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Re-use of materials in coastal and river engineering - an overview

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RE-USE OF MATERIALS IN COASTAL AND RIVER ENGINEERING - AN OVERVIEW

J.D. Simm, M.J. Wallis, K.J. Collins, and R. Atkins

The increased demand for materials for flood and coastal defences as sea levels rise and rainfall increases needs to reflect a sustainable use of natural resources. Recycled and secondary materials offer significant potential to reduce the demand for primary materials, but the way in which this is done in a sensitive water environment will be of interest to the whole of the construction industry. The paper examines five criteria that should influence choices between materials options for projects: whole life costs, technical efficacy, impact on the local environment, environmental impact of materials production and procurement policy. The latter is examined in the context of the sensitivity of the procurement of tropical hardwoods, which are in particular demand because of their durability. A case example is given of the reconstruction of the fire-damaged Southend Pier in which reclaimed tropical hardwoods were imported from the Netherlands for most of the work. Finally two examples of the reuse of tyres in baled form are examined. One example looks at the technical advantages of using these recycled materials in a flood embankment project and the other at a pilot project to examine and try to allay concerns about leachates from the tyre material.

1. Introduction

Flood defences are essential in some areas to reduce the risk to human life. They also reduce risks to property, the loss of which can be both distressing and costly. To reduce the risk of severe river flooding, the effects of predicted sea level rise and the potential impacts of climate change, it is expected that many coastal and river structures will need to be renovated, improved or reconstructed in the coming years. It is anticipated that the increase in demand for construction materials will be proportionately greater in this sector of civil engineering than for general construction.

In England and Wales, some 1.7 million residential properties, 140,000 industrial and commercial properties and extensive areas of agricultural land with an economic value in excess of £200 billion are at risk from flooding and coastal erosion.

The potential consequences of climate change for the UK include extreme weather conditions that may lead to more frequent flooding. Storm damage may also be more severe, causing increased erosion of coastal areas and higher maintenance costs for flood defences. In addition, more frequent low pressure systems could increase the occurrence and height of storm surges and increase the risk/severity of overtopping of coastal and estuarine flood defences. The current annual average damage arising from flooding and coastal erosion is around £400 million and without investment in mitigation measures this could rise to as much as £2 billion per annum.[1]

With many defences in poor condition and the threat of greater dilapidation and inadequacy due to increased storminess and sea level, this cost is likely to rise.

Given this high demand it is therefore important that coastal and river engineers, in particular, review their use of natural resources wherever possible to ensure that materials are provided sustainably. The Environment Agency has introduced targets to encourage the use of alternatives to primary aggregates to this end. In addition to reducing the basic resource demands, there are further potential advantages to the natural environment in reducing the impacts (CO_2 emissions, embodied energy etc) associated with the extraction, processing and transport of primary materials to construction sites.

With the pressure to reduce primary resource use, the water sector of civil engineering can provide a crucial pathfinder role in promoting new civil engineering applications of alternatives to primary materials. There are three reasons for this:

- the sensitivity of the water environment and the flora and fauna living in it, limiting the levels of allowable contaminants
- the harsh conditions, especially on coasts, requiring use of strong and durable materials
- the need to limit scheme costs, given the limited funding available.

Successful applications of alternative materials in this way can contribute to a general reduction in both the demand for primary resources in construction and in the disposal of materials from construction and demolition to landfill. They will also lead to a specific improvement in the sustainability of river and coastal engineering, reducing their present demands for primary aggregates.

Coastal and river engineering presents both opportunities and challenges for the re-use of materials. There is a long history of certain forms of re-use such as beach recycling and re-use of constructional materials such as timber. Recent changes in legislation, policy, taxation, combined with scarcity of, or reluctance to use, some traditional materials (e.g. tropical hardwoods) led to a programme of research at HR Wallingford over the last 5 years to investigate more thoroughly the opportunities and barriers for materials re-use.

Recent studies by HR Wallingford and CIRIA[2] have suggested that more use could be made of some secondary aggregates and other waste products. Re-use of vehicle tyres is an example of a recent area of interest and this paper summarises some laboratory and field research that is now underway on this topic together with experience from two pilot construction projects using tyre bales, and their associated environmental and engineering monitoring programmes.

The marine environment presents particular challenges for durability and size of timber that means that hardwoods remain an attractive option. However sustainable forestry practices around the world are limited and one way of addressing this problem is to make use of recycled timber. The case study of Southend Pier described below illustrates good practice towards this end.

2. Potential use of alternative materials

The use of alternatives to primary materials in coastal and river engineering structures and schemes on the whole have been insufficiently researched and existing applications poorly documented and publicised. This only serves to perpetuate the perception that there is an increased risk in the design of such structures and schemes if such materials are used. This perception of increased risk is associated with the fear that extra risks could arise from the quality, availability or environmental effects of alternative materials.

In recent years, engineers have become increasingly aware of liability and professional indemnity issues associated with the work that they carry out. This has tended to foster conservatism in the design of schemes and structures which means that they can be slow to adopt innovative approaches that are perceived as high-risk or have uncertainty associated with them.

Unfortunately, to date, the perceived costs and environmental (and social) risks associated with the use of alternative materials often outweigh any expected benefits to the environment of a successful scheme using them. Furthermore any cost advantages are rarely enough to influence a decision to use alternatives instead of primary aggregates, and indeed the example of recycled timber given in section three suggests that costs at present may be higher in certain circumstances.

There are now serious reasons to reconsider this stance and question those perceptions:

- the general drive for sustainable solutions and client targets
- European waste directive banning disposal of some materials and requiring reduction of inert waste to landfill overall
- fiscal measures; the aggregates levy and landfill tax
- the new European standards which do not distinguish between primary and alternative materials. (i.e. same test methods and requirement levels for quality control for both types of material)
- new quality control protocols being developed and adopted by the recycling and construction and demolition industries to meet the standards
- development of new systems, tools, products, technical information and guidance.

However, we are still faced with a 'Catch-22' situation where designers and engineers are being encouraged for the above reasons to consider and utilise alternative materials but are reluctant to do so without adequate technical guidance, case history of use and greater assumption of risk by the client.

A recent CIRIA publication on the potential use of alternatives to primary aggregates in coastal and river engineering addresses many of these issues in detail.[2] It also recommends further funding for pilot trials and monitoring in order to build a technical dossier of information and case histories to which engineers may be able to refer. This should then serve to engender greater confidence in the use of alternatives by disseminating the information and lessons learned, demonstrating benefits and suitability, defining limitations, and reducing perceived risks and associated costs.

2.1 Criteria for choosing between materials options for projects

Engineers and designers require a reliable way of comparing material options at an early stage in the design process if sustainable solutions are to be properly considered in construction. This must enable the comparison of the costs, technical efficacy and environmental impacts of material options.

Whole life costs

Consistent with the drive towards procuring solutions that are cost effective and sustainable is the whole life costing of a product, system or structure. The objective is to minimise long-term expenditure by taking all costs associated with the provision of a structure into account including initial construction and subsequent maintenance, and monitoring and selecting the approach that offers the best value in the longer term. Civil engineering, including the water sector, is dominated by public works, this in turn enables the best use of public money in encouraging high and sustainable levels of economic growth.

Consideration of whole life costs at an early stage in the process can provide quantitative consideration of the financial effect on the project and structure of:

- risks
- potential problems
- monitoring and maintenance requirements
- functional performance
- material specification
- long term durability
- downtime and loss of business.

The existing approach to funding flood defence and coastal protection in England and Wales does not yet encourage the use of whole life costing (Although changes in the legal and institutional framework are being considered). There are separate budgets (and sources of funds) for capital and maintenance works, and costs are not linked. Funds for maintenance have to be applied for annually for which separate benefit - cost analyses have to be calculated. Peculiarly, even though coastal protection capital schemes require full benefit – cost justification for grant aid, in which maintenance costs are supposed to be included, the mechanism by which maintenance works can access or apply for grant aid funds are restricted to projects such as beach management schemes.[3]

Despite the above problems HR Wallingford has compiled a database of maintenance cost information (accessible at www.wholelifecosts.org) to assist the coastal and fluvial engineer adopt a consistent approach to estimating these costs for port, coastal and fluvial structures. It provides an indication of the likely maintenance and monitoring costs associated with groynes, breakwaters, seawalls, jetties, wharves/quays, beaches and revetments.[3]

Some cost details are given for the case examples later in this paper. As will be seen, the tyre bales example offered significant volumetric savings for an embankment irrespective of any saving on the unit cost of fill. However, as the timber example illustrates, pure marginal cost considerations may sometimes need to give way to broader sustainability objectives.

Technical efficacy

Perhaps the most powerful driver for engineers is if the choice of an alternative recycled material offers significant technical advantages. The increasing use of industrial by products such as pulverised fuel ash since the 1950s[14] either as lightweight fills, lightweight aggregates for low-density concrete and for low bearing capacity ground fills, was entirely driven by their durability and low weight advantages. There is no reason why new materials coming onto the market may not be able to offer comparable advantages. The case example of the use of tyre bales in the River Witham project described below is a prime example of this, where the bales offered lower ground bearing loads and enabled a reduced structural envelope with associated environmental and cost advantages (see section 4.2).

Impact on the local environment of the material selected

The European standard allows the use of comparable materials so long as their engineering performance meets acceptable levels. In the case of aggregates, there are no explicit requirements for control of leachates other than the requirement not to breach national legislation or regulatory controls. The introduction of such materials must therefore be matched by a programme of testing for leachates and an assessment of the level of harm that they may or may not cause. For this reason, the proposal to introduce tyre bales as part of beach or embankment fills in coastal and river engineering has been matched by a programme to measure leachate levels and assess their impact. The Pevensey case study described below summarises some early results and a similar programme is underway in the larger River Witham pilot.

Environmental impact of materials production

In addition the 'Ecopoints Estimator' has been developed by the Building Research Establishment (BRE) and HR Wallingford in collaboration with representatives of the construction materials sector. It enables the identification of scheme and material options that have less impact on the environment and are more sustainable. Ecopoints are calculated from the effects on the environment of the extraction, processing and transport components of the life cycle of each material up to the time they leave the factory gate.[4] Further details of this tool and an example of use alongside whole life costings was given in Crossman and Simm, 2002.[13]

Procurement policy to encourage sustainable management of primary materials

As well as adopting the use of recycled materials, engineers need to preferentially use any biomaterials that are renewable and have the advantage of capturing carbon dioxide emissions. Timber is the main example in civil engineering although there are also examples of use of live woods (e.g. willow for bank stabilisation, etc).

The difficulty with timber is that for coastal and river engineering the technical requirements are severe because of the aggressive and abrasive environment in which the material has to operate. It is for this reason that many coastal and river structures such as piers, groynes, lock-gates, jetties and river-bank cladding are comprised either entirely or partially of timber, mostly from tropical forests. However there has been increasing public awareness and concern relating to the environmental damage caused by industrial scale logging of forests and the environmental costs of long distance transport of materials.

The Global Forest Resources Assessment 2000 estimates that 14.6 million hectares of natural forest are lost each year and a further 1.5 million hectares are converted to forest plantations.[7] Although the rate of deforestation was slower in the 1990s than the 1980s, most of the losses were in the tropics and it is widely accepted that the rate of destruction is still unsustainable.

Whilst unsustainable logging for exportation does contribute to this degradation of tropical forests, only a comparatively small portion of the timber harvested is actually shipped abroad. Much of the timber is used for firewood, local construction or wood products such as paper in the countries of origin. However, the responsible specification and purchase of timber can have a significant impact in discouraging illegal and unsustainable practices.

There is an urgent need to encourage the implementation and practice of sustainable forest management world-wide. In recent years, this has resulted in the establishment of a suite of international agreements, government policies and statements and intense lobbying activities from non-Government organisations.

Examples exist at various administrative levels within the UK of policy decisions being taken to use or not to use particular materials on the grounds of sustainability. Avoiding the use of non-renewably sourced tropical hardwoods has been a particularly sensitive socio-political issue for many councils and some, like Southend Borough Council, have adopted a hierarchical policy of using soft woods or recycled hardwoods as far as practicable (see section 3). Such approaches are now finding their way into national guidance documents and policy guidance.

A recently published report by the government and its Executive Agencies suggests a basis for public sector timber procurement in the UK.[8] It addresses appropriate sustainability criteria and recognises that it is necessary to adopt a proactive approach to eliminating timber logged illegally and/or unsustainable practices.

In order to identify whether a timber is legal and sustainable it is essential to have verification of where it has come from. This requires the 'chain of custody' to be recorded and verified through some form of independent auditing. To be meaningful in forestry terms, certification should be complemented by labelling. However, construction materials are often not directly labelled, but the certification reference numbers should be quoted on advice and delivery notes. These can then be verified directly by the recipient with the accrediting organisation (such as the Forestry Stewardship Council (FSC), often via the Internet.

It is unlikely however that this certification process is going to be taken up by suppliers overnight, or indeed globally, or applied to the full range of timber used in coastal and river engineering structures. A framework for assisting with the procurement process in spite of these difficulties is presented by Crossman & Simm[6]. This framework (Figure 1) demonstrates the iterative nature of the design and selection process and intentionally excludes cost criteria. Whilst there may be a cost premium for certified timber, it is likely to form a relatively small element of the overall scheme value.

As a matter of policy many engineers and client bodies in the UK are looking to procure their timber from recycled materials wherever possible. Several projects have now been completed in the UK that have used significant quantities of recycled timber. One such project is the repair of the fire damage to Southend Pier in Essex.

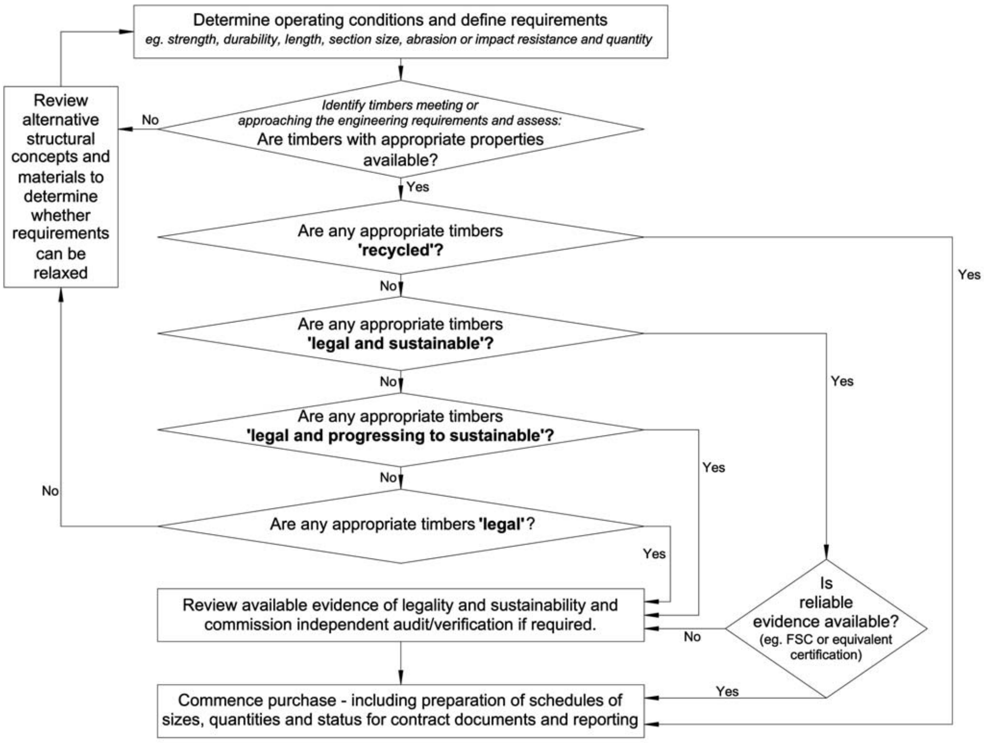

Figure 1 Proposed procurement framework ***(After Crossman & Simm, 2004)***

3. Southend Pier Case Study

Southend Pier was severely damaged in a disastrous fire in 1976. The worst damage lay in an area constructed of 35cm square greenheart timbers. The Pier is a grade II listed building and it was decided to reproduce, as closely as possible, the original structural form with heavy framing and cross-bracing.

A new "Environmental Charter" adopted by the Southend Borough Council in the 1990s included a requirement to 'refrain from the purchase of tropical hardwood where practicable.' Strict compliance would have created huge difficulties for this and other maintenance and construction projects.

Consequently a relaxation was sought from the Council and a procurement route established and agreed for cases where tropical hardwood was clearly the material of choice. This established an order of preference for high demand schemes in procuring hardwoods:

1. Material recycled from the demolition of existing structures.
2. Locally grown material where appropriate (Good quality oak is available from the management of Council owned woodland).
3. Independently certified (FSC or similar) sustainable material.
4. Where no alternative exists, nationally certified material.

The Pier refurbishment scheme was also to provide replacement upper and lower embarkation decks, two new staircases and new furniture such as guard-railing, boarding gates, lighting and seating. It was decided to construct as much as possible of the sub-structure from recycled material, but that to ensure unmarked material for the decks, new FSC certified timber would be used.

Figure 2 Fire damage to Southend Pier (courtesy of Southend Borough Council)

3.1 Procurement

A contract was agreed requiring the contractor to pursue recycled timber in accordance with the written procedure, before resorting to use of new material. Tender prices, however, reflected the uncertainty of the recycled timber market and, perhaps, contractors' unfamiliarity with it. Unit prices included timber provision costs of £900/m^3, and offered savings of £392/m^3 for the substitution of new material for recycled. The intention remained, however, to implement the procedure and the contract was renegotiated on the basis that timber procurement would become a Compensation Event under the NEC conditions.

All costs of procurement were included in the Compensation Event; purchase, inspection, loading, transport, clearing of intrusions, milling, storage and security. With the assistance of Ecotimber, a company specialising in sustainable procurement, large quantities of used Ekki and Greenheart were located in Holland. These supplies ultimately provided enough timber for the heavy framing, beams and joists. New Massaranduba was used for the 50mm thick upper deck and 75mm Red Angilim for the lower deck.

From a total 909m^3 of raw used timber purchased, 603m^3 were measured net in the structure. The out-turn unit rate for provision of recycled timber was therefore £636/m^3, compared with the £900/m^3 originally included in items by the lowest tenderer. Quantities had been heavily under-estimated at the design stage because of the difficulty of safe access to the damaged areas for close inspection.

Figure 3 Refurbishment of the Pier using recycled timbers (courtesy of Southend Borough Council)

3.2 Quality

Timber quality was specified, much as for new material. D60 or D70 material to BS5268 was to be used with various additional quality requirements, but with limits on permissible section losses due to the inevitable drilling from original usage. In raw form, the stockpiled piles and beams removed from old structures appeared depressingly unpromising. Internally, however, most of the material was in excellent condition and machining to section transformed it. On delivery to site it appeared indistinguishable from new timber apart from the occasional bolt-hole and unmachined surface.

The scheme was successfully carried out between September 2002 and July 2003 by main contractor J Breheny of Ipswich.

4. The Re-use of Tyres

Whole tyres have been used in port, coastal and fluvial structures for many years. There are numerous case studies from around the world, including Australia, the United States and Israel illustrating a wide range of uses and designs such as boat and quayside fenders, floating breakwaters, revetment work and as artificial reefs.

Technology now exists to produce tyre bales typically containing 100 tyres with dimensions of ~ 1.5m x 1.25m x 0.75m and weighing around a tonne (see figure 4). Being cubic in shape, they can be built into sea defences and bank protection, potentially opening up new structural applications for tyres.

With the implementation of the Landfill Directive and the End of Life Vehicle Directive the Tyre Industry faces the challenge of dealing with post-consumer tyres in a sustainable manner. The risk is that with the implementation of the Landfill Directive, lack of provision of sufficient reprocessing capacity will cause the rapid increase of illegal dumping and stockpiling of post-consumer tyres.

Figure 4 Tyre Bale (courtesy of May Gurney)

Of the used tyre arisings in 1998 41%were not reprocessed but disposed of in landfill, stockpiled or illegally dumped. The high cost of responsible disposal of post-consumer tyres is contributing towards the growth of unregulated tyre disposal.[9]

Concentrating on solutions for post-consumer tyres is important now because of the immediate challenge of the Landfill Directive which banned the landfilling of whole tyres in July 2003 and will also prohibit shredded tyres by July 2006 (though some landfill sites will not have to comply until July 2007). The European Directive on End of Life Vehicles also specifies targets for increasing reuse and recovery within this waste stream.

By compacting into bales it may be possible to utilise around an estimated 2 million tyres per annum over the next 5-10 years in port, coastal and river engineering schemes - around a fifth of the total diversion from landfill required.

Some engineering schemes utilising tyres in this field in the past have not been fully successful due to a lack of knowledge of performance characteristics and, subsequently, inappropriate design and construction practice. However there are some characteristics of tyres that make them potentially an ideal solution for particular engineering problems.

4.1. Testing

Physical testing of tyre bales has been conducted by HR Wallingford to determine some of these characteristics. In addition to immersion and weighing tests to determine porosity and density of tyre material, bale permeability and interbale friction have also been investigated.

Bale permeability was assessed by flume testing (all flow being forced through the bale) and found to be of the order of 0.1m/s (+/- factor of 2). This is roughly equivalent to that of typical gravel.

The interbale friction coefficient was tested simply by measuring the load required to drag one bale over another. After several tests this was assessed to be about 0.7.

Scale model bales were made out of rubber chip (see figure 5) after careful testing to ensure that bale density and permeability could be replicated. Revetment models constructed in the flume were then tested for wave and current action. For wave action the bales were shown to be highly unstable, being displaced by waves of height between 0.2 and 0.5m prototype.

Figure 5 Model bales and revetment tested for wave action in the flume

It was concluded that although bale permeability at 0.1m/s was high for steady state conditions, its was too low to allow dissipation of large transient wave action induced pressure gradients.

In the fluvial model tests, eventual collapse of the bale bank was generated from the top to the bottom, an untypical failure mechanism for river revetments where instability at the toe is usually the trigger for collapse. In this case it appears that the bank failed due to settlement of the backfill (most likely caused by water seepage) followed by detachment of the bale units. Although this could not be directly observed, it is likely that the bales separated from the backfill along the depth of the bank. Without back support the units had insufficient weight to remain stable and the wall started to bulge outwards.

It was concluded that tyre bales positioned at a 6^o angle to the vertical are likely to withstand relatively high flow velocities (up to 4m/s) in water depths of less than 2.5m. However, it should be stressed that the test results were very dependent on the method adopted for bank construction and the choice of backfill and cannot therefore be considered as a general recommendation. Further research is necessary to investigate the effect of parameters such as the revetment slope, backfill material and bank construction method on bale stability.

4.2. Pilot project - River Witham, Lincoln

In 1997 an Environment Agency (EA) Strategy Study for the Lower River Witham system, carried out by Bullen Consultants (Bullen) concluded that some of the flood embankments were in poor condition. A phased scheme of improvements was drawn up involving approximately 130km of defences and storage embankments and berms. A Contract Package to address the most urgent embankment works is currently being progressed as a partnership between the EA, Bullen and May Gurney Construction.

The site utilising tyre bales is a 1700 metre stretch of river embankment; however the same embankment serves as a flood defence barrier for Branston Island. This is an emergency flood storage area during times of extremely heavy rainfall and high water levels in the system.

An assessment of the embankment reported that it was only approximately 2.5 metres wide at the crest and badly eroded. The crest needed to be widened to improve structural integrity and performance and also to improve safety during access along the bank for maintenance works. The plan involved stabilisation of the flood defence by widening the crest to 4 metres, reprofiling the embankment, berm reinstatement and toe protection (see figure 6).

Figure 6 Construction of the River Witham Flood Embankment (courtesy of the Environment Agency)

However there were problems to be overcome. The embankment sits on a peat base. In order to prevent slippage of the embankment, its slope would have had to be 1:4. This would widen the footprint of the base of the embankment encroaching on 11kVA powerlines and a soke dyke both running parallel to its entire length. Having to move both of these would have been costly and undesirable. Tyre bales being of lesser density material meant that the footprint of the embankment could be reduced and concurrently the slope made steeper, removing the need for additional works and related costs. It is estimated that when complete the scheme will have utilised over a million tyres.

The cost of the tyre bales (per m^3 equivalent) were about the same as clay fill (per m^3). This was because transporting bales was costly in this instance. However there was a cost saving as less volume of tyre bales than clay was needed due to the steeper profile of the embankment.

As the scheme is a pilot project the Environment Agency has set up a water monitoring programme. There are currently two surface water quality monitoring points that are already part of a regular sampling programme and further sampling points have been installed at various points along the length. Samples will be tested for zinc, dissolved zinc and Polycyclic Aromatic Hydrocarbons (PAH). Biological samples are to be taken at set locations twice a year in spring and autumn.

4.3. Pilot project – Pevensey Bay, East Sussex

300 tyre bales (30,000 tyres) have been installed within a large gravel beach on the south coast of England in Pevensey Bay in East Sussex. This pilot project is exploring the option that tyres can be used as a replacement for gravel deep in the beach. This excavated material can then be used as a source of beach recharge material as an alternative to that from offshore marine reserves.

Figure 7 indicates the position of the bales within the beach and figure 8 shows the structure, with sampling tubes in place, being built up layer by layer.

The design allows the tyres to be partially inundated by tidal ingress and for the environmental and engineering performance of the structure to be monitored.

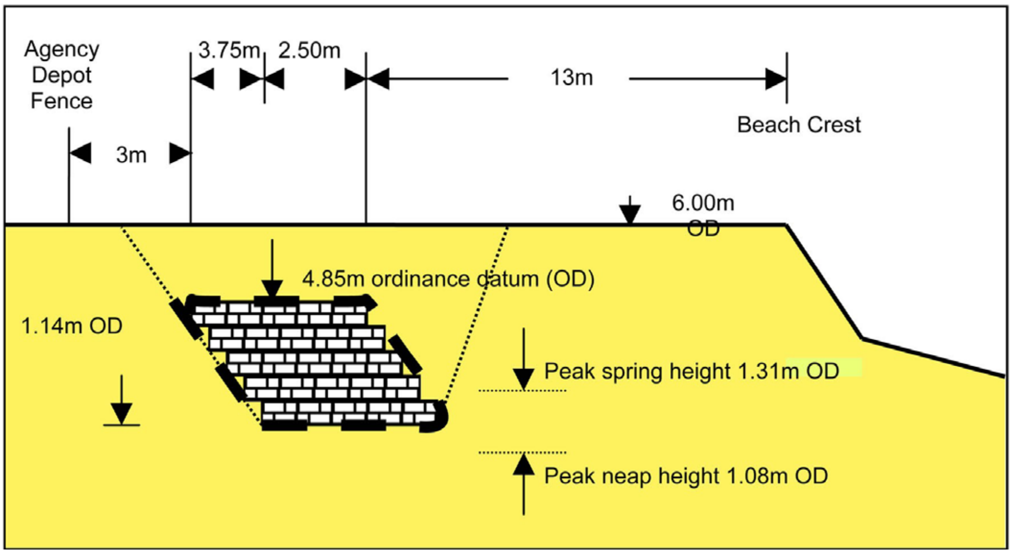

Figure 7 Plan Section of Pevensey Beach tyre bale structure.

Specially installed metal plates measure bale compression over time and water sampling wells allow samples to be drawn from the bottom of the structure for analysis of water quality and leachate levels.

So far the physical monitoring indicates that vertical compressive strain/creep of the bales (over 12 months) is about one percent, considerably less than expected, and other settlement and movement is negligible.

Analysis of water samples indicates that there is an ongoing decline in the release of zinc, the main leachate tracer, down to levels comparable to normal seawater. It is thought that this reduction is due to the tyres now being covered and removed from Ultra-violet (UV) light.[10] UV light degrades rubber over time allowing water ingress and leaching of metals from the tyre. In this scenario, once zinc has leached from the previously degraded surface no further leaching occurs as no further degradation from UV light can take place.

It is estimated that a total of about 10mg of zinc may be released from one tyre in this situation. Existing results suggest that there is unlikely to be a significant environmental impact from leachates, which are probably significantly lower than those arising through runoff from tyre deposits on road surfaces.[11,12]

Figure 8 Tyre Bale Structure in Pevensey Bay Beach (courtesy of Pevensey Coastal Defence)

5. CONCLUSIONS

Coastal and river engineering provides a particular challenge to the sustainable use of materials: a sensitive environment, harsh physical conditions to engineering structures, demands for large quantities of materials and a limited whole-life budget available to deliver solutions. Use of alternatives to primary materials has been shown to have a significant role to play here as a pathfinder for the rest of civil engineering. Five criteria have been shown to be significant in making choices between materials options: whole life costs, technical efficacy, impact on the local environment, environmental impact of materials production and procurement policy.

Where primary materials are required, they have to be obtained in a sensitive way, no more so than in the case of timber where the demands for durability and strength have historically led to the use of tropical hardwoods. The paper shows that such hardwoods can be procured in a legal and sustainable way, but also demonstrates an alternative using recycled hardwoods in the example of the reconstruction of Southend Pier.

Waste materials can also be used if the real and/or perceived physical, environmental and regulatory barriers can be overcome. Many of these barriers can be surmounted when pilot projects are successfully implemented and monitored, especially if real technical advantages can be identified as in the case of the use of tyre bales in embankments.

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NOTES

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Working with water

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