distribution of loads (e.g. walings)
3. Tertiary members for cladding purposes and the distribution of loads into rest of the structure (e.g. planking and sheeters)

It is good practice to detail the tertiary members and their connections in a manner that will maximise their ability to also distribute loads into the structure.

The following key factors should be taken into account when designing individual members:

1. Operational bending moments	Special attention should be given to any dynamic loadings.
2. Operational shear forces	Again, dynamic loadings should be fully recognised.
3. Constructional stresses	Larger section sizes may be necessary to cope with constructional stresses such as driving piles into hard ground.
4. Abrasion	Also larger section sizes may be necessary to cope with anticipated abrasion during the life of the structure. This is particularly critical for members where replacement or maintenance would be difficult.
5. Connection details	Allowances may be necessary to compensate for loss of timber at boltholes, bolt recesses, notches etc. Also, allowances may be necessary to suit other connecting members.
6. Available sizes	It is good practice to work with a limited number of section sizes for a given structure, and to use standard section sizes. Also, the design should work within the scope of available lengths. There may be situations where it is necessary to use a larger section size in order to have available a longer length.

Connections
From a design perspective, connections typically fall into one of the following four categories:

1. Overlap connection This is the simplest type of connection and involves two or more members passing across each other. This connection can pass large forces, and depending on the section sizes, and number of fixings moments too. Examples are the connections between main pile and waling, between waling and sheeters, and between main pile and planking.

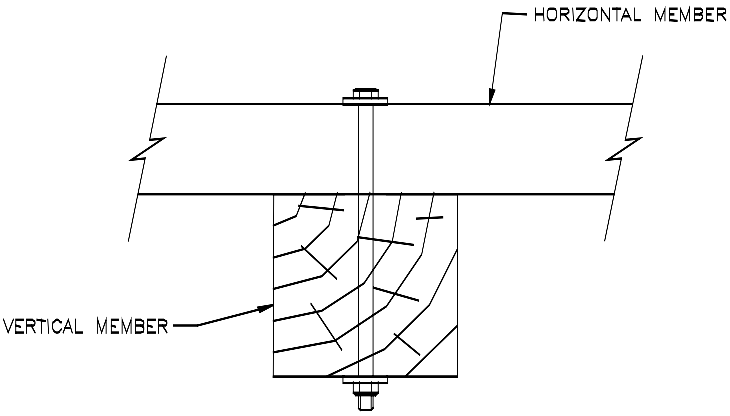


Figure 49. Overlap connection

2. Butt joint This connection involves two or more members converging to a single point. The members are usually within the same plane. This arrangement demands a higher degree of fit than the overlap connection. Butt joints are usually carried out using steel plates, overlying the entire connection. Depending on the steel plates, this connection may resist high loading. Butt joints are commonly used when in-line planking meets at a main pile. In this case hardly any forces are transmitted through the joint.

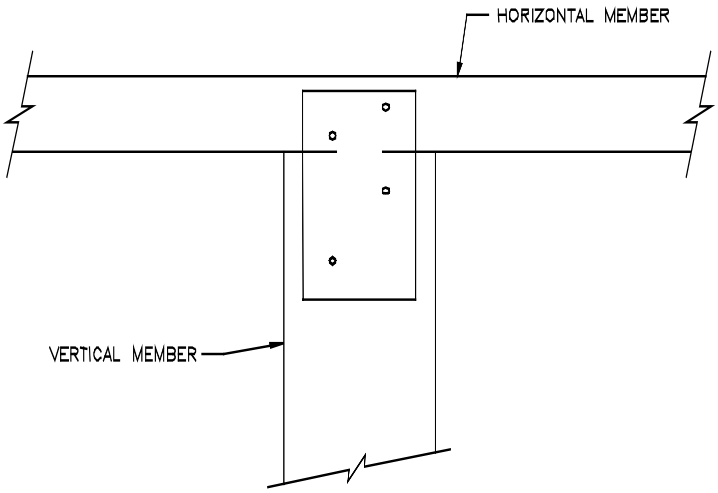


Figure 50. Butt connection

3. Scarf joint This connection usually involves a splice connection for the in-line extension of a member. Usually this joint is carried out with steel plates on both side sides of the members, and thus can transfer high loadings (moments and forces).

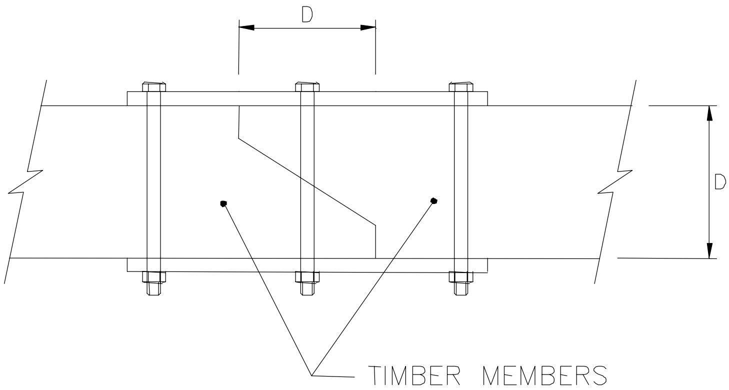


Figure 51. Scarf connection

4. Notch connection This connection involves cutting a notch in one timber member in order to receive a second member. This requires precise workmanship, or can be done by machinery, for example for the tongue and groove of sheet piling, which is a type of notch connection. Although this connection can resist high forces in certain directions, it is not used very often, as the connection is more vulnerable to rot.

When configuring the arrangement of connections within a structure, first preference should be given to designing with connections that work in compression. Namely, where the main load path is from timber to timber and the fixings (e.g. bolts) play only a secondary role. The second preference should be for shear connections where the main load path between timbers is transmitted via the fixings working in shear. Double shear connections are more efficient than single shear connections (see Figure 52), but of course should only be incorporated in a design when necessary (i.e. when loads are high).

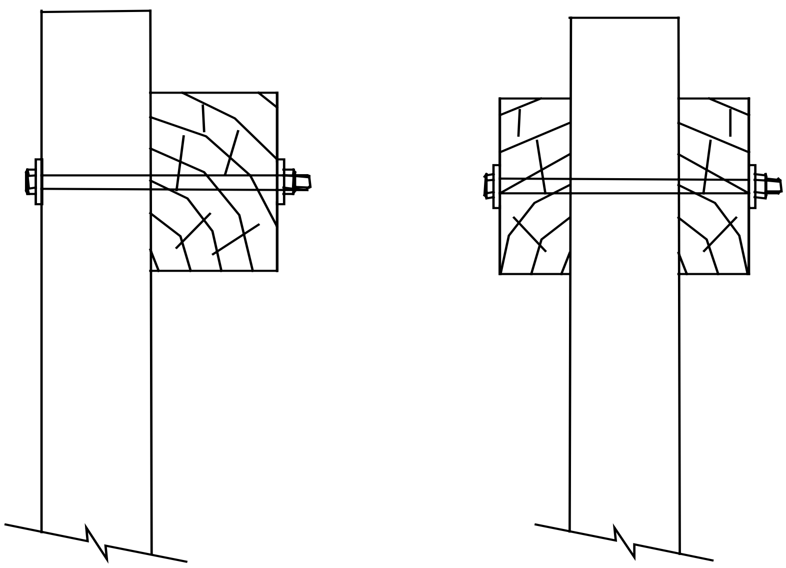


Figure 52. Single and double shear connection

The third preference should be for tension connections where the main load path is via fixings working in tension. The fixings will usually be carried out in steel, and is discussed below.

During construction precise workmanship is necessary to assure that timber interfaces at connections are in full contact. As a general rule no packing pieces, shims or similar should be used in connections. Any shaping or trimming of members at connections should avoid producing thin sections and “feather edges” and any notching of timber at connections should be kept to a minimum.

In general a design should always use as much staggered connections as possible within a structure to avoid lines or planes of weakness.

Fixings
The potential types of fixing for use in connections are as follows:

1. Bolts For most situations this is the preferred method. Bolts have hexagonal or square heads and threaded shanks, and provide a robust connection and are relatively straightforward to fix. Galvanised, coarse threaded, mild steel bolts are usually the most cost effective solution but other types such as stainless steel cannot be ruled out. Where bolts pass through the timber they should be a tight fit. Holes should only be drilled from one side of the timber member. Within a connection, bolts should not be designed to bridge an air gap. The length of bolt between the head and nut should be fully enclosed. Close attention should be paid to the edge distances between the boltholes and the timber faces and the spacing between bolts. Where possible nuts should be located on the more sheltered side of the connection. Bolts used as tightened fasteners should have washers under any heads or nuts, which are in contact with the timber.

   As a general rule in coastal engineering large diameter bolts are to be preferred. For most situations 20 mm and 25 mm diameter bolts tend to be suitable. Larger diameter bolts have the advantage in terms of exerting lower secondary stresses on the timber and coping better with corrosion. Timberwork washes should have a diameter of at least 3 times the diameter of the bolt and a thickness of 0.3 diameter to provide a full bearing area

2. Coach screws These are normally limited to fixing cladding such as planking and decking. They are suitable for multiple lightweight connections but installation requires a higher degree of workmanship than bolts. Typically they are galvanised mild steel, for example 16 mm in diameter with a 25 mm square head. In situations where it is likely to be necessary to remove fixings for operational or maintenance purposes, coach screws are less suitable than bolts. Their heads are less robust than bolt heads and their grip within the parent timber is susceptible to deterioration through repeated fixings. For locations where the members may stay connected throughout the life of the structure, such as sheeters or lower planking they are convenient.

   Coach screws and bolts are available in ordinary mild steel to BS 4320, or hot dip galvanised in accordance with BS EN ISO 1460. Stainless steel bolts and nuts can be obtained manufactured from Grade 316S31 steel complying with BS 970: Part 1 or BS 1449: Part 2. In selecting the position of bolts in a connection consideration should be given to ease of installation and removal, and also to protection of the head and nut. One method of improving protection and appearance is to use the bolt in a countersunk hole so that the head or nut does not protude above the surface of the timber member. However this is not recommended as this will result in accumulation of water, and will affect the timber. The head or nut can be surrounded with mastic to fill the hole, but often this is removed or gradually deteriorates.

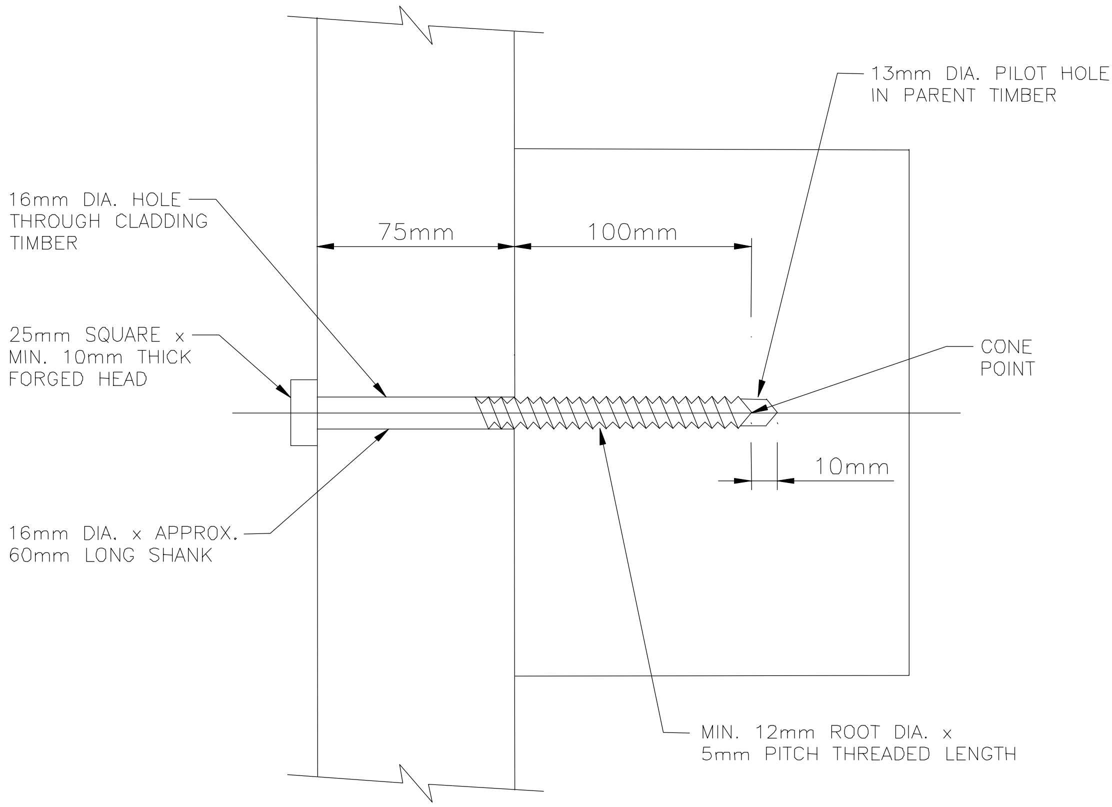


Figure 53. Coach screw fixing

3. Dowels Timber dowels can be used but are rare due to the high standards of workmanship required. Their main advantage over steel is their ability to expand, contract and deflect in harmony with the surrounding timber members. For these reasons such connections often remain tighter for longer periods of time and can be particularly appropriate for structures experiencing high impact loads such as mooring jetties.

4. Nails Heavy-duty nails may be used in limited situations such as for decking timbers. However, compared with coach screws they have two main disadvantages, they are unsuitable for resisting tensile loads and they cannot be easily removed if the need arises.

5. Shear plates Shear plates, split ring connectors, etc. are rarely used due to corrosion and the difficulties associated with forming connections in situ, especially in hardwoods.

6. Glue Glued connections are generally impractical, especially as stand alone connections. In a marine environment their performance may be questionable.

There are a number of additional devices that can be used to facilitate or strengthen a connection:

1. Steel washers These are normally used with bolts in order to reduce the local bearing pressures exerted by the bolt heads and nuts on the timber. To provide effective load distribution and to cope with corrosion the washers need to be of the order of 10 mm thick. Typically washers are in galvanised mild steel and have diameters of 50 mm, 75 mm and 100 mm. It is not useful to use washers with coach screws, as their working loads are lower than for bolts. If there is an issue with significant pull-out loads then it is usually advisable to use bolted connections instead of coach screws if at all possible.

2. Steel flat plates Again these are normally used with bolts. The main purpose of plates is to increase the capacity of the connections in their ability to transfer load from one member to another. Usually they are used in butt joints and scarf joints. Plates can be used singly or in pairs. Where pairs are used the first plate has close fit boltholes and the second has oversize holes to allow for drilling tolerances through the timber. Pairs of plates are more efficient than single plates (due to the advantages of double shear) but their installation demands higher standards of workmanship. Also, the greater the number of bolt holes the more difficult the installation. Plates are typically in galvanised mild steel and of the order of 12 mm thick.

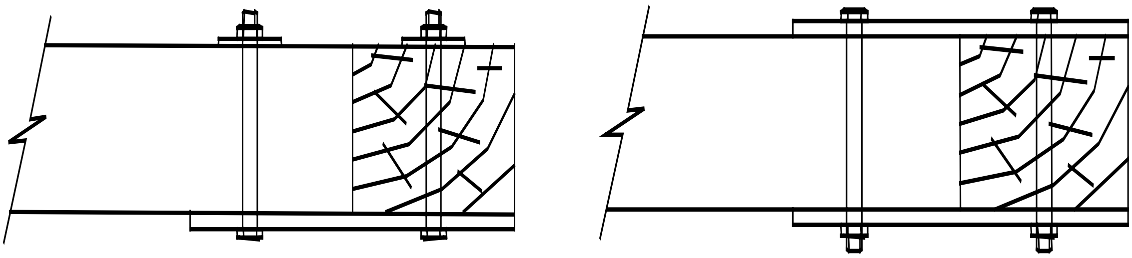


Figure 54. Single and double steel plate connection

3. Steel angles Their application and detailing are similar to flat plates except that they are mainly, but not exclusively, used in overlap joints.

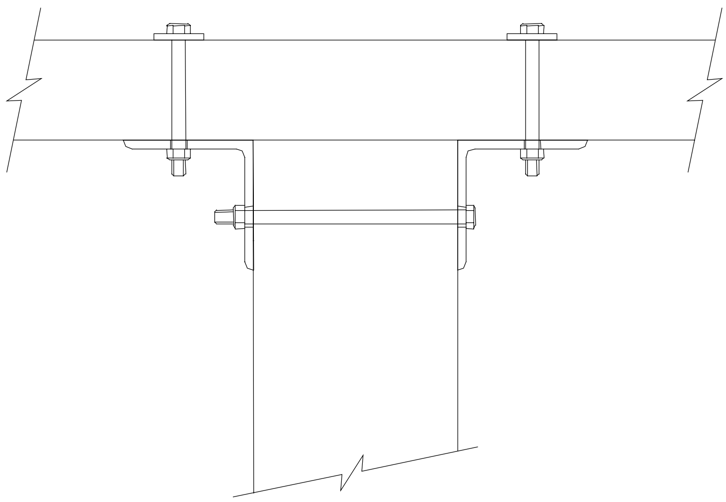


Figure 55. Steel angle connection

4. Steel straps These are broadly similar to plates and angles except more versatile in as much as they can be bent to various shapes including curves. Also they lend themselves to being wrapped around members thereby reducing the number of positive bolt or coach screw fixings required.

5.4. Finishes and fittings

All fixings on groynes are exposed to severe wear and oxidation, due to the aggressive marine environment. Therefore as few bolts, as possible should be used, these never being placed in the same grain line of the timber. Galvanised steel fixings are commonly used but stainless steel fixings have the advantage that the groyne can be dismantled or refurbished more easily and the fixings can be reused. The arrangement of finishes and fittings should be kept as simple as possible and as few as possible.

Due to the often aggressive environment in which coastal and fluvial timber structures operate, the range of practical finishes tends to be limited. As a general rule timbers are left in their original as-sawn or planed condition. However there is a tendency for timber fibres to separate (broom) at both the head and toe of the pile during heavy driving, resulting in a loss of structural strength. Pile rings and shoes can be fitted to protect the head and toe of the piles. Finishes can include construction facilities such as steel strips on the top planking of a groyne, to allow plants to drive over the groyne. Finishes and fittings of this nature need to be properly sized for their function, and carefully fitted. Poor workmanship can result in such fittings becoming a hindrance rather than a help.

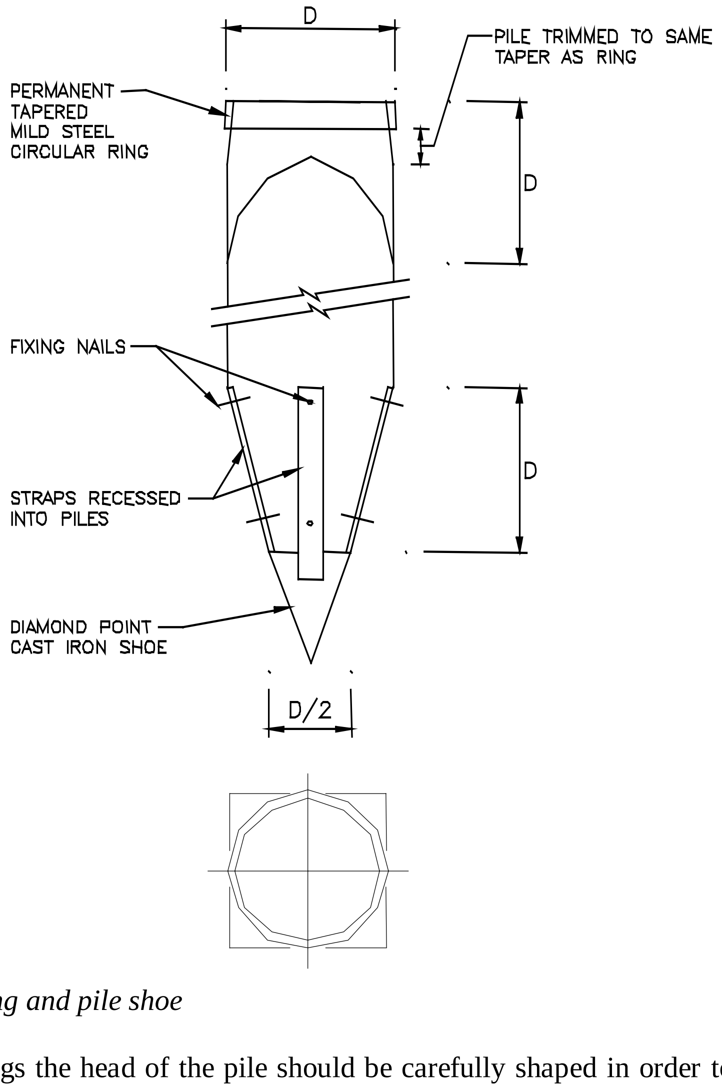


Figure 56. Pile ring and pile shoe

When applying pile rings the head of the pile should be carefully shaped in order to ensure good contact between the timber and pile ring. After fixing the pile ring the top of the pile must to be trimmed where necessary to ensure the driving face will be horizontal. The pile shoes must be fitted symmetrical, and firmly fitted onto the suitably shaped end of the pile, ensuring a maximum possible contact area between the shoe and the pile in order to avoid overstressing during driving.

5.5. Health and safety

Health and safety issues can be divided into those that mainly relate to the construction stage and those that mainly relate to the operational stage. The role of the designer is to design in such a way as to eliminate or reduce risks to the health and safety of those who are going to construct, maintain, repair, demolish, or clean any type of structure. The remaining risks should be as few and as small as possible. The overall design process need not be dominated by the need to avoid all risks during construction and maintenance but to reduce unnecessary levels of risk.

Construction stage

- Working in wet conditions on an unstable beach or floating craft

Machinery and clothing should be suitable for working in wet conditions, above but sometimes even below water. Minimising in situ working and simplifying fixing, handling and lifting operations should be incorporated in the design and planning of a contract. Prefabrication of sheet pile panels can largely reduce the amount of in situ work.

- Working between high tide periods

Often the construction of a groyne necessitates working between high tide periods. The contractor should be aware of this when doing so and provide with sufficient beach access routes, in order to leave the beach safely in time. This requires a strict planning of the work, and machinery in a good condition.

- Handling toxic timbers

Clothes providing with protection when handling with timber must be standard during the construction and processing phase of a project. For example good quality gloves should be provided to personnel handling or working with Greenheart or Ekki as the splinters are very poisonous and can cause severe swelling.

Operational stage

- Public

When designing and constructing groynes one must be aware of the fact that the public shall use the beach along the groynes. Therefore trip hazards and dangerous protruding bolts must be avoided in the design. Misuse of the structures must be discouraged too.

- Maintenance

To facilitate maintenance operations plant access bays should be designed within a groynes scheme to provide with a safe exit route for machinery at work on the beach.

5.6. Natural environment

This deals with ways in which the design can influence the impact of the use of timber on the natural environment, particularly in terms of species, overall volumes required, processing and wastage. This research project has led to the belief that this is probably the issue in which the design and construction of groynes can be improved most.

- Specification

Specify species of timber from sustainable sources.
Allow for a range of timber species in order to spread demand.

- Durability by design

Use cladding timbers and other tertiary members to contribute to the overall stability of the structure thereby reducing the total timber requirement.
Use rubbing pieces at locations of anticipated high wear and tear (see Figure 59).
Assure that the gaps between planking, or other members is minimal, to prevent them from widening.
Main piles should be designed with an over height to make adjustments possible in the future.

Extending planks beyond piles.
Use oversize members at locations of anticipated high wear and tear.
Avoid local traps, passageways and other configurations, which might encourage high wear and tear through the channelling of water and/or water borne sediment.
Avoid connections, which are reliant on single fixings.

- Recycling of timber

Recycling and reusing timber can obtain an enormous reduction of the need of new timber. Timber that has been used in a structure under beach level will hardly suffer any loss of quality, and thus can excellently be used again. Piles can possibly be placed upside-down back in the ground, leaving the abraded section under the ground. If the pile is severely damaged above beach level the useful remaining part can be used as a shorter pile elsewhere. Old planking or sheeters can well be reused as sheeters or rubbing pieces because these elements require limited section lengths.

- Minimise waste

Match member section sizes and lengths with the optimum available from the original logs.
Specify careful storage of timber on site to reduce likelihood of warping and end damage, especially for smaller section sizes.
Allow some flexibility in accommodating variable lengths and section sizes of timber members.
Standardise lengths and sizes.
Order in both metric and imperial unit lengths.
Design for minimum wastage when replacing elements of the structure.

- Design simple

Keep to a minimum the need for cutting, drilling and shaping.

- Minimise pollution

Use whole natural tree trunks or hewn timbers to reduce processing for, for example props or ties.
Minimise transport distances between for example scheme location and storage area.

Figure 57. Attaching recycled sheeters (courtesy to Posford Haskoning)

5.7. Construction

Constructing a groyne scheme involves great expertise of the contractor, as the work is carried out under harsh circumstances. Heavy equipment is used on unstable slopes and beaches, often within the tidal range. The placing or driving of piles can be carried out with excavation plants, high-pressure water lances or simply a drop hammer, as described below. When fixing planking or sheeters, the surrounding area usually has to be excavated to reach the required level. Precise workmanship, with heavy equipment is needed to keep within the set tolerances.

Piling

Timber piles, being relatively easy to handle, can be driven using simple trestle frames and drop hammers. There is however the danger that the pile head will broom and the pile toe crush under heavy driving. Limiting the drop and number of blows of the hammer can reduce the likelihood of these problems. A driving cap or "dolly" should be used when driving. It is recommended in BS 8004: 1986 Code of Practice for Foundations, that it is desirable that the weight of the hammer should be equal to the weight of the pile for hard driving conditions and not less than half the weight of the pile for easy driving. Unnecessary high pile driving stresses can be avoided by ensuring that the pile head is central with the hammer and normal to the length of the pile. A pile should not be allowed to run out of position relative to the leader. When a timber pile reaches the "set" on a groyne scheme it is often useful to leave it in place a few tidal cycles before trying to re-drive it. It is often found that the pile can then be successfully driven. Once the pile has been driven then the ring should secured to the pile with nails. It is possible for piles within grading tolerances to be "bent" such they will not comply with the driving tolerances if the bend is across the line of the groyne. In this case the bend may be best located along the line of the groyne and the planking adjusted to suit.

Sheeters

Timber sheeters are widely used for the sections of groynes below beach level and are normally fixed to a lower waling or plank. Sheet piles are normally driven to final position in sequence. The toe is often shaped in such a way as to aid penetration and ensure the pile forms a close fit with the adjacent pile installed previously. As mentioned earlier, the prefabrication of sheet pile panels can largely reduce the amount of in situ work.

Planking

When fitting planking it is necessary to obtain a tight fit, usually achieved by pushing the plank down onto the lower plank whilst fixing. Planks can be fitted to piles using coach screws or bolts, the latter preferably used where replacement will be necessary during the structures lifetime. Coach screws must be wound using either wrenches or spanners. Holes for coach screws should be pre drilled using augers of slightly different diameters. The hole should be equal to the diameter of the coach screw for a depth equal to the length of the unthreaded shank and then reduced in diameter (typically by 3mm) to a depth of 10mm more than the length of the screw. This may be produced using two separate bits, but it is often more efficient to have custom bits manufactured to suit the profile required.

Many of the issues under health and safety and the natural environment also have an impact on the buildability of a design. Other issues include:

- Recognise and facilitate dimensional, constructional tolerances for installing members, depending on the working conditions. Use planted posts instead of driven piles where closer positioning tolerances are required. Be aware of significantly larger tolerances for hewn piles than sawn piles.

- Simplify the structure to facilitate difficult working conditions (e.g. at extreme low tide or with very poor access).

- Minimise the need for long slender boltholes where there is a risk of deflection of the drill bit.

- Appropriate use of recesses for bolt heads, nuts and coach screws.

- Facilitate prefabrication to reduce the amount of in-situ working. Prefabrication of elements such as panels of sheet piles, fixed near or below low water, can increase safety and improve the quality of construction. Prefabrication may also enable the use of preservative treated timbers and minimise waste.

- Avoid gaps between planking. There have been considerable problems with gaps between planks being enlarged by transport of sand through them and reducing the efficiency of the groynes. A number of potential solutions include:
  -Gaskets between the planks
  -Tongue and grooved planks
  -Plywood boards nailed to groyne

- Avoid placing bolts in the same grain line of a timber member.

- Line one side of all main piles out, to obtain a straight planking line.

- Make sure bolts and washers are “locked off” once in place, by destroying the thread, welding the nut or bending up locking washers.

5.8. Maintenance

5.8.1. Operations

Maintenance of timber structures involves repairing or replacing damaged elements of the structure as well as adjusting the structure to perform in the most efficient way. During this stage of the life cycle, wastage arising from the use of timber in construction has potentially the largest impact on the environment.

Issues concerning maintenance operations include:

- Members such as cladding, which may need replacing within the lifespan of the structure, should be relatively easy to access and disconnect (fixings should be accessible and the need to remove other members should be avoided).

- Allowance should be made where reasonable for the possibility of adding new primary and secondary members within the scope of the structure at a later date.

- Bolts are recommended for attaching members that require replacing throughout the structures lifetime. Using coach screws may lead to “nailsick members”, i.e. perforating the timber with too many holes.

- Don’t use paint on hardwood, as this will possibly cause the member to rot under the paint film, due to the excess of moisture under the paint.

- Provide with wide enough access to the structure

Pile extension
Groynes should be adjusted to the optimal height, matching to the changing beach profile, possibly several times throughout their lifetime. In some cases extending groynes to the preferred height, as illustrated in Figure 58 a and b, may be an attractive solution instead of rebuilding an entire groyne. On the other hand, when constructing a groyne, an allowance may be provided in the pile length for extra planking.

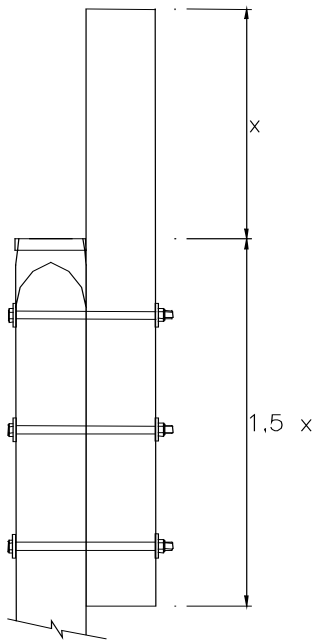



Figure 58. *Pile extension*
Figure 59. *Rubbing pieces*

Rubbing pieces
To protect piles from abrasion, softwood or recycled timber rubbing pieces can be attached to the piles at critical levels. Extending planks beyond piles may also reduce wear, increasing the life of the pile. Members should be sized with an allowance for wear and the connections carefully chosen. Maintenance will require regular inspection of the structures and replacing of worn rubbing pieces.

5.8.2. Design stage

When designing an efficient and safe structure it is important to estimate the correct balance between capital and maintenance expenditure through a whole life costing approach. In order to choose the appropriate level of service the link between asset condition, serviceability and performance should be understood. On every £1 the Environment Agency spends on constructing an asset it only spends 38 p on the maintenance of that asset over its design life, which in general, is assumed to be 60 years. (Garrod, CIWEM meeting 2002). Perhaps the lifetime or performance of the structure can be increased if more is spent on maintenance.

To provide sustainable maintenance the following criteria would need to be achieved:

- The lowest whole life costs, provided that the required functionality is retained
- The least impact on the environment in maintaining and operating the asset, including the sourcing of the construction materials used in any repairs
- The functionality of the defence is retained whilst maintenance and repair of specific assets is carried out
- Predictable performance under the impact of an extreme event beyond the design standard
- The ease of repair
- The lowest negative impacts and the maximum benefits to society over the of the life of the asset

5.8.3. Programming of activities

Timber structures should be monitored and surveyed as part of a regular maintenance regime. The frequency and extent of the surveys will be dependent upon the level of risk the structure is exposed to and also, on previous survey results. For example, a timber structure situated in a location where there is a high incidence of marine borer would have to be monitored at more frequent intervals than a comparable structure located where there is a low risk of marine borer. Furthermore, a structure made of a moderately durable timber would, generally, have to be monitored more frequently than a structure made out of a very durable timber.

When programming maintenance activities, several strategies can be followed. All activities can be carried out at scheduled times or repairs can be done directly after problems arise.

Regular maintenance should be carried out in order for:
-The structure to retain its function
-Minimise hazardous situations for the public
-Avoid damage to increase rapidly
-Possibly increase its effectiveness.

Bournemouth Borough Council's rolling programme

The Bournemouth Borough Council maintains and replaces 51 timber groynes along their coast. The groynes have a life expectancy of 25 years and a rolling programme has been established to replace two groynes each year. This has the following advantages:

- Continuity in design and construction experience
- Opportunity to incorporate evolutionary refinements in groyne construction as they are developed
- Opportunity to adjust groyne profiles to changing beach profiles and rising sea levels
- Opportunity to refine groyne spacing

The present construction cost of each groyne is approximately £200,000, which is in part due to the small tidal range and length of the groynes, which necessitates considerable temporary works (a steel platform is constructed to provide access for a crane). The hard underlying strata necessitate pre-boring for the piles with high-pressure water lances.

Monitoring beach levels within the groyne bays assesses the performance of the groynes. This has led to several improvements in both the profiles and positions of the groynes. The groynes themselves are also regularly inspected and prioritised for replacement.

6. CONCLUSIONS

Timber groynes have proven to be an excellent system to control a coastal area under certain circumstances. As beaches constantly change as they respond to natural processes, a flexible structure is required to retain the beach. Removing or adding planking to a groyne can obtain an optimal profile throughout the entire lifetime of the structure.

An adequately designed, constructed and maintained groyne provides a physical barrier to the movement of the beach material and diverting longshore currents away from the beach. However, groynes cannot prevent cross-shore transport of sediment and because they only interrupt the longshore drift. When erosion is a result of the onshore-offshore transport of sediment a different structure should be considered.

In many cases timber may offer lower whole life costs and environmental advantages over alternative materials, due to the relatively ease of construction and small quantities of construction material. To be an environmental responsible material it is necessary that the timber is either recycled or is obtained from sustainable managed forests. Reuse and recycling of timber can substantially reduce the need for new timber, and should be incorporated in the design and maintenance of structures. The durability of a structure is largely determined by design details, such as the spreading of loads and connection details.

When designing a groyne system it is important to understand the processes that take place in the nearshore area, before and after construction of the groyne field. Preferably the designer has both practical experience and knowledge of coastal engineering, as no two beaches are the same and consequently, there is not a groyne design that is universally effective. Because groynes have been constructed for hundreds of years, almost every possible mistake has been made. By studying several structures before simply replacing an existing groyne, an optimal system can be attained.

Before choosing for a conventional timber groyne it is essential that other alternatives are considered. When comparing the alternative options, the following issues must be taken into account:

- Effectiveness as coastal defence
- Sustainability
- Economic viability
- Socio-cultural impact

As the design of a groyne system cannot be summarised within a few pages, some general comments of good practice are stated that can benefit the design or maintenance of groynes:

To minimise downdrift erosion beach nourishment should be incorporated in the design of a groyne system

Reusing timber that has been under the ground in an earlier structure can be included in the design or maintenance of a groyne. By placing piles back upside down can possibly double their lifetime. Recycled members or shorter remaining lengths can be used for (prefabricated) sheet panels or rubbing pieces.

Simple connections such as overlap connections are recommended within a structure. Keeping the whole design as simple as possible will facilitate in fast and effective construction.

Bolts should be used to attach planking at high levels, in order to make replacing possible. Coach screws can be used at lower levels, not requiring the drilling of holes through thick members.

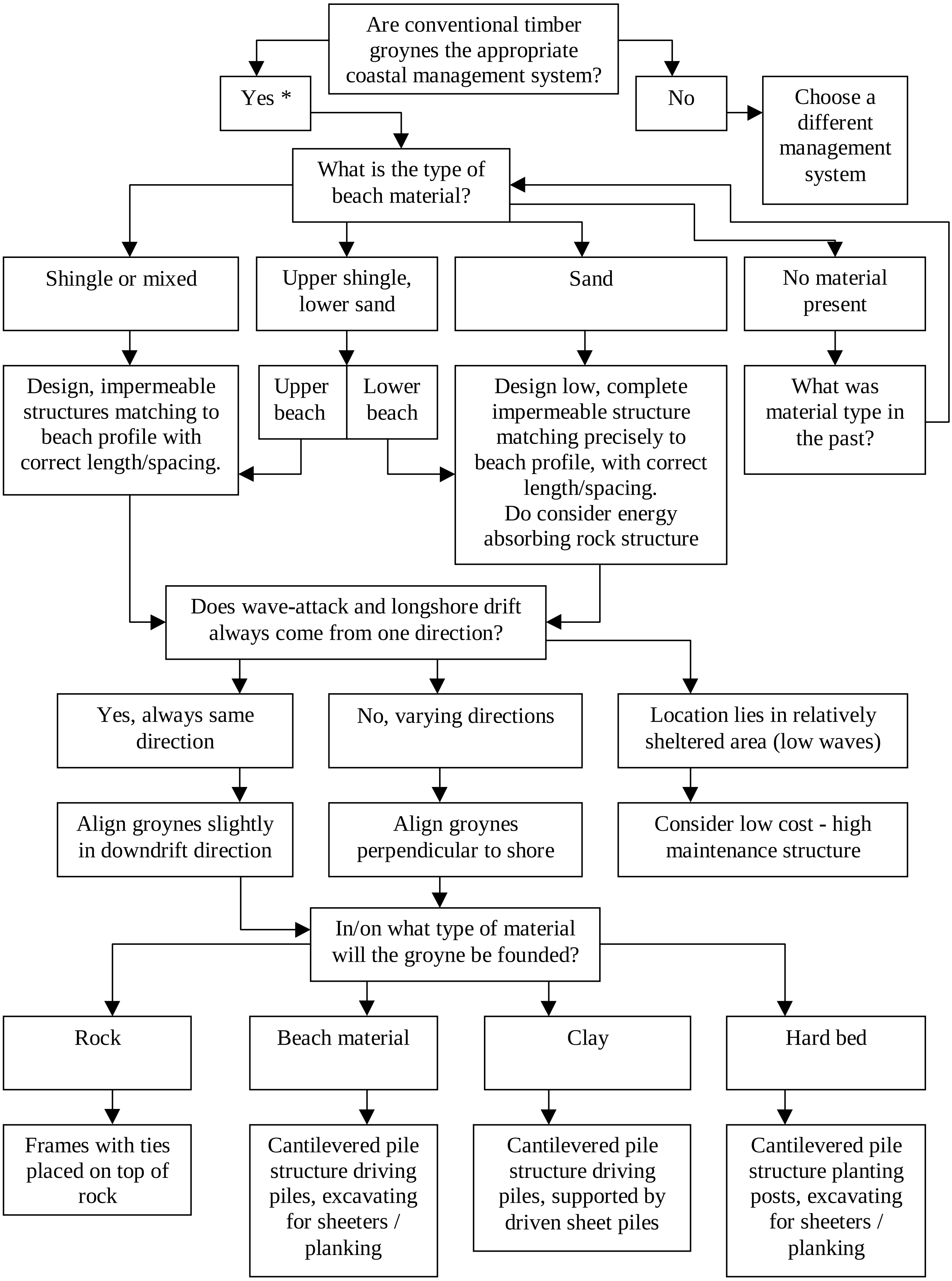
Pile shoes and pile rings will prevent end grains of posts from brooming when driven into the ground.

Regular maintenance can avoid major damage on a structure, and thus decrease the cost of repairing.

Finally, Figure 60 presents the combined use of timber and rock. The timber groyne forms the barrier, requiring a small quantity of material, and the T-shaped head can be advantageous in some situations. The rock breakwater like structure minimises reflection by absorbing wave energy and will result in minimal scour too. Thus the positive characteristics of both construction materials are combined.

Figure 60. Combined use of rock and timber

On the following page a decision tree is presented, giving a basic overview of the design process of a conventional timber groyne for a specific location.



* The main erosion problem is caused by longshore sediment transport. Wave induced currents are an important factor in the longshore currents. If tidal induced currents are the main transport mechanism, consider permeable and rock structures.

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Appendices

Appendix 1 Calculations on a groyne

Strength calculations for a statically loaded groyne

In this example a simple calculation shall be made of a groyne with anchors, with sand and water on either side of the groyne as illustrated below. The minimum height of the groyne shall be calculated using the chosen water- and soil-level differences. After the simple calculation comparisons shall be made, for varying groyne heights and soil level differences, using computer calculations.

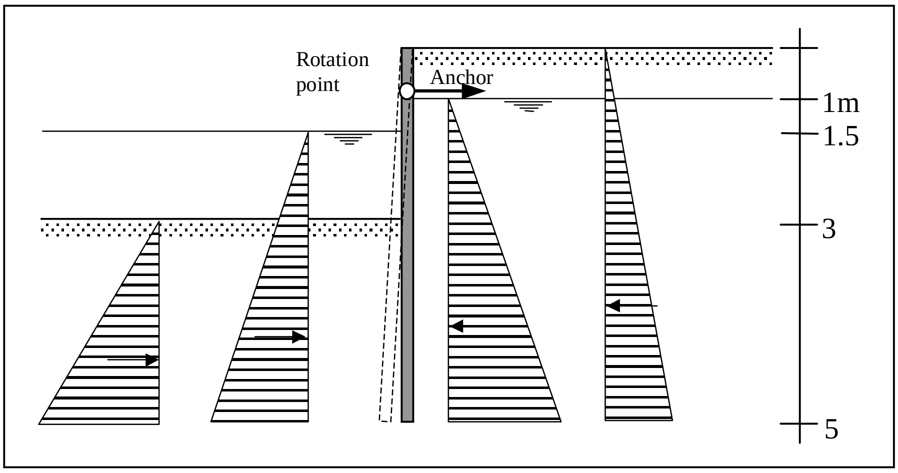


Figure 61. Loads and reactions anchor system

The following values are used in this calculation:
γ_d = 17 kN/m^3
γ_w = 20 kN/m^3
ϕ = 30˚ (friction angle of soil)
δ = 0 (friction between sand and groyne for calculation)
c = 0 (cohesion of the soil)

$K_p = \dfrac{1+\sin\phi}{1-\sin\phi}$ = 3 (passive pressure coefficient)

$K_a = \dfrac{1-\sin\phi}{1+\sin\phi}$ = 1/3 (active pressure coefficient)

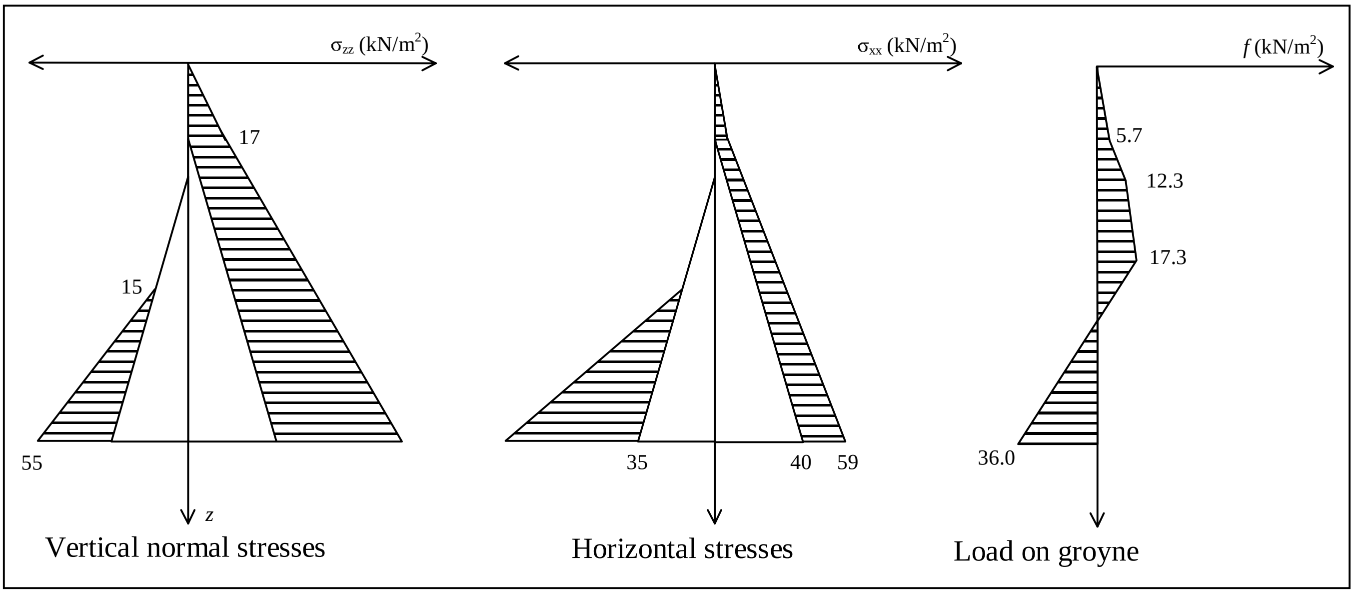


Figure 62. Stresses and load on groyne

The minimum required height, to assure stability of the groyne is 4.75 meters. The maximum bending moment is graphically determined to be: M_{max} = 18.75 kNm per meter and the anchor force is 21.75 kN/m. So for a 2.5 m spacing between the piles the maximum bending moment in a pile is:
M_{max} = 46.9 kNm = $46.9 \cdot 10^6$ Nmm.
A pile of 230 * 230 mm has a section modulus of $Z = 1/6\ b^3 = 2.03 \cdot 10^6\ mm^3$ which is used to calculate the following stress: $M/Z = 23.1\ N/mm^2$.
Greenheart has a permissible bending strength of for example 33.4 N/mm^2 (TRADA, 1991), so the chosen pile dimensions are sufficient.

In practice it is however wise to choose the height of a groyne larger than the minimum required height, calculated above, to avoid accidental (e.g. beach level drop) instability. For a deeper groyne the distribution of the soil reaction is shown below. The basic idea is that the pile is displaced towards the left (by the higher soil-level) except at the lower end, where a displacement towards the right occurs. Without using anchors the same principle occurs, known as the cantilever system.

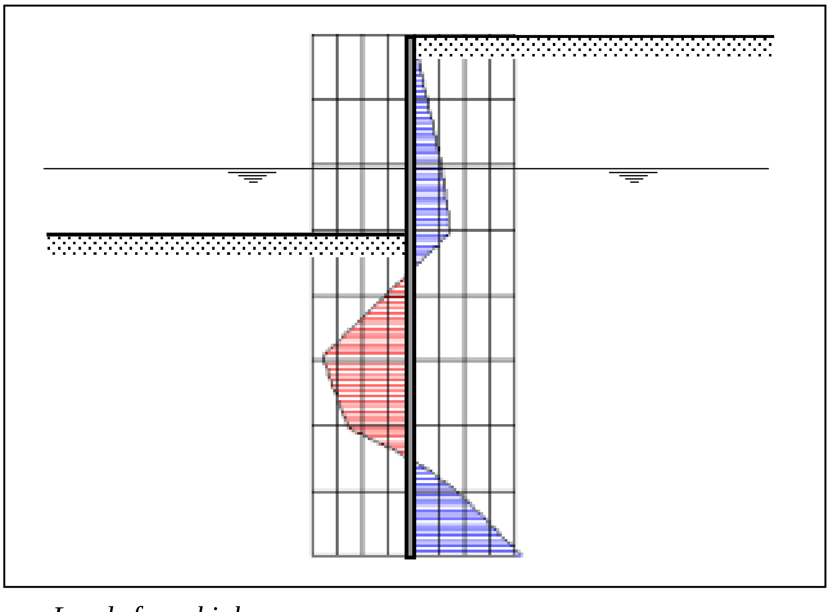


Figure 63. Loads for a higher groyne

Calculations using SPW 2001

With the software program SPW2001 (sheet pile wall) calculations have been made for several load situations. To check whether the program's results correspond with the calculations made before, exactly the same situation is calculated. The maximum bending moment calculated by SPW2001 is about the same, as can be seen in the table below.

In the tables and graphs the following symbols are used:
z = depth
w = lateral displacement
M = bending moment
Q- = shear force just above a point
Q+ = shear force just below a point
F = concentrated force at a point
f = resultant soil pressure

i	z	w	M	Q-	Q+	F	f
	m	m	kNm/m	kN/m	kN/m	kN/m	kN/m²
41	2.050	-0.012533	15.811318	9.522188	9.522188	0.000000	-14.083340
42	2.100	-0.012501	16.269615	8.809688	8.809688	0.000000	-14.250000
43	2.150	-0.012468	16.692079	8.088855	8.088855	0.000000	-14.416660
44	2.200	-0.012434	17.078292	7.359688	7.359688	0.000000	-14.583340
45	2.250	-0.012399	17.427839	6.622188	6.622188	0.000000	-14.750000
46	2.300	-0.012363	17.740303	5.876355	5.876355	0.000000	-14.916660
47	2.350	-0.012326	18.015266	5.122188	5.122188	0.000000	-15.083340
48	2.400	-0.012287	18.252313	4.359688	4.359688	0.000000	-15.250000
49	2.450	-0.012248	18.451027	3.588855	3.588855	0.000000	-15.416660
50	2.500	-0.012208	18.610990	2.809688	2.809688	0.000000	-15.583340
51	2.550	-0.012166	18.731787	2.022188	2.022188	0.000000	-15.750000
52	2.600	-0.012123	18.813001	1.226355	1.226355	0.000000	-15.916660
53	2.650	-0.012080	18.854214	0.422188	0.422188	0.000000	-16.083340
54	2.700	-0.012035	18.855011	-0.390312	-0.390312	0.000000	-16.250000
55	2.750	-0.011988	18.814975	-1.211145	-1.211145	0.000000	-16.416660
56	2.800	-0.011941	18.733688	-2.040312	-2.040312	0.000000	-16.583340
57	2.850	-0.011893	18.610735	-2.877812	-2.877812	0.000000	-16.750000
58	2.900	-0.011843	18.445699	-3.723645	-3.723645	0.000000	-16.916660
59	2.950	-0.011793	18.238163	-4.577812	-4.577812	0.000000	-17.083340
60	3.000	-0.011741	17.987709	-5.440312	-5.440312	0.000000	-17.250000
61	3.050	-0.011688	17.694724	-6.279121	-6.279121	0.000000	-16.776180

Figure 64. SPW calculations results

Comparisons

Now using the program SPW2001, calculations are made for two cases:

- Varying the soil level differences, with a constant groyne height.
- Varying the groyne height, with a constant soil level difference.

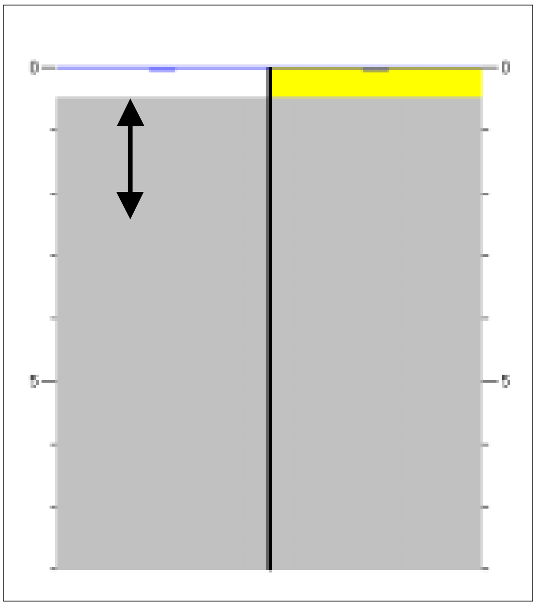
In both cases the water level is chosen to be the same on either side of the groyne. No dynamic loads have been taken into account in these calculations.

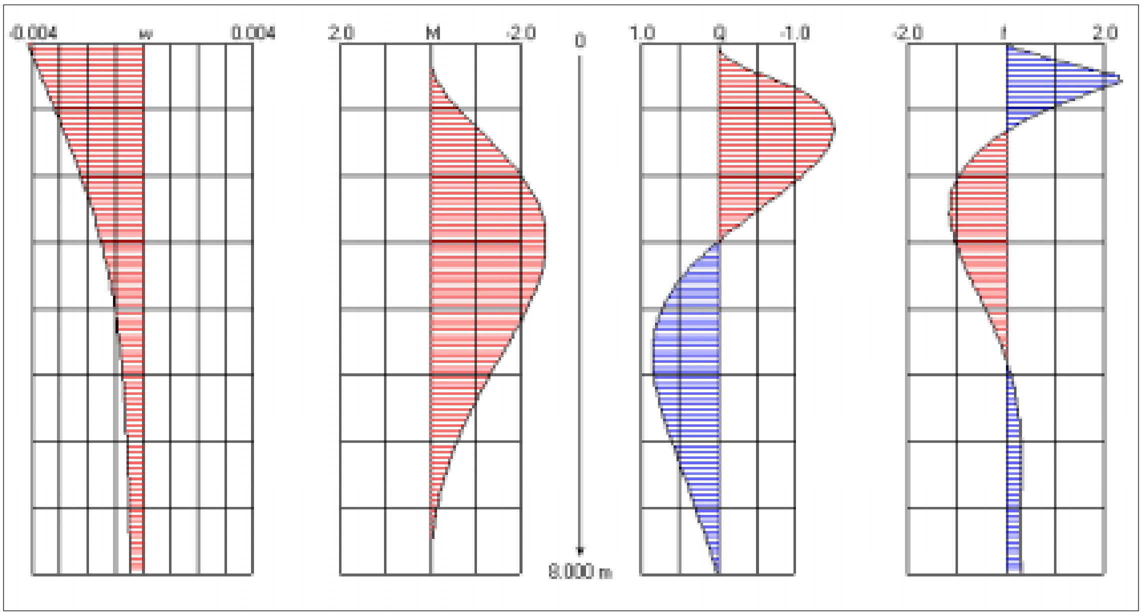
Soil level variations

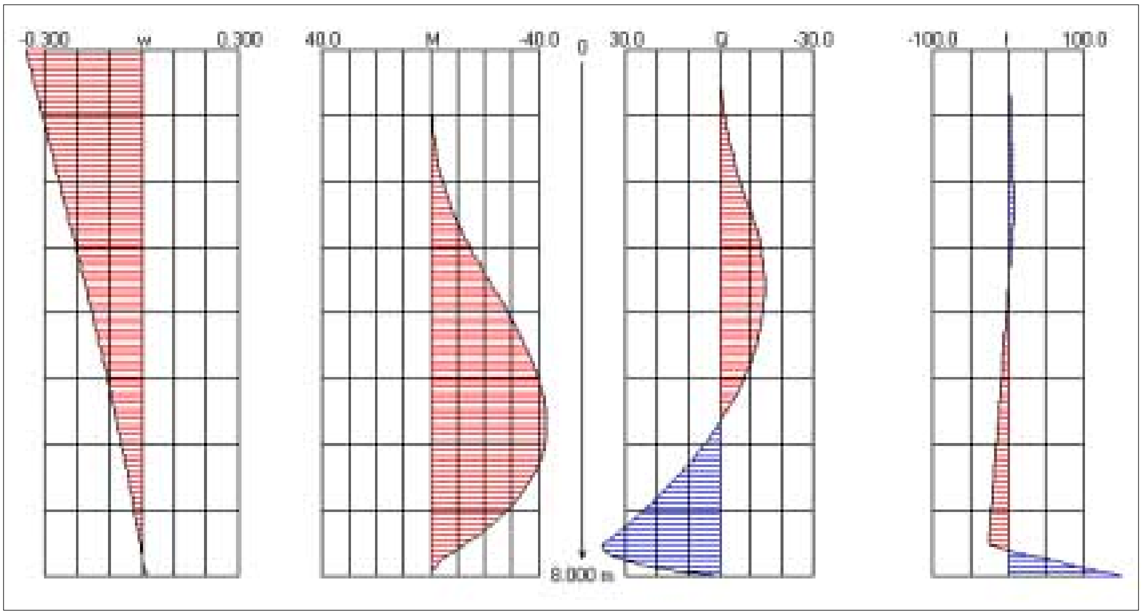
Calculations have been done using SPW2001, for soil level differences from 0.5 to 2.4 m. The height of the groyne is 8.0 m.

The top figure on the right, shows graphs for a soil level difference of 0.5 m, the bottom one is for a level difference of 2.4 m.
Instability occurs for higher soil level differences.

w = lateral displacement (m)
M = bending moment (kNm/m)
Q = shear force (kN/m)
f = resultant soil pressure (kN/m^2)



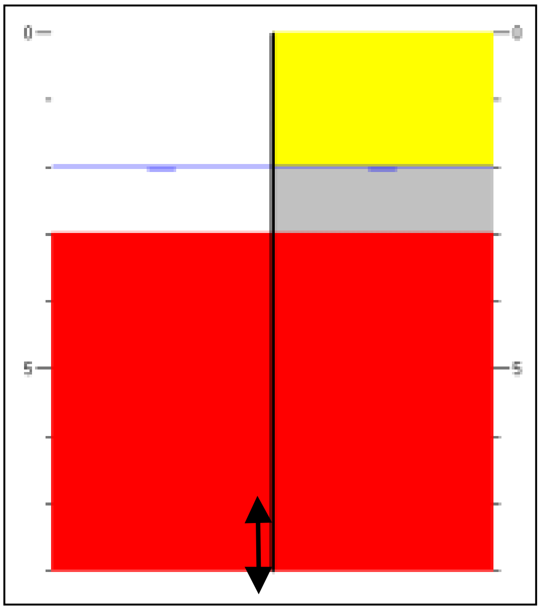


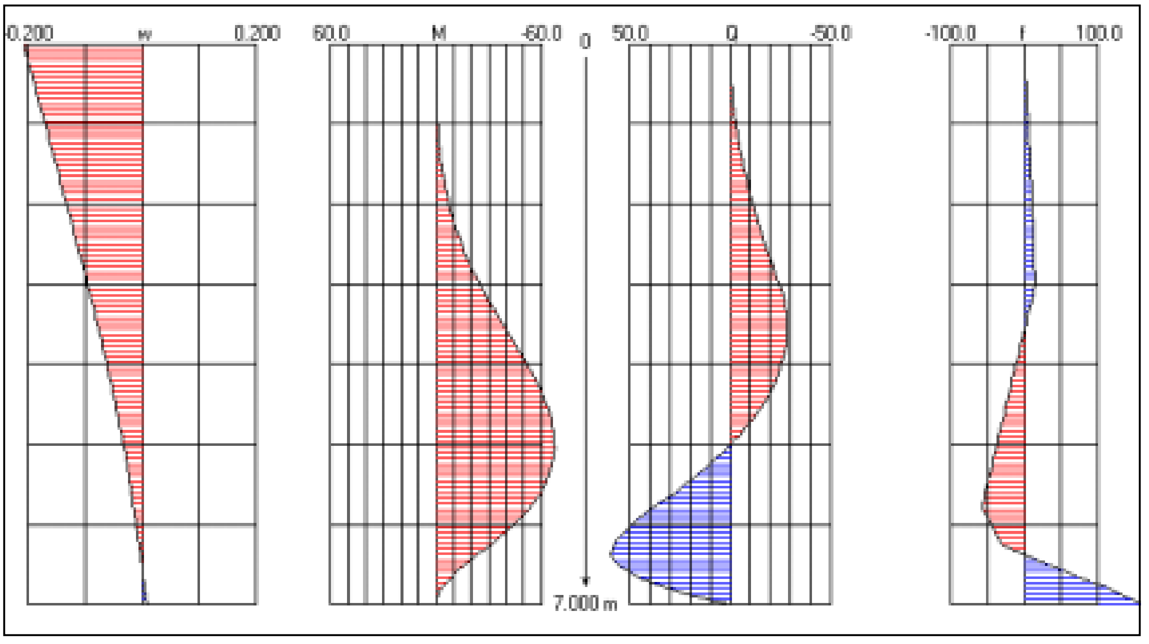


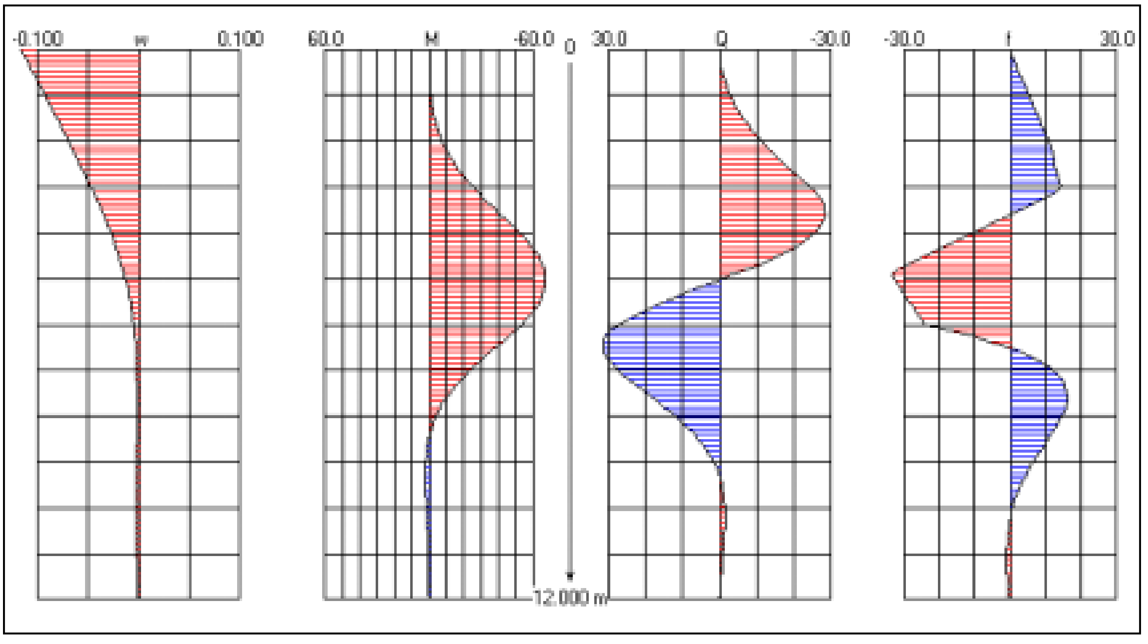
Groyne height variation

Calculations have been done using SPW2001, for groyne heights from 6.9 to 12 m. The soil level difference is 3.0m. The top figure on the right, shows graphs for a groyne height of 6.9 m, the bottom one is for a groyne height of 12 m.
Instability occurs for smaller groyne heights.

w = lateral displacement (m)
M = bending moment (kNm/m)
Q = shear force (kN/m)
f = resultant soil pressure (kN/m^2)







Conclusions

On the previous pages some graphs are presented, giving a better understanding of how variations in soil level differences or groyne height effect the loading on the groyne.
In all cases the bending moment is decisive for the pile dimensions, but in most cases the permissible lateral displacement will be decisive in design practice.

- Varying the soil level differences, with a constant groyne height.

The maximum bending moment and thus the minimum pile dimensions increase exponential with an increasing soil level difference.

- Varying the groyne height, with a constant soil level difference.

The maximum bending moment is constant for a constant soil level difference, but varying groyne height. However an initially high lateral displacement decreases exponentially until equilibrium is reached at a certain groyne height.

For both cases the lateral displacement might be the decisive criterion. The displacement is dependent on the modulus of elasticity and the moment of inertia of the pile. The dimensions increase exponential with a decreasing displacement, as illustrated below.

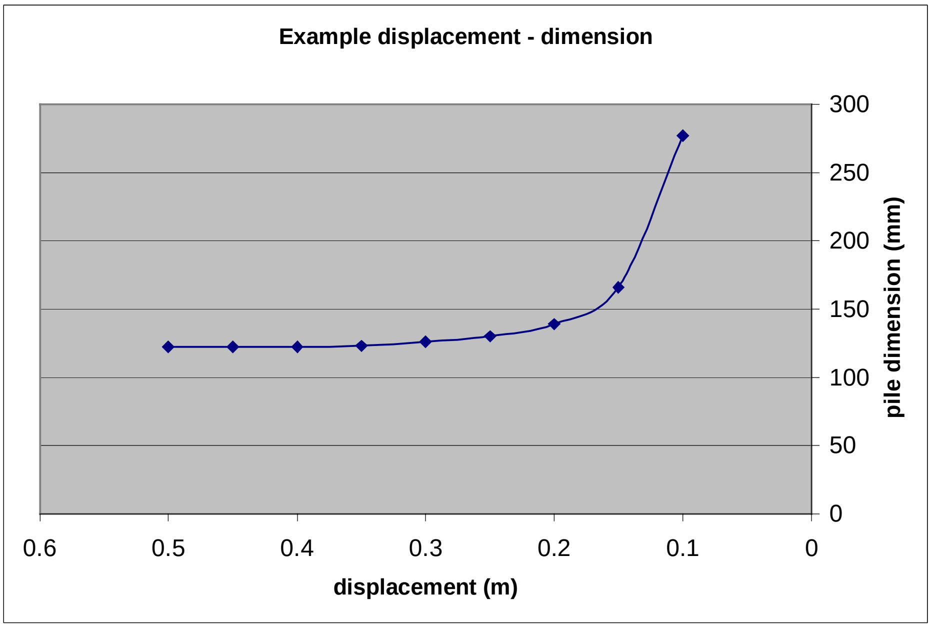


Figure 65. Example displacement-dimension graph

In these calculations no dynamic loads have been taken into account. These loads will have a significant impact on the stresses in the piles, so should definitely be included in groyne design calculations.

Dune fencing, wave barrier fencing and thatching

Several techniques have traditionally been used to stabilise or restore dunes, often using any form of timber or brushwood cuttings. It should be remembered that vegetated sand is the best form of coastal protection, and the aim of stabilising dunes. Dune or sand fences, placed parallel to the shore reduce wind speed across the sand surface and thus encourage the deposition of wind blown sand. Further the fences will help protect existing or planted vegetation by stabilising the surface and reducing trampling. Another use of sand fencing is to keep roads or paths leading through the dunes free of drifting sand.

Timber fences may be constructed as barrier fencing at the base of a dune, protecting it from erosion due to occasional wave attack. Sand moves onshore with low waves and offshore when high waves attack the shore during storms. Protecting dunes against storm waves is an effective method to decrease erosion. The most common type of wave barrier fencing is known as a Dutch fence, constructed of brushwood or chestnut paling in a rectangular shape at the toe of the dune. More solid structures can be built for the same purpose, including vertical or sloped permeable revetments. Wave barrier fencing should always be built above the limit of normal wave run up to avoid undermining.

Laying a thatch of brushwood over the surface of the sand and planting marram grass or sowing grass seeds in the gaps can help recover areas with no or little supply of sand. If willow and poplar species are used, the thatching can be dug into the sand to encourage growth from the cut stem. Dunes are often stabilised or restored in a whole management scheme of dune grass planting, thatching, fencing and beach renourishment.

Figure 66. Dune fencing, Greatstone on Sea, UK

Choice of timber structure
As a natural material timber and brushwood are aesthetically more appreciated than synthetic materials. Secondly sand fencing can best be constructed using biodegradable materials, as the fences will get buried if successful or in some cases get washed away if not successful. For the same reason it is preferable to use low-cost materials such as brushwood. However fencing is usually constructed using long lasting wire, which may cause to be a hazard on the longer term. Although natural materials are preferred, synthetic

snow fencing has successfully been used for dune fencing and its use may be considered in some cases. Further straw bales have proven to be effective to repair small blowouts.

The labour costs for dune management schemes are considerable. In many cases however, conservation volunteers carry out the necessary maintenance, as the dunes are often of high ecological value.

Operating conditions

Dune fencing, wave barrier fencing and thatching will resist some erosion, but cannot prevent erosion where wave attack is continuous and damaging. Where wave attack does occur regularly, it may be necessary to place substantial timber piles to avoid annual reconstruction. To prevent rotational failure support piles must be buried adequately, as beach levels will drop during storms.

Wave barrier fencing, placed just in front of a dune helps prevent severe damage caused by storm wave attack. The rectangular shaped Dutch fences have two lines of brushwood, the outer acting as the main barrier against waves and the inner protecting the dune base. Both dune fencing and wave barrier fencing may be removed for part of the year on high amenity value beaches. However this method is not recommended as the extra work may damage the dunes and the fences may not be beneficial at all in this way. To reduce the amount of work on temporary fences, permanent posts can be placed, to which the fencing is attached seasonally. A sloped timber revetment as a wave barrier fence will suffer less toe scour than a vertical wall, but cannot resist continuous wave attack either.

Public access routes must be built into the design of dune retaining structures, especially on popular public beaches in order to prevent the public damaging fences to create their own paths. The tracks should follow the natural contours of the dunes as much as possible. In popular areas fences should be designed as vandalism-resistant as possible, e.g. secure fixings. Dune fencing adjacent to paths will stabilise the sand and prevent trampling of the dunes.

Timber species

The choice of materials for dune fencing or thatching will depend on required life, length of the frontage, level of maintenance and potential for vandalism. Beach users often remove thatching and fencing materials for bonfires. Fencing materials include chestnut palings, pine, birch, wooden slats or synthetic fabrics. Brushwood can be made up of a number of different species e.g. local sea buckthorn or conifer trimmings. Locally available timber offcuts can be used but may result in being hazardous, as they are likely to generate splinters and loose staples. Sea buckthorn is likely to spread uncontrollably if the branches are not dead or still have berries on them.

Wooden slat fences are not recommended, as they are relatively expensive to construct and are stolen by beach users. Wooden slats tend to deflect the wind, causing erosion whereas brushwood traps sand because of its filtering action. Posts and wave barrier revetments can be constructed using treated softwoods or in some cases hardwood, possibly being recycled as the required lengths are short. Railway sleepers may be used to create vertical wave barrier fencing in more vulnerable areas, acting more like a sea wall rather than fencing.

Overall configuration of structure

Dune fencing

Brushwood fencing and chestnut paling are the two most common fence types. Brushwood fencing is an upright hedge of stacked brushwood, whereas chestnut paling is constructed using support posts and tensioning wires. Fencing should be aligned parallel to the dune face, forward of the toe of the dunes although in some cases the fencing is set up at right angles to the prevailing wind. Posts and wires are best set up to last for several years, as they are costly to replace. The posts should be long enough to ensure the stability of the fence at the lowest expected beach level. Sand will build up 1.25 m leeward of the fence. Initially fences should be constructed at the downward end of where the build up is required. When the sand level has increased additional lines of fencing can be added, spaced at a distance of 4 times the height of the fence. Short spurs may be constructed up a dune, spaced at 6 times the fence height, at areas subject to local erosion to restore that specific part of the dune (Ecopro, 1996). Spurs running seaward are less useful and may be damaged by swash zone debris or by beach users trying to walk along the shore at high tide. A porosity of 30% to 50% is required for dune fencing to be effective (Scottish Natural Heritage, 2000). Standard paling fences around construction sites have a porosity larger than 50% and should therefore not be used for dune management.

Wave barrier fencing
Constructing wave barrier fencing may generally be the same as dune fencing, other than the rectangular layout of the wave barrier. Dutch fences are constructed using brushwood and arranged in the form of a rectangle. Trenches are dug at the toe of the dune in which the brushwood is placed upright. The primary function of wave barrier fencing is to absorb wave energy, but they will encourage sand build up too. Often chestnut paling is used, as used for dune fencing with a porosity of 30% to 50%, and fixed between 1.25 to 2 meter long posts (Ecopro, 1996).

A different approach is the more solid sloping or vertical revetment-like wave barrier. The porosity of these structures lies between 20% and 50%. Sloping structures will reflect waves less, thus suffering less toe scour and are more stable under wave impacts. Railway sleepers have been used as wave barriers, acting more like a seawall than a fence. They are a relatively cheap option compared to rock armouring

Dune thatching
Thatching should cover 20 to 30% of the sand surface (Scottish Natural Heritage, 2000) and be laid above the line of normal wave run-up. Biodegradable mats can be used for the same purpose but are more likely to be damaged in the marine environment. Dune thatching or matting should always be complemented with the planting of marram grass or sowing of grass seeds in the gaps or in holes. It is recommended not to use thatching on slopes steeper than 1:2. In these cases the dunes will have to be reshaped or renourished to obtain the required dune profile.

Maintenance
Regular maintenance is required for both fencing and thatching in order to carry out repairs as soon as possible. Maintenance can be carried out during the whole year, but planting of marram grass preferrably is done in spring. When planning maintenance, nesting and migration of birds, public access and safety should be taken into account.

Appendix 3 Faggot structures

Bed protection, fascine mattresses, accreting faggots and other brushwood structures

The primary function of bed protections is to prevent scour at unwanted locations. Preventing all scour is impossible, and may take place in area's where it will do no harm. The geotechnical stability of the soil is the main criterion for the protection, which is achieved by forming a filter layer between the soil and currents. The protections may be used for various purposes to prevent scour: as aprons behind outlet structures, along the toe of revetments and around structures such as bridge piers.

Bed protections can be made of numerous materials including granular material, geotextiles, asphalt, timber and brushwood. Fascine mattresses consist of sticks or twigs, (of hazel, willow, birch, thorn or sweet chestnut) tied together in bundles. The bundles are arranged in mattresses, which are covered with stone after positioning to resist currents. The mattress is constructed beside the water and towed to its final location, as shown in Figure 67. When in place the mattresses have to be permanently submerged, in order not to deteriorate.

Fascine mattresses have been used for centuries but are hardly used nowadays because of the high labour costs. Geotextile is used in its place often with concrete blocks attached to it. However in area's where it is hard to obtain geotextile or where labour costs are low fascine mattresses may be an attractive solution. Using local materials such as reed, willow or bamboo an excellent filter layer can be constructed.

Figure 67. Construction of a fascine mattress (courtesy to DWW)

Submerged screens and groynes may be used in rivers to control the riverbed to guarantee a navigable channel. Open pile screens or spur-dikes are relatively cheap permeable structures, but can easily be clogged by floating debris, resulting in greater loads on the structure and more erosion at the head. These screens can be made of flexible branches, such as willow, woven around posts. Similar to these submerged permeable screens in rivers are screens or accreting faggots in shallow tidal areas or riverbanks encouraging the deposition of sand, mud and slib. The sediment and silt is trapped as the water flow is reduced. After a certain time the faggots are entirely covered with sediment and natural vegetation. The Netherlands have extensively used this technique for foreshore building in their mud-flat areas. In rivers the faggots are staked along the shore with the butt end pointing upstream, in order to retard the flow and collect sediment. Faggots along waterways can be constructed using live as well as dead material, live material should be collected and installed between October and March. Building a latticework of poles and branches to form a crib can form an alternative submerged structure, which is filled with rocks for stability.

Figure 68. Accreting faggot, Holwerd, The Netherlands

Appendix 4 Use of timber along UK coast

To help document the current use of timber along the UK coast the following questionnaire is held among 33 local authorities. Almost half of the authorities responded, but hardly any schemes appeared to suffer attack from marine borers. More likely is that most local authorities are not aware of any attack.

Questionnaire

1. Please indicate whether your organisation has used any timber on the coast or rivers for the following structures?

- Groynes
- Jetties
- Decking
- Slipways
- Other (please specify)

2. What timber species have been used?

- Balau
- Douglas fir
- Ekki
- Elm
- Greenheart
- Kapur
- Oak
- Pitch pine
- Other (please specify)

3. Are you aware of any biological attack on structures in your area?

- Shipworm (Teredo)
- Gribble (Limnoria)
- Other
- Not sure

	Timber structures	Timber species	Biological attack	Other
Angus Council	Groynes, beach access steps	Ekki, Elm	no evidence to hand	
Blackpool Borough Council	No use of timber			
Borough of Poole	Groynes, jetties	Douglas Fir, reused Greenheart	not aware of any attack	
Bournemouth Borough Council	Groynes	Greenheart	gribble attack	
Canterbury City Council	Some oak planking we tried on some groynes in Whitstable and were constructed in 1991 are displaying decay both above and below HWL - rot? and borers. The Greenheart piles on the groynes show no signs of decay as far as we can see from the surface.			
Christchurch Borough Council	Groynes; Decking; Revetments & Weir Gates	Douglas Fir; Elm; Ekki; Greenheart; Oak & Pine	Non on our coastline, but Bournemouth yes	8 yrs ago we began replacing damaged/missing planks with Douglas Fir and found a financial saving, also we have not found a great difference in abrasion wear
Conwy County Borough Council	Groynes, jetties, decking, slipways, storm boards	Greenheart, ekki, kapur	not aware of any attack	
Fareham Borough Council	Groynes	Greenheart	not aware of any attack	
Havant Borough Council	Groynes, sloping revetments	Balau, ekki, greenheart	not aware of any attack	reason for repair/replacement is predominantly down to abrasion in the intertidal zone
North East Lincolnshire Council	Groynes, decking	Balau, Douglas fir, Greenheart (and recycled plastic)	not sure	
North Norfolk District Council	Groynes, Revetments, Slipways, small jetties, decking, barriers, retaining walls, props, folding wedges, cliff steps	Greenheart, Ekki, Balau, Barcilarta, Jarrah, Kapur, Opepe, reused pitch pine	not aware of any attack	60 year old pitch pine planks on groynes!
West Dorset District Council	Groynes, decking, slipways, Walings, cladding, fendering (harbour walls and piers) mooring piles, quay side kerbs, access steps, ladders	Ekki, Greenheart, Iroko (cladding/fendering)	gribble attack suspected in harbour access ladders, but not sure	

Appendix 5 Case study data

General

Scheme name				
	Bexhill - Beaulieu Road			
Location and orientation				
	East Sussex, facing south-south-east			
Responsible authority				
	Rother District Council			
Consultant				
	Posford-Duvivier			
Scheme life				
	30-40 years			
Construction date				
	1977			
Beach type and profile / substrata				
	Mixed shingle and sand with siltstone bed (uncovered at low tide)			
Beach material				
	No material on siltstone bed, after nourishment shingle/sand			
Beach slope				
	Siltstone bed 1:28.9			
Tidal range				
	MHWS	3.7	m OD	
	MHWN	2	m OD	
	MTL	0	m OD	
	MLWN	-1.7	m OD	
	MLWS	-3.1	m OD	

Design and detailing considerations

Timber species used				
	Balau piles and waling, kapur planking			
Section sizes and lengths				
	King piles	300 x 300 mm (20x)	250 x 250 mm (8x)	230 x 230 mm (10x)
	Waling	230 x 300 mm	230 x 150 mm (last 10 bays)	
	Planking	230 x 75 mm (100 thk under 13 planks)		
		230 x 50 mm for last 10 bays		
	Plant access bays:	230 x 100 mm (8 planks 150 thk)		

Groyne dimensions

Length 85.8 m
Pile lengths varying 6820 mm to 2180 mm
Piles 2300 mm c/c
Braces and posts varying (7 different types) 300 x 300 mm and 250 x 250 mm
Total slope beginning-end groyne 1:13, but planking with 6 steps

Structural analysis

Frame with post and brace (props and ties) placed in concrete
Horizontal ties: 2 steel U profiles on either side of post/prop
Diagonal brace: 60 degrees angle with post and axis line intersecting at level of waling

Other features of interest

At time of construction no material was on the beach. The groynes were constructed on the siltstone bed and an estimation for a possible beach level was made.

Reuse of timber

Previous structures

Old structure founded in sand/shingle

Demolition and dismantling

Old structure washed away

Construction techniques and significant features

Temporary works and access

Acces bays 4600 mm c/c Concrete working platform constructed on upper beach

Prefabrication

The frames were constructed off-site and reassembled on-site

Piling or placing

Posts and braces (frame) placed in trench filled with concrete
25 mm dia x 900 long deformed bars are used to give more support in concrete

Joints and fixings

Scarf joints in waling at pile fixed with bolted (5x) metal plates (post notched to receive metal plate)
Coachscrews (2 per plank) used for planking, except at several braced posts (1 bolt per plank)
Washers used for bolts only, nuts on landward side
Post-brace connection with plates and 4 + 3 bolts in each
Round metal post rings 50 x 12 mm and min IDiam 6 mm less than post dimension

Beach nourishment / material / source

Beach nourishment carried out

Figure 69. Aerial photograph of Bexhill scheme (courtesy to Multimap)

General

Scheme name
Bournemouth

Location and orientation
Dorset, facing south

Responsible authority
Bournemouth Borough Council

Consultant
Bournemouth Borough Council, technical services division, coast protection section

Scheme life
25 years

Construction date
Varying, but groyne building scheme completed in 1991

Capital costs
Approximately £195,000 per groyne

Beach material
Sand

Tidal range

HWMST	0.84 m AOD
LWMST	-1.19 m AOD

Design and detailing considerations

Timber species used
Greenheart

Section sizes and lengths

King piles	305 x 305	mm
Waling (upper and lower)	300 x 200	mm

Planking 300 x 100 mm
Sheeters 300 x 100 mm
Ply panels on planking 2400 x 1200 x 20 mm

Groyne dimensions
Nominal length: 70.8m
Pile length: 9.1m pile 29/29 12.7 m with top mark
Piles 2195 mm spacing (c/c 2500 mm)
Upper/lower waling 2000 mm c/c
Top planking horizontal at 2.8m AODN till chainage 5.5m, then 1:25 slope (0.2m AOD at pile 29/29)
Planking 1500 mm high

Structural analysis
Cantilever system, with piles, sheeters and planking

Other features of interest
All piles flush with top of planking, except piles 19 to 29 (of 29)
Fillets (200 x 100) used in each corner (post-plank and planking-top waling)

Construction techniques and significant features

Piling or placing
Piling into sand substrata. Square pile rings used.

Joints and fixings
Stainless steel bolts, coachscrews, washers and pile rings. Lap joints in waling (not at piles)
Butt joints in planks (at pile), planks double bolted to piles
Sheeters double/single coachscrewed to upper/lower waling (at piles: 2 bolts/1 bolt+1 coachscrew)
At upper/lower waling, sheeters+waling double/single bolted to piles
Ply panels nailed to planking

Scheme performance

Biological attack
Gribble attack

Figure 70. Aerial photograph of Bournemouth scheme (courtesy to Multimap)

General

Scheme name
Calshot

Location and orientation
Hampshire, facing south-east

Responsible authority
New Forest District Council

Scheme life
Approximately 10 to 12 years

Construction date
Various dates 1997 - 2002

Capital costs
Relatively cheap

Beach material
Shingle

Design and detailing considerations

Timber species used
Douglas fir and recycled hardwood (greenheart)

Section sizes and lengths
Douglas fir stakes 2.0 m
Main piles longer and approximately 200 x 200 mm

Configuration and spacing groyne field
Zig zag shaped

Procurement of timber

Specification
Locally grown douglas fir

Reuse of timber

Reuse
Hardwood from other schemes

Construction techniques and significant features

Piling or placing
Placing softwood stakes between double hardwood waling

Beach nourishment / material / source
Renourishing beach updrift of scheme with material of spit at the downdrift end.

Figure 71. Aerial photograph of Calshot scheme (courtesy to Multimap)

General	
Scheme name	
	Eastbourne coast protection
Location and orientation	
	East Sussex, facing south-east
Responsible authority	
	Eastbourne
Consultant	
	Posford Duvivier
Scheme life	
	60 years
Construction date	
	November 1995 - April 1999
Capital costs	
	Total £30.633 million. Average cost each groyne £95,000
Beach type and profile / substrata	
	Shingle upper beach, flat sandy area uncovered at low tide, chalk under beach at Holywel
Beach material	
	Shingle D50 = 20.00 mm
	Sand D50 = 0.19 mm, D90 = 0.35 mm

Beach slope			
	1:9		
Significant wave height			
	3.9 m (return period 5 years)		
Tidal range			
	MHWS	3.75	m ODN
	MHWN	1.85	m ODN
	MTL	0.3	m ODN
	MLWN	-1.45	m ODN
	MLWS	-2.95	m ODN
Longshore and cross-shore current			
	West to east		
Length of coastal defence			
	5.5 km		

Design and detailing considerations

Timber species used		
	Greenheart except for ties (oak boles or recycled greenheart recovered from old works)	
Section sizes and lengths		
	King piles	305 x 305 mm
	Waling	230 x 230 mm
	Planking	230 x 75 mm / At plant access bays 305 x 150 mm
	Sheeters (where used)	230 x 75 mm
Configuration and spacing groyne field		
	About 70 m spacing	
Structural analysis		
	A design without ties proved to be uneconomic. Every 4 piles one brace has been placed.	
	At Holywell, where the chalk platform rises, the king piles have been installed in concrete-filled trenches.	
Other features of interest		
	Purpleheart steps (user friendly and no splinters)	
	Enough room for extra planks on top end pile	
Design tools/methods		
	Historical research (photogrammetry)	
	Physical modelling, HR Wallingford, flume scale 1:25 and basin scale 1:66	
	Numerical modelling	

Procurement of timber

Specification	
	From a supplier in Guyana, operating a green charter similar to that of the FSC

Pre-ordering

Once Posford Duvivier had justified the decision to use greenheart, the original supplier had gone into receivership. A replacement supplier had to be found which led to delay of the scheme.

Reuse of timber

Previous structures

Eastbourne has used English oak for coastal defence structures

Reuse

Used timber sold by contractor, lost to sea and taken away (fire wood)

Types, grades and sizes of timber

Old planks 2 inch, new 3 inch

Construction techniques and significant features

Temporary works and access

Plant bays have been constructed with doubled pilings at both sides of the bay.

Piling or placing

The hard driving meant that some piles had to be stopped high. After two to three tidal cycles, piling could be restarted, and posts driven to design depths. At Holywel first the piling was placed in a trench, the waling was attached and then the trench was filled with concrete.

Joints and fixings

Hot-dipped galvanised coachscrews, bolts and washers were used

Waste minimisation

The contractor produced a very detailed cutting schedule for supply to their timber merchant against which they would price.

Beach nourishment / material / source

Around 780,000 m3 of material was pumped ashore

Figure 72. Aerial photograph of Eastbourne scheme (courtesy to Multimap)

General

Scheme name
Felpham

Location and orientation
West Sussex, facing south

Responsible authority
Arun District Council

Construction date
1998 - 1999

Beach material
Mixed sand and shingle with blue clay or chalk substrate

Design and detailing considerations

Timber species used
Greenheart

Section sizes and lengths

King piles	230 x 230 mm	
Waling	230 x 150 mm	
Planking	230 x 75 mm	
Sheeters (where used)	230 x 75 mm	1.8 m length

Other features of interest
Rock toe in front of concrete seawall
Greenheart specified GR.01 of the Guyana Grading Rules for Hardwood Timber

Figure 73. Aerial photograph of Felpham scheme (courtesy to Multimap)

General

Scheme name	**Tankerton coast protection works**
Location and orientation	Kent, facing north
Responsible authority	Canterbury city council
Consultant	Canterbury City Council Engineers
Beach material	Shingle with clay substrata
Beach slope	About 1:6 to 1:8
Tidal range	MHWS 2.66 mOD MLWS -2.44 mOD
Longshore and cross-shore current	East to west longshore current
Length of coastal defence	36 groynes over 1450m

Design and detailing considerations

Timber species used

Ekki

Section sizes and lengths

Planks	230 x 76 mm
Piles	230 x 230 mm
Sheeters	230 x 76 mm 1.8 m long (end oblique, 150 mm diagonally cut of)

Waling = bottom plank with countersunk coachbolts to pile, prior to driving + bolting sheeters

	Strut 230 x 230 mm
Configuration and spacing groyne field	
	Spacing either 39, 40 or 42 m
Structural analysis	
	Cantilever system, with piles, sheeters and planking
	Strutted piles at existing concrete block apron (1:3), concrete to be broken out to allow piles to be driven and then backfilled with concrete
Other features of interest	
	Planks cut flush with face of pile
	Distance top pile to first plank either 300 or 530 mm
	Strutted pile attached to pile with y-frame raking strut (30 to 45 degrees angle with horizontal)

Reuse of timber

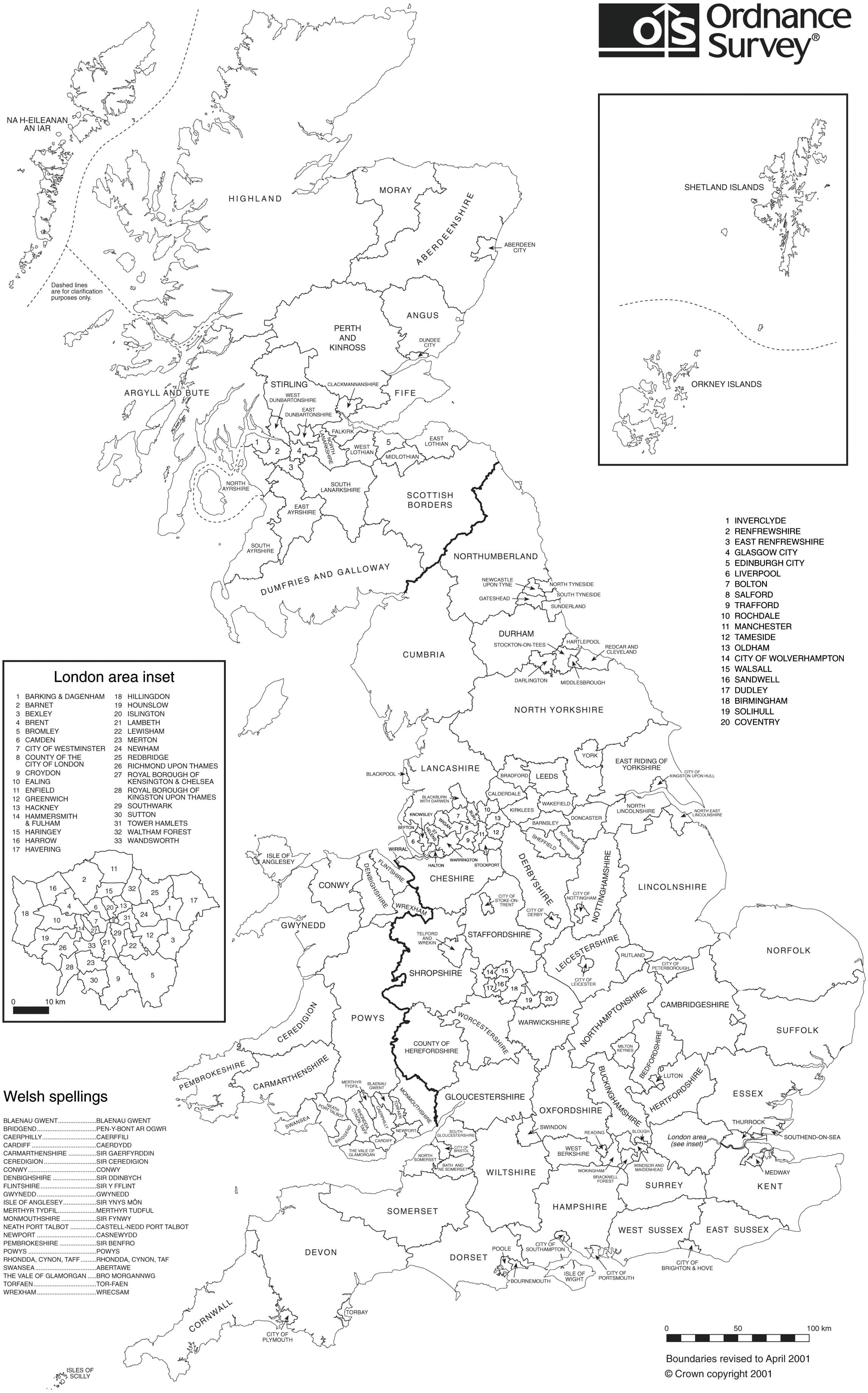
Previous structures	
	4 types: A built in 80's, B built in 70's, C saw tooth groynes in 70's, D before 1960
Reuse	
	All good timber reused in contract or other structures
Demolition and dismantling	
	Excavate to waling/clay level and remove planking + piles (leave timber waling and steel sheet piling)
Types, grades and sizes of timber	
	Greenheart piles, Greenheart, Kapur, Balau planks and waling with various sizes
Processing required	
	Cut of ends square, to form 1,8 m long sheeters

Construction techniques and significant features

Temporary works and access	
	Plant access over groynes with steel plates (2 x 1800 mm long) protecting planking
Piling or placing	
	Pile rings 230 dia, 50 x 12 mm fixed with 4 nails
	Pile shoe min 12.5kg iron
Joints and fixings	
	Butt joints in planks (at pile), planks single coachscrewed to piles
	Square washers line up square to the vertical
Beach nourishment / material / source	
	Nourishment 12,000 m3 of D50 = 10 mm beach shingle

Figure 74. Aerial photograph of Tankerton

scheme (courtesy to Multimap)



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