Environmental Sustainability of Constructing the Newquay Artificial Surfing Reef

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ABSTRACT

Artificial surfing reefs require the construction of large structures in coastal environments. They pose a challenge to sustainable development because their construction requires inputs of resources and energy. Sustainable development principles can be implemented into the construction of an artificial surfing reef. An evaluation of construction options for an artificial surfing reef proposed at Newquay in south-west England indicates that sustainable construction is related to consumption of non-renewable resources for construction materials and consumption of fossil fuels for transport energy. The reuse of waste materials such as tyres instead of sand or rock can reduce non-renewable resource consumption if the function, durability and stability of an artificial surfing reef are not compromised. Shorter distances and less energy intensive transport methods reduce transport energy consumption for the delivery of construction materials. However, both factors need to be considered in tandem in order to identify the most environmentally sustainable construction option.

ADDITIONAL INDEX WORDS: *Sustainable development, resources, energy, marine sand, rock, tyres*

INTRODUCTION

Sustainable Development

Sustainable development incorporates a triple bottom line approach to projects because it requires a commitment to economic, environmental and social objectives. It recognises that there are strong, interdependent links between economic, environmental and social sustainability and, for example, it seeks to avoid economic development at the expense of the environment and society.

In the UK, construction places the largest industrial demand on natural resources. It requires 260 million tonnes of non-renewable minerals per annum for raw materials and aggregates (DETR, 2000), which equates to 6 tonnes of construction materials per person per year (HOWARD, 2000), and the transport of construction materials accounts for around 5% of the UK energy burden (ENERGY SAVING TRUST, 2003).

Artificial surfing reefs require the construction of large structures in coastal environments. Like many other projects can be regarded as unsustainable because they replace a natural environment with a man-made environment. In addition to their effects on the local environment, artificial surfing reefs can be environmentally unsustainable in terms of the global environment because their construction requires significant inputs of natural resources and energy, particularly non-renewable minerals such as sand and rock.

There are several artificial surfing reef projects being progressed at various locations around the world. Each reef will undergo construction and will contribute to the global utilisation of non-renewable resources and global energy consumption. Developing in the least unsustainable way is an important challenge for all construction projects and is a key objective of the Newquay artificial surfing reef (WEIGHT, 2004). Many construction materials including non-renewable resources and reused wastes can be used to construct artificial reefs for non-surfing purposes (e.g. LUKENS, 1997), but only a few are suitable for constructing functional, durable and stable artificial surfing reefs.

Newquay Artificial Surfing Reef

The Newquay Artificial Reef Company (NARC) is proposing to construct an artificial surfing reef on the seabed approximately 300m offshore of Tolcarne Beach, Newquay, situated on the north Cornish coast in the south-west of England. A feasibility study (ASR LTD, 2002) produced a design for a double arm reef generating world-class surfing waves with 200m long rides. It also identified a series of construction options for the reef's core using sand, rock and tyres.

Figure 1. Newquay Artificial Surfing Reef (courtesy of NARC)

SUSTAINABLE CONSTRUCTION

The sustainable construction of the Newquay artificial surfing reef is considered in terms of non-renewable resource consumption and transport energy consumption.

Non-Renewable Resource Consumption

An evaluation of the non-renewable resources consumed for the construction of the Newquay artificial surfing reef construction is based on options for the reef's core materials presented in ASR Ltd (2002). The reef's volume for all options is 88,500m^3. The core materials are considered to account for virtually 100% of the reef's volume, to be the dominant product required to construct the artificial surfing reef, and to be equally durable such that they will last for 50 years following construction. The volumes for other products, such as geotextiles, are considered to be negligible and are excluded from this study.

Table 1. Volumes of Core Construction Materials for the Newquay Artificial Surfing Reef (derived from ASR Ltd, 2001)

Option	Reef Construction	Volume of Core Materials (m^3)		
		Sand	Rock	Tyres
RB1A	Sand filled geotextile containers (1.8m^3)	88,500	0	0
RB1B	Sand filled geotextile containers (10m^3)	88,500	0	0
RB1C	Sand filled geotextile tubes	88,500	0	0
RB2	Rock core + sand filled geotextile mattresses	22,125	66,375	0
RB3	Tyre core + sand filled geotextile mattresses	22,125	0	66,375
RB4	Sand filled geotextile container core + geotextile mattresses	88,500	0	0

Assuming that the core materials are derived from conventional sources such as the seabed for sand and quarries for rock, then reef options RB1A, RB1B, RB1C, RB2 and RB4 have the potential to consume 88,5000m^3 of non-renewable resources. Option RB3 consumes a smaller volume of non-renewable resources because 75% of the core material volume comprises reused tyres.

Transport Energy Consumption

Energy consumption is often considered as embodied energy and can be related directly to construction materials. Embodied energy provides a measure of the energy consumed during the entire lifecycle of a construction material, including the energy required during pre-construction (raw material extraction and processing and transport), construction (installation and maintenance) and post-construction (reuse or recycling and disposal). The embodied energy incurred during pre-construction, or the upstream end, of a construction material's lifecycle, typically takes the form of fossil fuel consumption. Energy is consumed during the extraction of minerals and other raw materials and during processing to produce materials such as bricks, cement and metals. Embodied energy does not take account of the environmental sensitivity of the construction material, its place of origin or its waste products.

Artificial surfing reefs use mineral-based construction materials such as sand and rock. These types of materials generally require little or no processing before they can be used in construction. For example, quarry run core material for an artificial surfing reef will undergo no processing to remove small pieces of rock if no particular rock size is specified. Less processing means that the embodied energy of sand and rock is generally low compared to other construction materials such as concrete, brick and steel.

It is not sufficient to simply compare the embodied energy of construction materials in order to decide which is the most sustainable. For example, after extraction and processing, the embodied energy of concrete will be higher than the embodied energy of rock. However, smaller quantities of concrete in one coast defence structure (e.g. wave reflection wall) may be sufficient to perform in the same way as higher quantities of rock in another structure (e.g. offshore breakwater). For this reason it is preferable to compare the total embodied energy for different options.

The embodied energy of core materials of artificial surfing reefs comprises low amounts of energy during extraction and processing, and negligible amounts post-construction. Therefore, energy consumption is dominated by transport of large quantities of construction materials, which increases rapidly with weight and distance travelled. The transport of construction materials between each of the lifecycle stages consumes energy through fuel consumption. It also affects the global sustainability of a project by producing carbon dioxide and depleting non-renewable fossil fuel reserves. Since energy consumption during the post-construction lifecycle of construction materials used in coastal structures is negligible (MASTERS, 2001), the sustainable performance of artificial surfing reefs can be improved by reducing the energy consumed by transporting materials during the pre-construction phases of projects.

CONSTRUCTION SCENARIOS FOR THE NEWQUAY ARTIFICIAL SURFING REEF

Marine Sand

All construction options for the Newquay artificial surfing reef include some degree of marine sand. There is no large-scale marine sand extraction off the north Cornish coast. The Bristol Channel is the nearest source of marine sand. For transport purposes, marine sand can be dredged and transported directly by ship to the reef construction site with a one-way trip of 100km and without the need for any land transport by road or rail.

Rock

Option RB2 has rock as its principal construction material. Due to the lack of large scale quarries in Cornwall and SW England and the economics of supplying rock for coastal projects, it is likely that the nearest economic source of rock will be imports from Ireland (Cork), France (Brittany) or even Norway. For transport purposes, it is assumed that the rock quarry is located 20 kilometres from its nearest port, and that rock will be transported by ship to the reef construction site without the need for any further land transport (Figure 2). The Irish and French ports are taken to be Cork and Brest and they require a one-way trip of 300km and 350km respectively.

Figure 2: Rock Barge during Construction of Coastal Defence Structure at West Bay, SW England (courtesy of Royal Haskoning)

Tyres

Option RB3 has reused tyres as its principal construction material. It is assumed that the tyres are prepared as bales (Figure 3) rather than used individually with cement ballast or anchors to the seabed. Each bale contains around 100 tyres that are compressed and strapped together by steel wires to form units of 1.5m x 1.25m x 0.75m which weight around one tonne (SIMM *et al.*, 2004). Since option RB3 requires 66,375m^3 of tyres, it consumes 47,410 bales (at 1.4m^3 per bale), which equate to 4,741,000 tyres. This is a substantial number of tyres and it is assumed that they are provided from more than one source generating an average transport distance of 50 km by road plus 200km by sea to Newquay. Each bale is strapped using four 5m long steel wires that are of 12mm diameter, consuming around 27m^3 of steel.

The construction scenarios considered for the Newquay artificial surfing reef are identified in Table 2. These scenarios are used to evaluate the relative sustainability of construction options.


Figure 3. Tyre Bale (courtesy of HR Wallingford)

Table 2. Construction Scenarios for the Newquay Artificial Surfing Reef

Scenario	Construction Material	Source	Transport Method	Distance (km)
RB1A	Marine sand	Bristol Channel	Ship	100
RB1B	Marine sand	Bristol Channel	Ship	100
RB1C	Marine sand	Bristol Channel	Ship	100
RB2 (1)	Rock	Ireland (Cork)	Truck + ship	20 + 300
	Marine sand	Bristol Channel	Ship	100
RB2 (2)	Rock	France (Brest)	Truck + ship	20 + 350
	Marine sand	Bristol Channel	Ship	100
RB3	Tyres	UK	Truck + ship	50 + 200
	Steel	UK	Truck + ship	50 + 200
	Marine sand	Bristol Channel	Ship	100
RB4	Marine sand	Bristol Channel	Ship	100

METHODOLOGY

The sustainability of the Newquay artificial surfing reef's construction options is measured using ecopoints and transport energy intensity. Ecopoints are devised by the Building Research Establishment (BRE). In the UK, ecopoints are calculated by dividing a project's environmental impacts (e.g. fossil fuel depletion, climate change) by the environmental impact of one UK citizen (for normalisation purposes), and then multiplying the normalised outcomes by a dimensionless impact weighting of sustainability (as %), to give a score in ecopoints (MASTERS, 2001). Impacts are scored individually and totalled for the project. More ecopoints equate to more environmental impact and less sustainability.

Ecopoints are used to quantify the environmental impacts of the different construction options in a sustainability context by measuring the environmental impact of the extraction, processing and transport parts of the lifecycles for sand and rock. Tyres are not included in the evaluation of ecopoints because they are a reused material and do not represent a non-renewable resource (with the exception of the steel wires required to create bales).

Transport energy consumption for construction materials relates to the weight carried and distance travelled and is measured as energy intensity in terms of consumption per tonne transported over one kilometre (t/km). Energy intensity for freight transport has been reasonably constant in the UK since 1990. Although vehicle efficiency has improved over this time, trucks have increased in size, carried more freight and have consumed more fuel (DTI, 2004). Both ecopoints and transport energy consumption are calculated for the different artificial surfing reef construction options using the ecopoints estimator spreadsheet developed by HR Wallingford and included in Masters (2001).

RESULTS

The results shown in Table 3 identify that resource consumption has the greatest influence on the relative sustainability of construction material options as measured by ecopoints. Of the options requiring non-renewable resources, the options based on marine sand (RB1A, RB1B, RB1C and RB4) incur less ecopoints for resource consumption than options based on rock (RB2A and RB2B). Ecopoints are not calculated for the resource consumption associated with the reuse of tyres in RB3, but in practice there will be at least ecopoints incurred for transport. Ecopoints calculated for the use of marine sand and steel in RB3 indicate that this option consumes at least one third of the resources of the other options. The results for energy consumption during transport identify that transport methods and distances are a major factor affecting energy consumption. Options based on marine sand (RB1A, RB1B, RB1C and RB4) incur less energy consumption than options based on rock (RB2A and RB2B) and tyres (RB3).

Table 3. Relative Sustainability of Construction Material Options

Scenario	Ecopoints (Resources)	Ecopoints (Transport)	Total Ecopoints	Transport Energy Consumption (GJ)
RB1A	88,611	7,169	95,780	4,280
RB1B	88,611	7,169	95,780	4,280
RB1C	88,611	7,169	95,780	4,280
RB2A*	126,335	36,484	162,819	20,825
RB2B*	126,335	41,173	167,508	23,624
RB3*	Tyres = reused Steel = 4,707 Sand = 22,153	Tyres = reused Steel = 63 Sand = 1,792	Tyres = reused Steel = 4,770 Sand = 23,945	Tyres = 18,015** Steel = 38 Sand = 1,070
RB4	88,611	7,169	95,780	4,280

* Based on truck size of 25+ tonnes for road transport

** Based on transport of “synthetic rubber”

DISCUSSION

Non-Renewable Resource Consumption

Marine sand and rock are non-renewable resources and they are the most likely core materials for artificial surfing reefs. Sand and rock have been used to construct artificial surfing reefs at Narrowneck (Gold Coast, Australia) and Cable Station (Western Australia) respectively. Sand filled geotextiles are attractive construction option because of ease of placement and low cost (RANASINGHE *et al*., 2001). Sand is estimated to have saved 50% of the costs of rock construction for the Narrowneck reef and allow the reef to be easily maintained (HEERTEN *et al*., date unknown). Although sand and rock both have low embodied energy compared to other construction materials that require more processing (e.g. bricks, concrete, steel), they strongly influence the sustainability of a construction project such as an artificial surfing reef if they are the predominant construction material.

In the case of the Newquay artificial surfing reef, construction options using rock incur 1.73 ecopoints per m^3 of resource consumed and are less sustainable than options using marine sand, which incur 1.2 ecopoints per m^3 of resource consumed. Resource sustainability for marine sand and rock reflects differences in extraction and processing. First impressions suggest that reusing tyres is likely to be the most sustainable option because it offsets the need to use large volumes of non-renewable resources even though processing into bales uses small volumes of steel, which incurs 174.3 ecopoints per m^3 of resource consumed. Fortunately, only $27m^3$ of steel is required.

Transport Energy Consumption

Transport incurs ecopoints due to global issues such as climate change and fossil fuel depletion, and local issues such as transport pollution and congestion. The importance of transport relates to the distance travelled, weight of materials, and the transport method. Transport energy intensities are the same for all construction materials but different for transport methods: 0.00039GJ/t.km for transport by ship, 0.00094 GJ/t.km km for transport by rail, and 0.00102 GJ/t.km km for transport by road (based on a 25+ tonnes rigid truck) (derived from MASTERS, 2001). Transport by ship is the least energy intensive and the most sustainable transport method for large volumes of construction materials. It consumes around 40% of the energy consumed by road transport.

Trucks can be the most energy intensive transport method. Figure 4 shows the relative transport energy consumption for different truck sizes (derived from MASTERS, 2001). Clearly, larger truck sizes consume less energy than small truck sizes if sufficient construction materials to fill larger trucks are being transported.

In the case of the Newquay artificial surfing reef, energy consumption for transporting rock for (RB2A and RB2B) and tyres (for RB3) by truck in combination with sea transport incur higher energy consumption than transporting marine sand by ship for options RB1A, RB1B, RB1C and RB4.

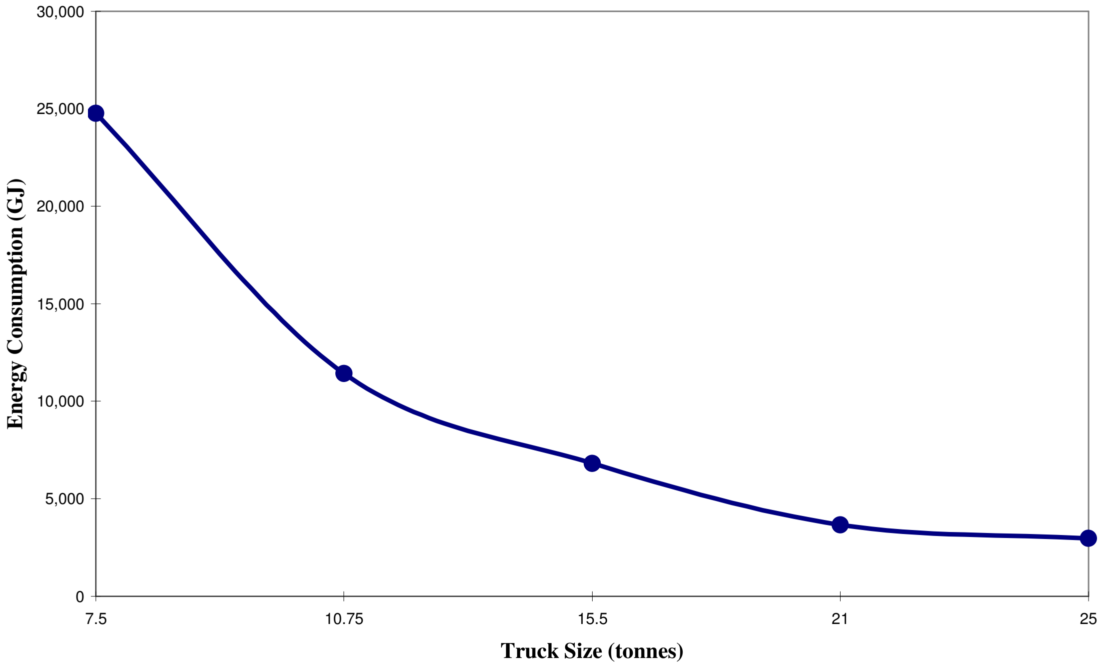

Figure 4. Road Transport Energy Consumption for Rock by Rigid Truck

Sustainability of Reusing Tyres

Overall, it appears that option RB3 offers the most sustainable construction option for the artificial surfing reef in terms of reducing the consumptions of non-renewable resources. The transport of tyres includes some road transport from source to Newquay and avoids an intermediate transport stage to a processing plant on the basis that mobile baling equipment is used. Tyre transport for RB3 incurs more energy consumption than reef options RB1A, RB1B, RB1C and RB4 using marine sand only transported by ship for the core material. Depending on the actual transport requirements for tyres, energy consumption could be significant enough to counter the environmental benefit of their reuse, potentially leaving marine sand as a more sustainable construction option.

However, the current practice of using tyres for construction in the coastal and marine environment is in its infancy and raises some uncertainties about the sustainability of tyres as the primary construction material for an artificial surfing reef. There is only one significant coastal defence project in the UK to date that has reused tyres as a primary construction material. This project - coast defences at Pevensey Bay along the south coast of England - reused around 30,000 tyres (300 bales) as a bulk filler buried beneath a new shingle beach and reduced the consumption of non-renewable gravel resources required to nourish the beach (SIMM *et al*., 2004).

There is some uncertainty about the long-term durability and stability of tyre bales in the marine environment, which may compromise a reef's design life of (say) 50 to 100 years. The durability of tyre bales relates to tyre degradation if exposed to ultra-violet light and to tyre buoyancy if bale integrity changes. Despite a bale's initial negative buoyancy, interconnected voids within its porous structure allow it to sink in water. However, the steel wires that compress and maintain a bale's integrity may degrade over time and break. Even though the tyres will retain their bale-derived individual forms, a change to a bale's integrity may change the interconnectivity of voids and affect buoyancy.

There is also some uncertainty about the stability of tyre bales exposed to the hydraulic forces that occur where artificial surfing reefs are constructed. An artificial surfing reef will increase wave impacts on its structure which means that stability is an important consideration for the structure's design (PILARCZYK, 2003). The tyre bales in the Pevensey Bay project are placed in a relatively benign hydraulic environment (buried beneath a beach) and are not exposed to the forces that may occur at an artificial surfing reef as a result of waves breaking in the open sea. Tyre bales require some form of physical protection from hydraulic forces if they are to be used successfully in high energy hydraulic environments.

Option RB3 for the Newquay artificial surfing reef has the inner tyre core overlain by sand filled geotextile mattresses that aid the reef's function, durability and stability. Requiring 49,167 bales, RB3 requires significantly more tyre bales than the 300 used for the Pevensey Bay coastal defence project. In the UK there is a Department for Trade and Industry (DTI) project investigating the sustainable reuse of tyres in ports, coastal and river engineering (see www.tyresinwater.net). Reporting in late 2004, this project provides guidance on planning, implementing and maintaining the reuse of tyres in construction projects in the UK and may be able to answer the uncertainties of reusing tyres for artificial surfing reefs.

CONCLUSIONS

In terms of consumption of non-renewable resources and assuming similar volumes of construction materials are needed to construct a reef's core, the reuse of waste materials (tyres) over non-renewable materials (marine sand and rock) is likely to improve the sustainability of constructing an artificial surfing reef. However, the reused material must be able to sustain the function, durability and stability required of an artificial surfing reef. If a reuse option is not available, then the use of non-renewable materials with low embodied energy (marine sand and rock) over materials with higher embodied energy such as (steel, brick and concentre) is likely to improve the sustainability of constructing an artificial surfing reef.

In terms of energy consumption due to transporting construction materials, the energy intensities of road, rail and sea transport methods are the same but the energy consumed per tonne of construction material per kilometre is markedly different. Transport by sea is more sustainable than transport by rail and road. Transport by road is usually the least sustainable method to transport construction materials, especially if small trucks are used when large trucks are also suitable. Artificial surfing reefs are constructed in the sea and offer an opportunity to transport construction materials totally by sea if the construction materials originate from the seabed (marine sand) or can be sourced from a location such as a coastal quarry (rock). Distance is fundamental to the energy consumed by transport but must be considered alongside the energy intensity of transport methods. For example, transporting construction materials over a short distance by truck may be less sustainable than a long distance by ship.

Both non-renewable resource consumption and transport energy consumption are important considerations for improving the sustainability of artificial surfing reef construction. However, they need to be considered in tandem in order to identify the most environmentally sustainable construction option.

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