Client Report :

UK Timber for Marine and Geotechnical Applications

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Executive Summary

This is the final report of the following project, full title: "UK Timber for Marine and Geotechnical Applications" (Project Details: PPD28/02, BRE project no. CV0287). The project objective was to investigate and provide guidance on the usage of UK hardwood and softwood timber for piles, marine use, retaining walls and foundations.

BRE Digest 479 *Timber Piles and Foundations* was based on this report.

This report also details the further work carried out on Copper Chrome treated sycamore, Fibre Reinforced Polymer coated timber, full scale axial load testing on Sitka spruce logs and compression strength tests on small scale samples.

Main Findings

Wooden piles are widely used overseas, but are not often considered in the UK for on-shore structures because of the perceived reliability and drivability of the principal alternative, pre cast concrete piles. Doubts about long term performance count against the use of timber. However, timber piles driven below the water table can last indefinitely; treated timber can withstand acidic and alkaline soil conditions better than concrete. The Canadian Permanent Wood Foundation (PWF) system using timber bearers on a drained gravel base will be viable for some types of structure in the UK, particularly in positions with poor access. Timber can and is used for retaining walls, and offers an attractive alternative to concrete.

For marine structures greenheart is the principal species used because of its availability in large sizes, drivability, marine borer and abrasion resistance. UK timbers such as oak and Douglas fir are being used for marine works, but in limited quantities, and are considered less durable. Waste plastic piles and Fibre Reinforced Polymer piles are beginning to enter the UK market and have been extensively used in place of timber in the US. The use of UK timber as a geotechnical material requires promotion and development, but will probably remain a niche market for on shore use. Tropical hardwoods for marine works are hard to match for durability and strength. UK grown timbers can offer viable alternatives for many of the less demanding geotechnical and marine roles, and should be used wherever possible. BRE Digest 479 *Timber Piles and Foundations* aims to provide suitable stimulus and guidance for the use of British grown timber in this respect.

Timber is a hugely capable civil engineering material, with the additional advantage of being sustainable. Trees, in particular conifers, make natural piles. Timber foundations may be particularly suitable for countryside structures such as bridges, forest chalets and activity centres, as well as post and beam timber buildings in waterfront or flood prone locations. Home grown treated softwood and hardwood timber should be considered as alternatives to imported tropical hardwoods wherever possible. Although CCA treated timber cannot from June 2004 be used for marine structures, it can still be used for freshwater and brackish water piles, as well as on shore. One of the suggested methods of reducing global warming has been to bury timber to create carbon dumps. Using timber for piled foundations would effectively achieve this. There is likely to be increased interest in the use of sustainable foundation materials in the future, and timber is a suitable alternative to concrete in a number of forms ranging from driven piles, to pads and retaining walls.

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1. Introduction

This is the final report for the following project, full title: "UK Timber for Marine and Geotechnical Applications ". Project Details: PPD28/02 (BRE project no. CV0287). The project objective was to investigate and provide guidance on the usage of UK hardwood and softwood timber for piles, marine use, retaining walls and foundations.

BRE Digest 479 *Timber Piles and Foundations* was based on this report.

This report also details the further work carried out on the following:

- Copper Chrome treated sycamore
- Fibre Reinforced Polymer coated timber for marine borer resistance
- Full scale axial load testing on Sitka spruce logs
- Compression strength tests on small samples
- A review of competing materials

2. Timber Piles and Foundations

Although timber piles are rarely used on shore in the UK, in other countries notably the United States, Canada and Australia, they are used widely. Timber piles are a highly suitable choice of foundation, given appropriate ground conditions, for many structures. Timber piles are economical, easy to transport, handle, cut to length and work with on site. They are particularly suited for locations with access difficulties, or where excavations and the delivery of concrete would pose problems. Unlike in situ cast concrete foundations, there is no delay for curing.

Short, driven timber piles can be the solution for foundations in ground with a high water table, and where firm strata exists below surface material of loose sand, soft clays, or organic soils (Figure 1). In deep silt deposits, where the capacity of the pile is determined by shaft friction, timber piles are particularly suitable being tapered and easy to splice. In Sweden timber piles are used below the water table, where they are practically invulnerable to decay, and extended to the surface using concrete sections (Figure 2). Timber piles are also resistant to acidic and alkaline soils, soils with high sulphate or free carbon dioxide content. Timber piles can also be driven for ground improvement, to densify loose granular soils.

Preservative treated softwood or durable hardwood timber can also be used for the construction of retaining walls, bank seats, as well as for foundation pads and footings. Recent advances in the development of cost effective wood modification and timber treatment processes will allow much greater usage to be made of timber species which are either non-durable or difficult to impregnate. Polymer encasement can also be used in conjunction with environmentally friendly preservatives to protect timber.

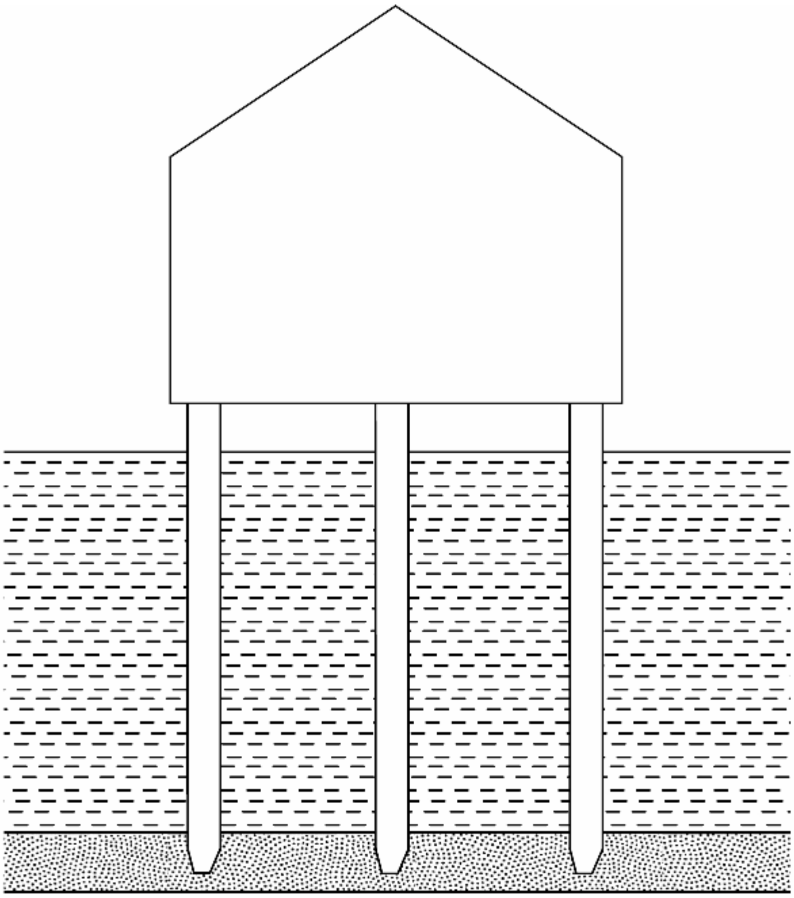

Figure 1: End bearing piles

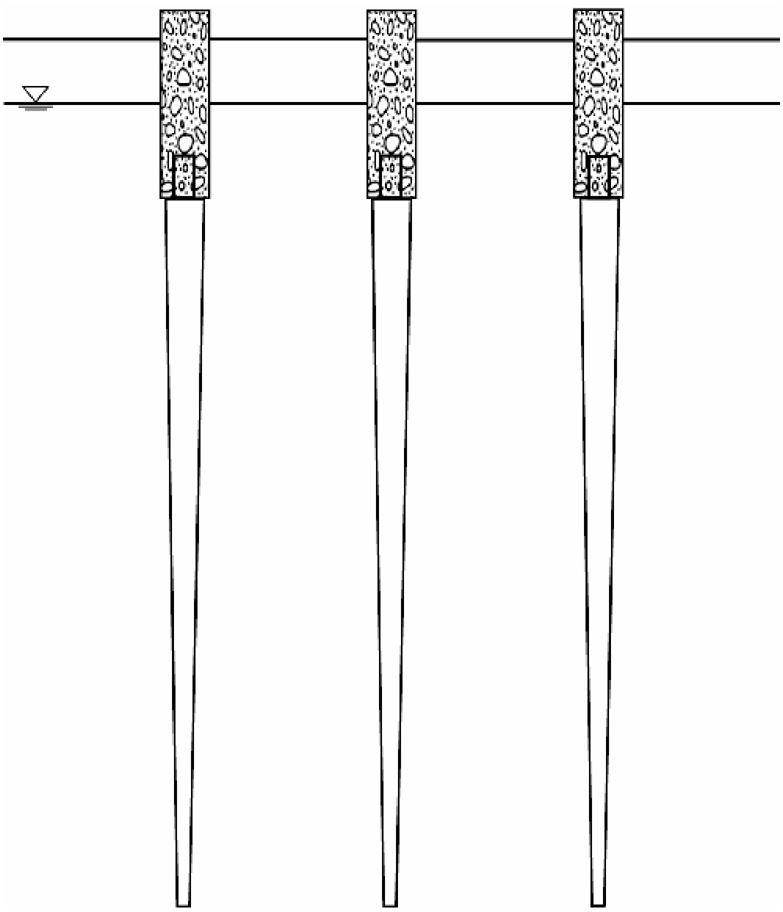

Figure 2: Tapered friction piles, extended above the water table using concrete sections

History and overseas use

Timber has been used for piled foundations for centuries (AWPI, 2002). Before 1900 nearly all piles were either untreated wood or stone. Old London Bridge was founded in 1176 on stone filled starlings constructed from elm piles, which lasted 600 years (Nash, 1981). The City of Louisiana is founded on timber piles, so too is the Pont Notredame bridge in Paris, The Royal Place in Amsterdam, The National Theatre of Finland, The Dome of Utrecht and The Reichstag in Berlin. The Brooklyn Bridge rests on 15 foot thick yellow pine pneumatic caissons, with a design load of 80,000 tons (McCullough, 1972). These immense foundations were each the size of four tennis courts and weighed three thousand tons. In 1902 the Campanile Tower in Venice was rebuilt on the 1000 year old piles, still in excellent condition, which supported the original structure (Haldeman, 1982). At Tobacco Dock in London, 160 year old Scots pine piles were recently re-used to support a new shopping and leisure complex (Mitchell et al, 1999).

Graham (2000) reports on the use of 30 tonne capacity timber piles for the foundations of the Cargo Terminal at John F. Kennedy Airport. Timber piles were also used for the 210m diameter Louisiana Superdome supporting 130,000 m^3 of concrete and 18,000 tonnes of steel. Timber piles with 70 tonne design loads are in use on a 300m long viaduct near Winnemuca, Nevada. In Canada over 30,000m^3 of treated wood piles are used annually. Most of the deep foundation support for highway bridges in North America comprise of treated timber piles. 500,000 timber piles are used per year throughout the United States. The US Army Corps of Engineers used over six million timber piles to construct the locks and dams for the Inland Waterway System. UK on shore usage of timber as a foundation material is somewhat limited, with few examples. At Barnes Waterside a bat sanctuary was built on timber piles, and at the Stoke Garden Festival site a timber footbridge is similarly supported. Primary usage of timber piles in the UK is marine, for the refurbishment of piers and groynes (Figure 3), and for use as fenders.

Figure 3: Timber piles being installed for beach protection (photo courtesy of Aarsleff piling)

Durability of timber piles

Untreated timber piles, when driven in below the water table, are virtually immune to biological degradation. Timber piles have been recovered from the remains of Roman and medieval constructions in a state of perfect preservation. The section of an untreated pile above ground water level is, however, vulnerable to decay and one option is to terminate the pile below the water table and continue the foundations in a different material such as concrete. In the past this was accomplished with stone or masonry. The timber piles of historic buildings may decay if the local water table is lowered below the tops of the piles for long periods, either by abstraction or drainage. Both York Minster and the Mansion House in London were originally built in marshy ground on timber foundations which subsequently degraded due to drainage. Boutelje and Bravery (1968) report on similar problems with buildings in Stockholm. In central Europe untreated species of non-durable softwoods such as Scots pine and Norway spruce were formerly used extensively. Below the water table sapwood (the outer layer of the log) is subject to slow biodegradation by anaerobic bacteria. Preservative treated timber piles, cut off below ground level and capped with concrete are expected to have lifespan in excess of 100 years. The expected service life of a treated timber trestle pile is about 60 years in fresh water in the UK.

Timber piles are highly resistant to both acid and alkaline soil conditions. In Australia, at the Ulan coal mine, treated hardwood timber piles (each with a capacity of 80 tonnes) were chosen for a bridge carrying ore trucks because the high free carbon dioxide levels and extreme acidity in the soil would have destroyed both steel and concrete piles. Timber piles were also used for the foundations of the Brambles Container Terminal in Burnie, Tasmania (soil pH 11.5) and the Auburn, N.S.W., Waste Transfer Station (soil pH 2.5).

Traditional timber species and treatments

In the United Kingdom Douglas fir in sections up to 400mm square and 15m length is the most common softwood used for piles (BS 8004, 1986). Pitch pine is also available in sections up to 500mm square. Greenheart was formerly the most commonly used hardwood, imported rough-hewn in sections up to 475mm square and up to 24m long. Other suitable tropical hardwoods given in BS 8004 include ekki, jarrah, and opepe. In the past, domestic grown hardwoods such as oak, beech, ash and sweet chestnut have been used for piles. Elm is also durable below ground, so much so that it was used for water pipes and coffins. The Rialto in Venice is supported on alder piles. In Scandinavia and Central Europe Norway spruce, Scots pine and to a lesser degree fir and larch have historically been used (Peek and Willeitner, 1981). In the US and Canada southern pine is used extensively as well as larch, red oak, lodgepole pine, western red cedar and Douglas fir.

Pressure injection of coal-tar creosote began in England in 1838. Following the use of pressure impregnated railway sleepers (railroad ties) in the United States the process was first applied to foundation pilings in the early 1880's. Today, pressure impregnation of creosote or copper-chrome-arsenic (CCA) are the two main types of chemical wood preservation applied to timber used for piles. Some species of hardwoods and most softwoods can be treated by chemical impregnation, although spruce and hemlock are difficult to treat. The preservatives are applied during a high pressure/vacuum process. In the case of CCA preservative, which is water-borne, the chromium acts as an oxidising agent and the metals become highly fixed into the wood structure. Timber is dried before impregnation of CCA and then allowed to dry again for between 7 to 14 days during which fixation occurs. Pressure cylinders of up to 25m length are available. Ammoniacal Copper Zinc Arsenate (ACZA) is an alkaline preservative system which was developed, in particular, for difficult to treat wood species.

Creosote is a complex mixture of over 300 substances derived from the distillation of coal tar, and is a very long serving and effective wood preservative which has low water solubility and is biodegradable when dispersed in soil. There are many instances of creosoted timber structures and wood piles still giving good service after 100 years of ground contact. Although fresh creosote will burn the skin, requiring gloves to be worn during handling of treated lumber, it is not a systemic poison. Freshly creosoted timbers may cause the formation of on oil sheen if in contact with water. There are two forms of creosote treatment, full cell and empty cell. In the full cell process all the available voids in the wood structure are filled as far as possible with creosote by first applying a vacuum to the timber, then flooding the pressure cylinder with preservative. After the vacuum is released atmospheric pressure forces the creosote deep into the structure. Further application of pressure after this stage achieves even greater penetration. At the end of the cycle, a second short period under vacuum is applied to withdraw a small amount of preservative from the surface of the timber leaving it dry and in a reasonable state for handling. In the empty cell process a longer period under vacuum is applied to remove a greater amount of preservative, leaving the voids in the wood only partly filled but with the internal walls of the wood cells coated. Although creosote is used undiluted by solvents, freshly treated timber is normally allowed to dry for up to 7 days to allow the more volatile components to evaporate. Creosoted timber is particularly suited for acid sulphate soils which can have serious effects on both steel and concrete piles. CCA preservative treatment is affected by dilute acids but unaffected by alkaline groundwater.

For softwood timber piles timber selected with a thick sapwood layer which adsorbs preservative treatment better than heartwood is beneficial since this provides a thick protective layer of well impregnated material. Spikes or hooks should not be used to handle treated timber piles since this may expose less well protected wood in the inside of the log. All cut-offs and drill holes should be liberally applied with preservative. For untreated hardwoods the vulnerable sapwood is removed and the timber normally supplied squared off.

Alternative preservative treatments

Creosote has been withdrawn by European Union member states from use in the DIY market (Directive 2001/90/EC, effective from 30th June 2003) but can still be used for industrial applications such as telegraph poles, sleepers, bridges and piles. Restricted uses include playground equipment and applications where there is a risk of frequent skin contact. A similar situation exists with CCA. Users and specifiers of treated timber should refer to British Wood Preserving and Damp-proofing Association for further guidance. Both creosote and CCA treated timber have good environmental and safety records, but are being phased out for some applications because more benign preservative systems are available.

Many preservative products have been developed over the last 10 years that have aimed to provide alternatives to creosote or arsenic based preservatives, such as Copper Chrome Boron, tebunconazole and ACQs. Copper compounds are very effective in protecting timber from biological degradation. At the Falun Copper Mine in Sweden, large diameter softwood poles seeped in aqueous copper, some of which are over 400 years old, form cribs and a retaining wall which at over 208 metres high was once the tallest wooden structure in Europe.

Natural durability of timber and resistance to preservative treatment

BRE Digest 429 gives the natural durability classifications of a large number of species, together with their (unmodified) resistance to preservative treatment. Table 1 (below) shows values for some common species, suitable for pilings on shore. It should be noted that the natural durability ratings relate to UK conditions, refer to the heartwood only, and only to fungal attack. For preservative treated softwood, timber with a high degree of permeable sapwood which will provide a protective envelope should be selected.

Timber Species	Natural Durability of Heartwood	Treatability of Heartwood	Treatability of Sapwood
Greenheart	Very durable	Extremely Resistant	Moderately resistant
Oak (European)	Very durable	Extremely resistant	Permeable
Elm	Non durable	Resistant	Permeable
Douglas fir	Non durable	Resistant	Permeable
Scots pine	Non durable	Moderately resistant	Permeable
Larch	Moderately durable	Resistant	Moderately resistant

Table 1: Timber Species in ground contact or freshwater use in UK (non marine)

Suitability of UK grown timber for pilings

A number of UK timbers are suitable for on shore pilings and marine usage:
Douglas fir, Scots pine, larch, oak, and Scottish elm. In general, these will be more suitable for installation below the water table on shore unless, in the case of softwoods, they are preservative treated. Douglas fir is available in large sections, up 500mm square and 12m long. UK grown oak and other softwoods can also give very useful service lives out of salt water.

UK grown Douglas fir piles in 300mm square section have been installed as fenders at Scarborough Harbour. UK grown Douglas fir was also used in conjunction with ekki on

Queens Wharf at Falmouth Docks for part of the superstructure, together with basraculous driven fenders. Oak tree trunks have been used, buried below the beach deposits, as land ties or struts in combination with tropical timber piles to form groynes. Scots pine is also available in large section sizes and lengths. Irish Sitka spruce has been used in trials to construct embankments and foundations suitable for roads, car parks and industrial floors (Rogers and Quigley, 2001). The current basic price of UK grown Sitka spruce sawlogs is around £38/m^3, which compares favourably with concrete (UK forest production rates are also set to double over the next 10 years). In the case of timber piles which are driven below the water table there is no need for kiln drying or preservative treatment. Butt logs in particular would make good piles because of the enhanced taper. Timbers which are classed as "perishable" in BRE Digest 429 but which are suitable for use as submerged piles also include beech and sycamore, both of which are comparable in strength to oak.

Figures 4 and 5: Irish grown Sitka spruce logs being used for pilings (photos courtesy of P.Quigley/NUI)

Wood Modification

The principal problem with the application of liquid preservative treatments to timber is the poor penetration into the wood structure of certain species, even under cycles of alternate vacuum and pressure. Impregnation can be improved by mechanical incising of timber, but this is limited to the outer 5 to 10mm only. Microwave modification of wood (Vinden and Torgovnikov, 2003) offers the ability to open up the cellular structure of wood with only nominal and manageable levels of strength reduction. This allows, for instance, timbers with poor permeability such as Sitka spruce and the heartwood of Douglas fir to be cost effectively processed with much higher levels of impregnation to both sapwood and heartwood. The level of preservative retention in the heartwood of Douglas fir can be increased from around 60 litres/m^3 to around 400 litres/m^3. In addition timber may also be modified by polymer impregnation to produce a wood polymer composite, which can give a softwood all the mechanical properties of a tropical hardwood. Wood modification will allow greater usage to be made of softwood timber, for applications such as piles and marine timber, where previously only tropical hardwoods had the necessary properties.

3. Marine structures

Timber has been long favoured for marine works because of its ability to absorb impacts, its ease of handling over water, and the poor performance of other materials such as reinforced concrete and iron. Timber is used for groynes and sea defence works as well as jetties, dolphins, fender piling and rubbing strips.

In seawater and brackish estuary waters untreated timbers are liable to attack by marine borers, around the British Isles principally the mollusc *Teredo* (the shipworm) and crustacean *Limnoria* (the gribble). *Teredo* bores circular tunnels up to 15mm in diameter and up to 150mm long horizontally and vertically in timbers leading, ultimately, to severe weakening. Occasionally *Teredo* damage is observed in timbers which have been floated in marine waters prior to sawing, the damage being characterised by lack of bore dust and the chalky white calcareous tunnel linings (Desch and Dinwoodie, 1996). *Limnoria* creates shallow tunnels approximately 2.5mm in diameter and penetrating less than 15mm in depth, the extensive nature of which leads to erosion. Another crustacean *Chelura,* is associated with attack by *Limnoria*, but cannot by itself burrow very far into timber.

Figure 6: Marine borer attack on 120 year old greenheart pile

The Sea Action Committee of the Institution of Civil Engineers (ICE 1947) found *Limnoria* and *Chelura* to be active in British waters, with *Teredo* active south of the Mersey and Humber. Greenheart, kauri and jarrah were found very resistant to marine borers, while oak and untreated softwoods were not resistant. Borer attack was found to be limited in polluted water such as in docks, although this observation may not be relevant nowadays. Greenheart was found in excellent condition after 60 years service in Liverpool and similarly Danzig fir after 52 years service in the Thames at Northfleet. Creosoted Baltic pine (i.e. slower grown Scots pine) was recommended for British ports on the grounds of its useful economic life. Other suitable softwoods include Douglas fir, Western hemlock and European larch. The Handbook of Hardwoods (HMSO 1972) lists a number of tropical hardwoods recognised as being resistant to marine borers such as basralocus, belian, okan as well as the Australian hardwoods jarrah, ironbark, southern blue gum and turpentine, the latter being particularly long favoured. Currently there are no Forest Stewardship Council approved sources of greenheart or ekki, although possible alternatives include acariquara and purpleheart. Even the most durable timber species are not permanently immune to marine borer attack (Eaton and Cragg, 1995).

In tropical waters untreated timber piles of non-durable species can have a useful life of only a few months. In Australia, for example, combined treatment of softwoods with CCA and creosote has been found very effective. Hardwoods, such as terpentine, will also benefit greatly from the provision of an outer barrier layer of treated timber. Large sections of timber species which are difficult to impregnate should be incised before impregnation. BRE Digest 479 stated that CCA treated timber was under review by the EU for usage in the marine environment, and this use has since been banned (effective June 2004). However, Copper Chrome Boron wood preservative has been found equally effective in combating marine borers (Eaton, 1989), although the boron, being water soluble, is rapidly leeched. BS 3452 (1962) specified retentions for Copper Chrome (CC) treated timber used in seawater. CCA treated timber can still be used for freshwater and brackish water piles, as well as on shore structures such as bridges and retaining walls.

BRE has carried out tests on Copper Chrome (CC) preservative treated sycamore, with promising results. Sycamore is comparable in strength to oak and likely to have better abrasion resistance than most softwoods, yet is permeable in both sapwood and heartwood to preservatives. It is also available in quite large section sizes and lengths. Although veneer quality sycamore is expensive, because the timber tends to stain much is cleared in the UK without harvesting. Figure 7 (below) shows a 150mm square sample cross cut after treatment with CC and application of an indicator chemical. The sample shows good preservative penetration, which was confirmed by quantitative analysis (Table 2). Marine exposure trials have been commissioned from Portsmouth University, and are currently underway.

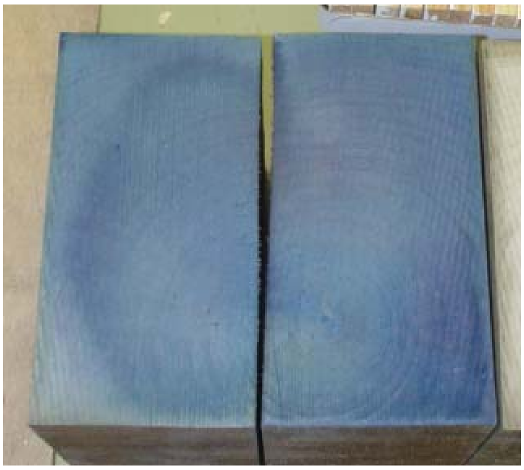

Figure 7: 150mm square sample of Copper Chrome treated sycamore after cross-cutting and application of an indicator chemical (blue) - showing good penetration throughout the specimen

Loading of Copper/Chrome	
Inner part of the beam	25 kg/m^3
Outer portion.	35 kg/m^3

Table 2: Results of copper chrome treatment on sycamore

The normal tropical specification for CCA is 48kg/m^3 for CCA, but in temperate waters 24kg/m^3 is adequate.

Marine timber piles may also be protected from borers by wrapping with PVC or polyethylene, sometimes in combination with bitumen based tape. Steiger and Horeczko (1982) report on the use of timber piles wrapped in heat shrunk polyethylene in the Port of Los Angeles. Naturally it is not necessary to sheath the part of the pile which is either driven below the sea bed or permanently above high water. The principal problem with all forms of pile sheathing is damage from boat impact and such protection systems will not be suitable where high abrasion resistance from scour is required.

BRE commissioned the Fibre Reinforced Polymer (FRP) coating of large section sizes of British grown Douglas fir (250mm x 250mm), see Figure 8. The FRP provides an impact resistant coating, with high durability in the marine environment. One of the typical uses of FRP (commonly termed “glass fibre ”) is boat hulls. The FRP should be applied to timber at fibre saturation (eg post preservative treatment) to prevent damage to the coating on possible expansion of timber during service.

Figure 8: Impact resistant and highly durable Fibre Reinforced Polymer coated UK grown Douglas fir, for marine borer protection.

Abrasion Resistance

Abrasion resistance to scour is an important design consideration for marine structures such as sea defences and groynes, particularly on shingle beaches. Timber structures can be protected from scour simply by providing a sacrificial layer of planking. Timber can, in certain circumcises, withstand wear in the marine environment better than either steel or reinforced concrete, with tropical hardwoods being particularly durable. Dense softwoods with well-developed latewood in the growth rings such as Douglas fir and pitch pine perform as well as hardwoods (Oliver, 1974). English oak also has good abrasion resistance.

4. Pile Driving and Design

Timber piles support loads by end bearing, shaft friction or combined end bearing and friction depending on the nature of the strata into which they are inserted. Most timber piles are displacement piles, although occasionally they are installed into pre-augured holes and set in concrete sockets. Timber piles are not suitable for driving through firm strata such as dense sand or gravels. Timber can be used as end bearing piles on rock, provided care is taken to avoid damaging the pile during insertion. Tapered timber piles are particularly suited for use as friction piles in sands, silts and soft clays where the pile capacity is determined by shaft friction. Driven thin end down, trees make natural tapered piles. Blanchet et al (1980) found in a comparative study that the effect of log taper doubled the shaft friction.

Timber is resilient to impacts and drives well. A helmet or cap protects the pile head from fracturing or brooming during insertion, and in addition the pile may be banded to prevent splitting. Conventional pile drivers are used to insert timber piles with the normal weight of a drop hammer being 1.5 times the weight of the pile. Typically for softwood piles a 0.5 tonne hammer is used, whereas for hardwood piles the hammer weights vary from 1 to 4 tonnes, with a drop height not greater than 1.5m (Maling, 2003). A long narrow drop hammer increases the chance that the pile is hit axially, avoiding damage to the pile and maximising the downward impulse. Diesel hammers are sometimes used for driving hardwood piles in stiff soils, but are not suitable for softwoods. Care must be taken with all hammers not to over-stress the pile or to cause splitting of the pile toe. The Canadian Foundation Engineering Manual (1992) gives the maximum hammer rated energy for softwood piles at 160,000 J. (N.m) times the pile head diameter. A low-velocity hammer should be used in combination with a soft cushion in the capblock. Driving is stopped when high resistance is encountered. All types of pile, including those made from steel and concrete, can be damaged by hard driving in an attempt to meet a prescribed set. This is usually avoided by adequate site investigation and realistic geotechnical design. Where there is a surface layer of hard fill a pre-bore may be performed using an auger rig. Timber piles can also be inserted using vibratory methods, hydraulically “pushed”, or jetted into sandy soil using compressed air or water which can be quick in operation and avoids damaging the pile. In peat, timber piles can even be driven manually (Orr and McEnaney, 1994)

Groups of timber piles inserted into soft clays and silts may need to be loaded temporally to prevent the effect on soil pore water pressures causing buoyancy. Timber piles can be spliced and extended in length using short sections of steel tube, angle or plates to reach load bearing strata or develop sufficient shaft friction. Timber piles can also be coupled to concrete or steel sections to avoid exposure above the water table.

Figure 9: Timber pile driving (photo courtesy Kardon Piling)

Timber has a high strength to weight ratio, and is particularly strong in compression parallel to grain. According to BS 8004, the timber selected for piles should be straight grained and free from defects and, in general, suitable sawn material is obtained from SS (Special Structural) grades. The centreline of a sawn pile should not deviate by more than 25mm throughout its length, and for round piles a deviation of up to 25mm on a 6m chord may be permitted. However, for non critical applications and where hard driving is not required, lower grades of material may be acceptable.

Figure 10: Pile installation (photo courtesy Kardon piling)

Piles are designed as columns, and consideration should be given to cross bracing for unsupported lengths above ground level. Typical axial design loads are in the range 100 to 500kN for softwood piles. Hardwoods piles are normally used for marine applications where either marine borer or high abrasion resistance is required. BS 5268 (2002) may be used to calculate the axial capacity of timber piles, including those which extend above ground level. Failure in buckling should be also considered for the pile section in weak soils with an undrained shear strength of less than 15 kPa, such as peat and soft clay. Table 3 (below) gives values of grade stress in compression parallel to grain for some commonly available UK species.

Timber species*	Grade**	Permissible stress in compression parallel to grain (N/mm^2) ***
Douglas fir	SS GS	6.6 5.2
Larch	SS GS	7.9 6.8
Scots pine	SS GS	7.5 6.1
Sitka spruce	SS GS	6.1 5.2
Oak	THA THB	10.5 9.0

*British grown
** SS = Special Structural GS = General Structural TH = Temperate Hardwood
***Service Class 1 and 2 (apply factor 0.6) for wet exposure

Table 3: UK Timber species and BS 5268 grade stresses for Compression parallel to grain

For example, UK grown Douglas fir of SS grade can support an un-factored permissible design stress of 6.6 N/mm^2 in compression parallel to grain. For a long term load the modification factor for duration of loading K_3 is 1.0, however for wet exposure conditions the modification factor K_2 equivalent to 0.6 should be used. For a 250mm square section pile, this results in an overall value for permissible load of around 250kN. The alternative Eurocode 5 (DD ENV 1995-1-1) Limit State Design approach uses characteristic values for the Strength Classes of timber given in EN 338. It should be noted that GS and SS grades refer to sawn timber and that there are, at the moment, no formal visual grading rules currently applicable to roundwood piles (although grading rules for transmission poles exist). On the basis of test work (Lavers, 1983) which resulted in a mean value of 16.1 N/mm^2 in compression parallel to grain (green strength) being obtained, most UK grown Sitka spruce could be expected to meet the GS grade value in this respect.

In a probably unique full scale test carried out at BRE on a 4.6m long green Sitka spruce log with an average top diameter 240mm and base 360mm; the timber withstood an axial load of 760kN (approx 76 tonnes) before failure (Figure 11), which is around 5 times the design value. A second log of similar size was proof loaded to 500kN.

Figure 11: Axial load test on a Sitka spruce log

Figure 12, below, shows the test results in graph form:

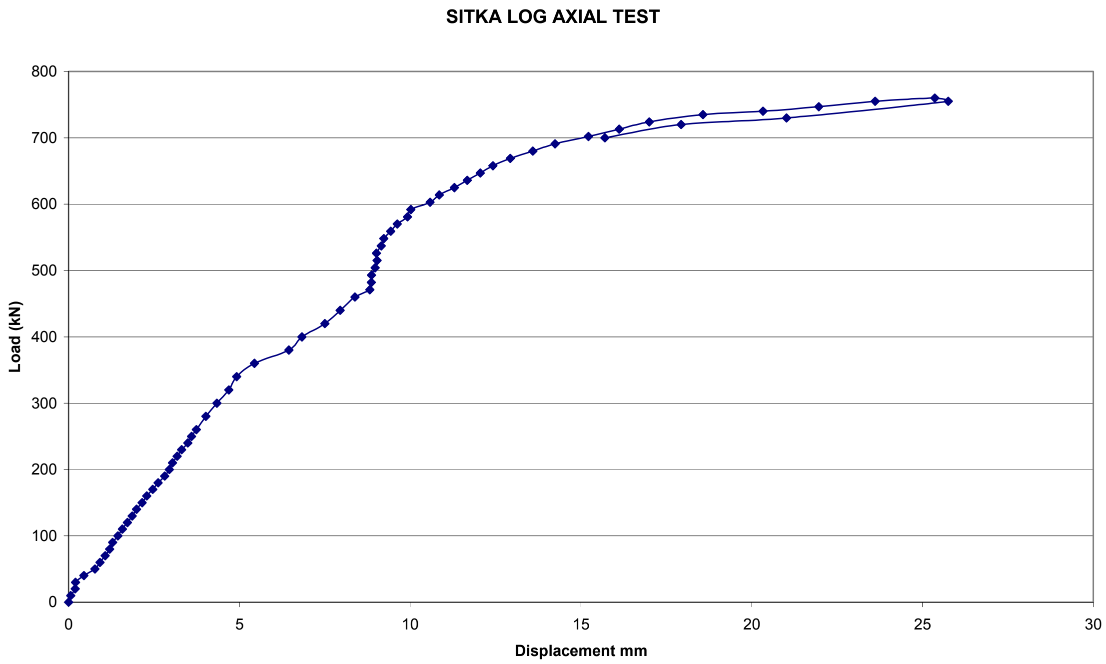

Figure 12: Axial load test results

Compression strength tests were also carried out on small scale samples (20mm square) across the diameter of an off-cut of the above Sitka spruce log, with the following results (Figure 13):

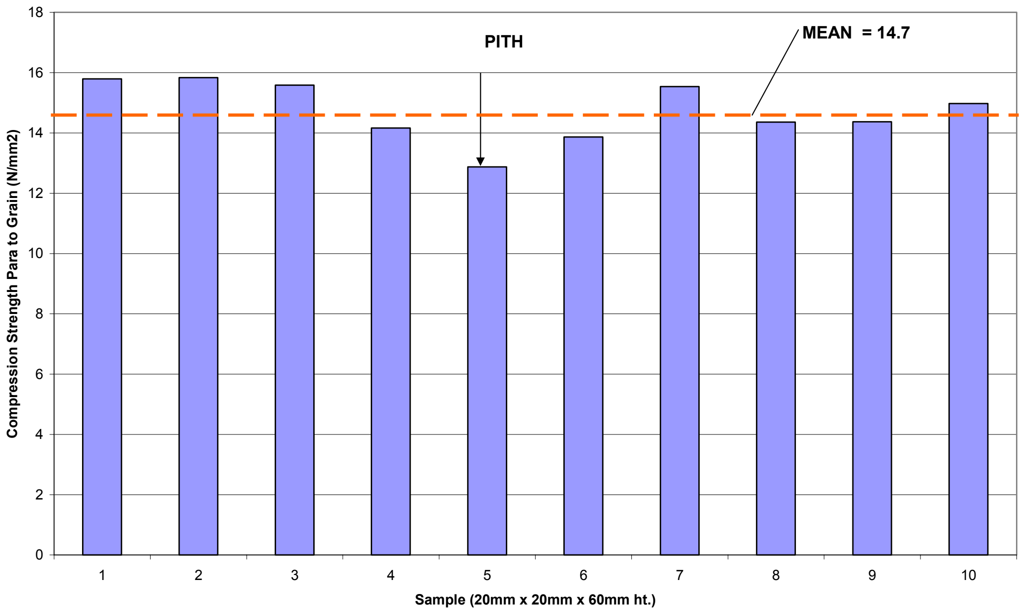

Figure 13: Compression parallel to grain tests on small scale samples

The above results show that there is a slight trend towards lower compression strength at the pith compared with the outside of the log, but that this is not marked. The compression strength results on small samples are slightly lower than for the full scale log, indicating some possible effect of scale or also shape (ie square samples verses round wood). All the results are in broad agreement with the values quoted in Bulletin 50 (Lavers 1969).

Design Methods

Similar methods exist for calculating the load carrying capacity of timber piles to those of steel and concrete, including those based on dynamic pile driving formulae. In the US, in particular, the traditional method of pile installation involved the Engineering News Formula, where the number of hammer blows per last foot driven equalled the number of tons of design capacity, depending on the rated energy of the hammer. This formula has been superseded by more rigorous techniques (such as those based on wave equation analysis) and is now only used for on-site indicative assessment.

For static pile design based on the undrained shear strength of soil, typically, a friction coefficient or adhesion factor (α) of 1.0 is used for straight driven piles and 1.2 for tapered piles. Pile design may also be based on in situ testing such as the Standard Penetration Test (STP) or Cone Penetrometer Test (CPT). Load testing and re-drive tests should be carried out to verify pile capacities. Further guidance, including appropriate factors of safety for foundation design are given in Eurocode 7. The American Wood Preservers Institute (2002) and Canadian Wood Council (1991) also give guidance and design examples for the use of timber piles both axially and laterally loaded.

5. Other geotechnical uses for timber

Timber is attractive, sympathetic with rural settings, and can be used for earth retaining structures such as bridge abutments and crib walls. Timber can easily be combined with soil anchors and geotextiles in the same way as concrete or steel. Round timber and sheet piles can provide an economical wall for moderate heights of retained material. Examples of interlocking timber sheet piles are given in BS 6349-2 (1988).

Further demonstration of the suitability of treated timber as foundation material is provided by the Permanent Wood Foundation (PWF). PWF (Canadian Wood Council, 1997) is a load bearing wood-frame system designed as a foundation for light-frame construction for residential houses, commercial premises such as hotels, factories and agricultural buildings (Figure 14). Its use dates back to 1967 in Alberta, Canada. Preservative treated timber is laid directly onto a granular drainage layer 300mm deep. This drainage layer prevents hydrostatic pressure building up against the foundations, and allows timber framed basements to be constructed in suitable locations. All connectors are corrosion resistant. A polythene moisture barrier extends over the outside of the walls below ground level terminating at the top of the drainage layer. A separate moisture barrier exists under the floor of the basement, either over-site concrete or a suspended timber floor.

The PWF system is reported to give service lives of around 100 years (even where a basement is constructed), but the expected lifespan of a concrete foundation system is much longer. In Canada concrete is difficult to deliver to remote locations, more expensive than timber, and difficult to use is sub-zero temperatures. This is not the case in the UK. Nevertheless, the PWF system will be viable for some types of structure in the UK, particularly in positions with poor access. The most likely uptake would be for environmental projects. In the UK concrete foundations in conjunction with ground floor slabs predominate over suspended timber ground floors, even for timber frame.

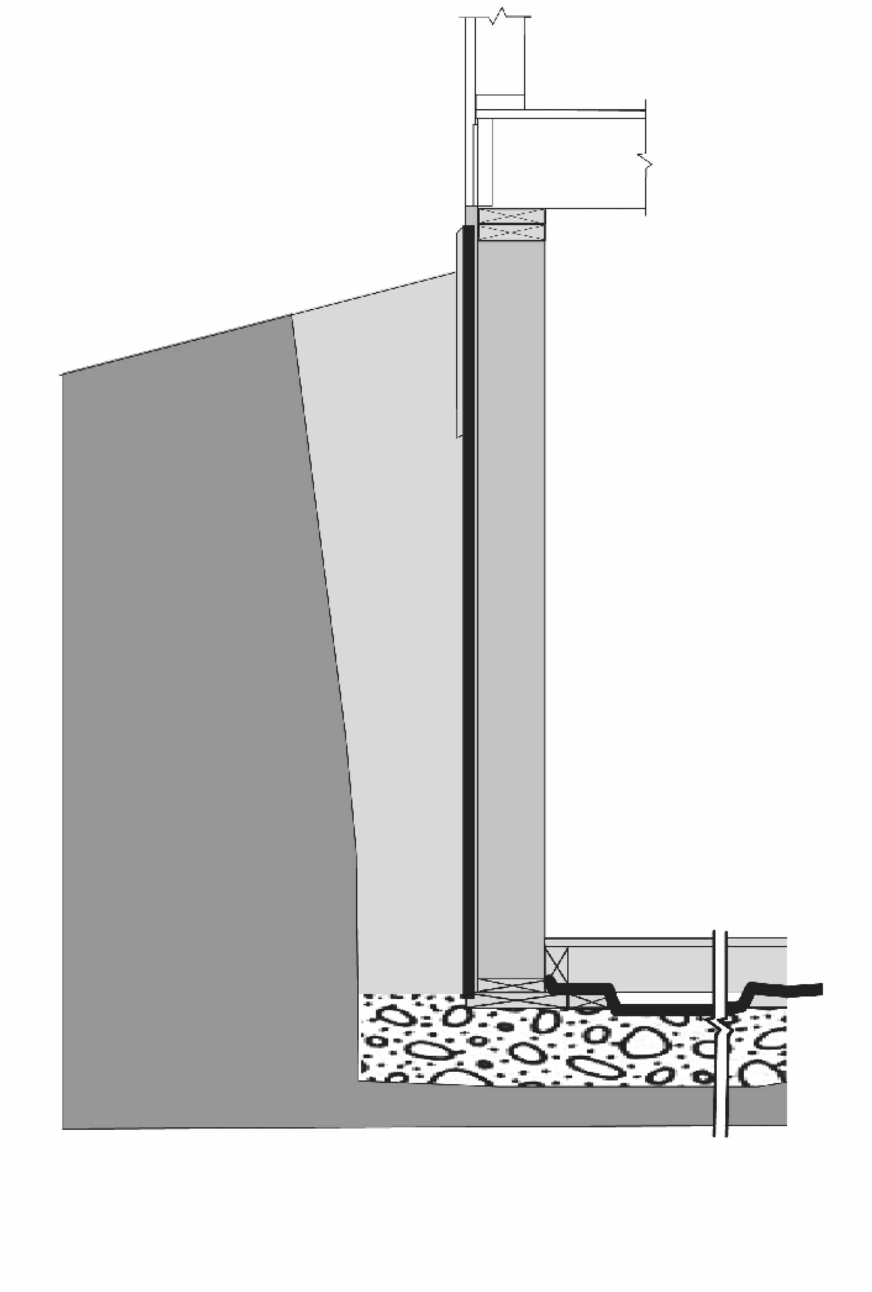

Figure 14: Basement constructed using Permanent Wood Foundation method (After CWC, 1997)

Stanchions and columns can be founded on footings comprising two layers of nailed treated timber running at 90 degrees to each other (Figure 15). The timber footing is laid on a thin layer of sand over undisturbed soil. A steel plate placed over the top of the footing helps to transfer the load from the column over the timbers. The principal advantages of these treated timber foundations are that they are economical, fast, require less plant, and unlike concrete do not need measures to protect them from freezing during curing - this last aspect being particularly important in Canada. Timber foundations also make excellent usage of an abundant, renewable and local material. Timber foundations can also take the form of embedded poles with concrete pads and collars. Examples of simple wood foundations for footbridges and countryside structures are given by Jayanetti (1990).

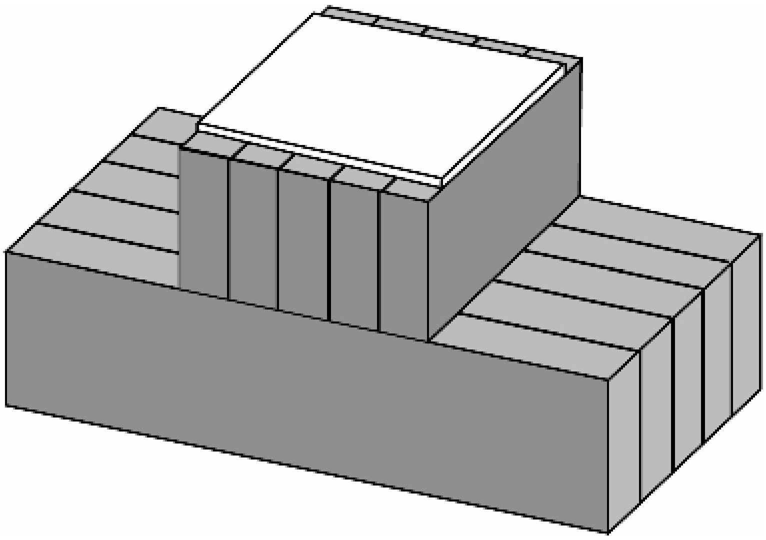

Figure 15: Column foundation pad (After CWC, 1997)

Footbridges can also be supported by timber caissons (Figure below)

Figure 16: Footbridge at Garpenburg, Sweden with timber supports

Some use is made of hazel, chestnut and willow brushwood faggots, weips and fascines for bank stabilization on waterways. Reclaimed sleepers are also used as economical foundations for lightweight prefabricated modular buildings such as schools, and in landscaping.

6. Competing Materials

Waste plastic piles and Fibre Reinforced Polymer (FRP) piles are beginning to enter the UK market and have been extensively used in place of timber in the US. Drivability can limit the usage of these polymer materials, in particular the “impedance” response to an impact hammer is a problem. Polymer composite piles up to 3m in diameter have been used in the US, in place of multiple timber piles. FRP does not, however, have the immediate workability or availability of timber. Other plastics-based alternatives, such as Recycled Plastic Lumber (RPL) and Wood Plastic Composites (WPCs), which are more workable, have been used for both decking and beams on marine structures, but tend not to have the same aesthetic appeal as timber, nor equivalent strength in bending.

UK grown timbers Douglas fir are weaker and less durable than the traditionally used tropical hardwoods. In particular the lower abrasion resistance, drivability as piles, and mechanical strength for connections is a problem - particularly for groynes which are subject to high wave loadings and a severe abrasive environment. Greenheart was used for Eastbourne groynes in preference to Douglas fir, for example. However, for less demanding marine situations such as marina jetties, estuary or dock use, treated Douglas fir and other softwoods perform well, and this represents a substantial market.

Timber was once used extensively for dock work and, historically, steel and reinforced concrete have not performed well in this respect. Today, however, marine structures can be built with high strength concrete and additional cover to reinforcement or with non-ferrous or coated steel reinforcing bars. Steel piles can also be coated, or designed with rates of corrosion taken into consideration. Cathodic corrosion protection and prevention technology is also available, as are remeadial repair methods such as polymer resin encasement (the latter being also applicable to timber piles). Thus concrete and steel predominate for large scale foundation and marine developments in the UK. Concrete and steel, for example, are being used to replace Falmouth docks, which was originally timber. Douglas fir was used in the recent refurbishment of Southwold Pier, as deck support beams (250mm square) out of water, although the replacement piles are steel; interestingly a few of the original landward piles are incised Douglas fir. Treated Douglas fir was used for fenders at Bawdsey Jetty although the main construction is in-situ concrete, and there are probably other numerous other instances where softwoods are either still required (eg to prevent damage to ships), or where they can be used instead of tropical hardwoods.

Timber is not presently considered in the UK as a piling material for on-shore structures because of the reliability and drivability of the principal alternative, pre cast concrete piles. Timber piles are less expensive than either steel or concrete. On a straight cost comparison for 200mm square piles, reinforced pre-cast concrete piles cost about £20 per m, whilst treated Douglas fir costs about £12 per m. However, material costs are usually secondary to installation costs for most piling projects. Perception of problems with drivability and doubts about the long term performance count against the use of timber. Concrete can be driven much harder past obstacles such as boulders. In softer ground, the use of cast insitu flight auger piling and driven pre-cast sectional concrete are used, as well as other economic methods such as vibro stone columns.

In low rise building foundations trench fill of concrete predominates, although there are market trends towards the use of short prefabricated concrete pile systems in conjunction with reinforced concrete ground beams. Foundation concrete is considered inexpensive at around £70 per m^3, relatively easy to place and level, and perceived to last indefinitely - although this is actually not the case. Particularly for waterfront timber houses, wooden pile foundations in conjunction with ground beams are not only entirely feasible but widely used around the world: “modern” variants were featured in the 1938 publication *Timber Building for the Country* . Timber post and beam construction can also be founded on concrete or local stone pads and there is considerable interest in this form of construction for flood prone areas.

7. Conclusions

Wooden piles are widely used overseas, but are not often considered in the UK for on-shore structures because of the perceived reliability and drivability of the principal alternative, pre cast concrete piles. Doubts about long term performance count against the use of timber. However, timber piles driven below the water table can last indefinitely; treated timber can withstand acidic and alkaline soil conditions better than concrete. The Canadian Permanent Wood Foundation (PWF) system using timber bearers on a drained gravel base will be viable for some types of structure in the UK, particularly in positions with poor access. Timber can and is used for retaining walls, and offers an attractive alternative to concrete.

For marine structures greenheart is the principal species used because of its availability in large sizes, drivability, marine borer and abrasion resistance. However, FSC certified greenheart is not presently available. UK timbers such as oak and Douglas fir are being used for marine works, but in limited quantities, and are considered less durable. Waste plastic piles and Fibre Reinforced Polymer piles are beginning to enter the UK market and have been extensively used in place of timber in the US. The use of UK timber as a geotechnical material requires promotion and development, but will probably remain a niche market for on shore use. Tropical hardwoods for marine works are hard to match for durability and strength. UK grown timbers can offer viable alternatives for many of the less demanding geotechnical and marine roles, and should be used wherever possible. BRE Digest 479 *Timber Piles and Foundations,* aims to provide suitable stimulus and guidance for the use of British grown timber in this respect.

Timber is a hugely capable civil engineering material, with the additional advantage of being sustainable. Trees, in particular conifers, make natural piles. Timber foundations may be particularly suitable for countryside structures such as bridges, forest chalets and activity centres, as well as post and beam timber buildings in waterfront or flood prone locations. Home grown treated softwood and hardwood timber should be considered as alternatives to imported tropical hardwoods wherever possible. Although CCA treated timber cannot from June 2004 be used for marine structures, it can still be used for piles in freshwater and brackish water, as well as in ground on shore. One of the suggested methods of reducing global warming has been to bury timber to create carbon dumps. Using timber for piled foundations would effectively achieve this. There is likely to be increased interest in the use of sustainable foundation materials in the future, and timber is a suitable alternative to concrete in a number of forms ranging from driven piles, to pads and retaining walls.

Recommendations:

This work has highlighted a lack of available information on abrasion rates for marine timbers subject to scour; and a lack of guidance (from manufacturers) on the long term performance of CCA alternatives with respect to marine borer resistance.

…continued

Some further work on the above issues, together with development by demonstration of timber for on shore piles would be useful

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