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Preface

This Geotechnical Special Publication (GSP) contains 13 papers that were accepted and presented at the GeoHubei International Conference on Sustainable Civil Infrastructures: Innovative Technologies and Materials, held in Hubei, China on July 20-22, 2014. Major topics covered are recycle and reuse of geomaterials, in-situ test methods for site characterization, design and quality control of earth structures and subgrades, dynamic behavior of soils and foundations. The overall theme of the GSP is innovative and sustainable use of geomaterials and geosystems and all papers address different research findings of this theme. It provides an effective means of shearing recent technological advances, engineering applications and research results among scientists, researchers and engineering practitioners.

The following individuals have assisted on preparing the GSP and reviewing the papers:

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Construction on Soft Ground Using Lightweight Tyre Bales

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ABSTRACT: Road construction over soft ground presents a considerable technical challenge. Such roads often serve remote communities, carry low levels of traffic, and construction and maintenance must be achieved within limited budgets. The two main approaches to such construction are above ground (floating) and below ground (buried) construction; costly lightweight construction materials are desirable. The use of lightweight, British Standard, tyre bales is described. Issues related to the use of tyre bales such as sustainability, waste management, costs and end of life are highlighted and their use in constructing road foundations over soft ground described.

INTRODUCTION

The construction of roads over soft ground, such as peat, presents considerable technical challenges. Many such roads serve remote communities, carry only low levels of traffic, and must be constructed and maintained within tight budgets.

If the depth of soft soil is significant (in peat *circa* 4m), construction may involve 'floating' the road on the subsoil. Temporary surcharging and/or reinforcement at the base of the construction to help spread the load and even out settlement may be used. If the depth of peat or other soft material is shallow (in peat <4m), excavation may be considered and it may be cost-effective to remove the soft material and replace it with more competent materials. This raises issues of disposal of the excavated material and prevention of the adjacent material from flowing into the excavation. The associated costs can be high and will increase with the depth of material excavated.

In both cases, the use of lightweight construction materials is desirable. This paper describes the use of tyre bales, focuses on their use as a road foundation material and draws on the author's experience in the UK and the USA. Relative to other lightweight foundation materials (e.g. expanded polystyrene) tyre bale construction is inexpensive.

MATERIALS

Around 48M tyres (480,000 tonnes) are scrapped in the UK each year and in the USA it has been estimated that over two billion used tyres are stockpiled, and that

285M are added each year (Winter et al. 2006). Until recently, the bulk of waste tyres in the UK was stockpiled, disposed of in landfill or sent for energy recovery (Hird et al. 2001). In Europe the Landfill Directive outlawed the disposal of tyres in landfill, with UK exceptions being made for engineered works. In the USA a number of fires in waste dumps of whole tyres, and concerns regarding the potential flammability of tyre shreds and chips, led the drive towards alternative solutions.

Whole tyres can be processed to form rectilinear, lightweight/low density, permeable, porous bales of relatively high bale-to-bale friction.

Composition, Properties and Behaviour

Tyre bales comprise 100 to 115 car/light goods vehicle tyres compressed into 800kg blocks of density around 0.5Mg/m^3. The bales are nominally 1.3m by 1.55m by 0.8m and are secured by five galvanized steel tie-wires running around the length and depth of the bale (Figure 1). Their low density and ease of handling places them at a premium in construction. A porosity of about 62% and permeability of about 0.02m/s (similar to sand) through the length and 0.2m/s (similar to gravel) through the depth (Simm et al. 2005) makes them ideal for drainage applications. The bale-to-bale friction angle is around 36° in dry conditions, around 27° in wet conditions, and stiffness in the vertical direction of Figure 1 is up to around 1GPa (Freilich & Zornberg 2009; Winter et al. 2006).

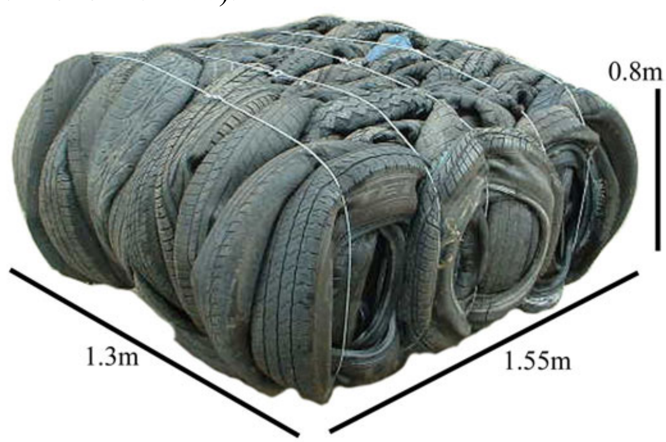

FIG. 1. A typical tyre bale with dimensions.

Potential leachates from tyres are already present in groundwater in developed areas. Studies indicate that leachate levels generally fall well below allowable regulatory limits and have negligible impact on water quality in close proximity to tyres (Hylands & Shulman 2003) and that rates of release of contaminants decrease with time (Collins et al. 2002). Similarly there is no evidence of significant deterioration of tyres buried in the ground for decades (Zornberg et al. 2004).

Spontaneous fires in whole tyre dumps are not known to the author. In the USA, while combustion of whole tyre dumps due to sparks from agricultural machinery and lightning have been reported, most observers suspect arson.

Baling reduces tyre volume by a factor of four to five, greatly reducing the available oxygen as well as the exposed rubber surface area as tyre-to-tyre contacts are formed, without exposing steel reinforcing in the tyres. The exothermic oxidation reaction potential is significantly lower than for whole tyres and the risk of spontaneous combustion from tyre bales is viewed as extremely low. A modelled storage condition for a 17.5m by 6.0m by 3.0m volume of bales needed to reach and maintain a temperature of 188°C for 39 days before spontaneous combustion became possible (Simm et al. 2005).

British Standard

The British Standard Publicly Available Specification (PAS) for tyre bales (Anon. 2007) assists manufacturers in the production of a consistent and traceable product for use in construction and helps to demonstrate the consistency of quality, via a Factory Production Control process, to end users. The PAS encompasses relevant activities from receipt, inspection and cleaning of tyres; handling and storage of tyres; production of bales (including ensuring traceability); handling and storage of the bales; transport, storage on site and placement of the bales; and factory production control. Guidance is offered to construction professionals on preliminary design and construction proposals as well as the measurement of relevant tyre bale properties; engineering properties and behaviour of tyre bales in construction; example applications for tyre bales in construction; and end of service life disposal options.

Supply and Production, Costs, and End of Life Issues

An adequate supply of tyres, and the resources to turn them into bales, is essential to any project that uses tyre bales. Figure 2 indicates the number of bales required to fill a given volume; the number of tyres likely to be used in their manufacture; and the number of eight hour (two man) shifts required to manufacture those tyre bales.

The total cost of construction work is determined by the unit prices of the materials, plant and labour required; the tendency to compare only the unit costs of tyre bales to those of the materials they replace must be avoided. Typically material costs are found to be similar to conventional alternatives. However, the ease of construction can lead to substantial savings in plant and labour costs as well as to time savings. In addition, the process of tyre bale manufacture consumes around 1/16 of the energy required to shred a similar mass of tyres (Winter et al. 2006).

Most waste management regimes require that end of life issues are considered form the outset. These are addressed in the British Standard PAS 107 of tyre bales (Anon. 2007). It should be noted that there is no evidence of significant deterioration of tyres buried in the ground, even after many years (e.g. Zornberg et al. 2004).

CONSTRUCTION

The two main approaches to road construction over soft ground are above ground (floating) and below ground (buried); Figure 3 illustrates their relative advantages and disadvantages. Both approaches use large volumes of granular fill. A crust in peat will often be formed from fibrous vegetation. Similarly, many normally consolidated clays and ‘quick clays’ may have a stiffer crust. Normally it is inadvisable to breach the crust and floating construction is preferred to buried construction. The decision-making process for floating/buried construction is explored by Winter et al. (2006).

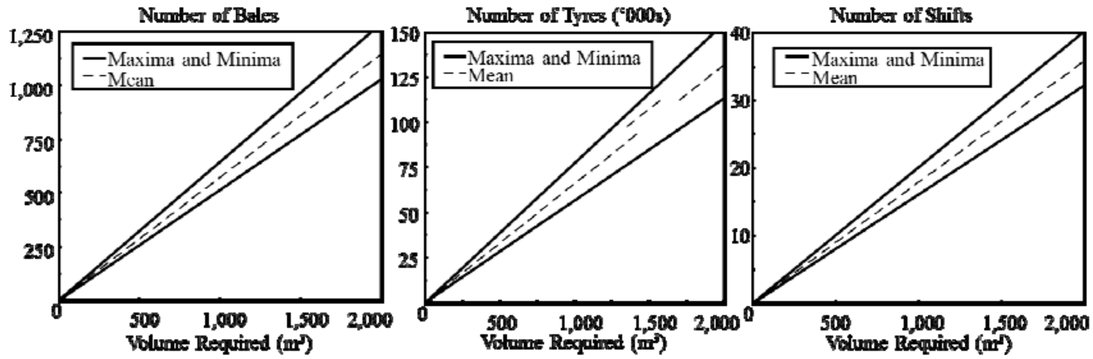

FIG. 2. Nomograms showing the number of bales required to fill a given volume (left); number of tyres required to make those bales (centre); and number of eight-hour shifts required to manufacture them (right) (after Winter et al. 2006).

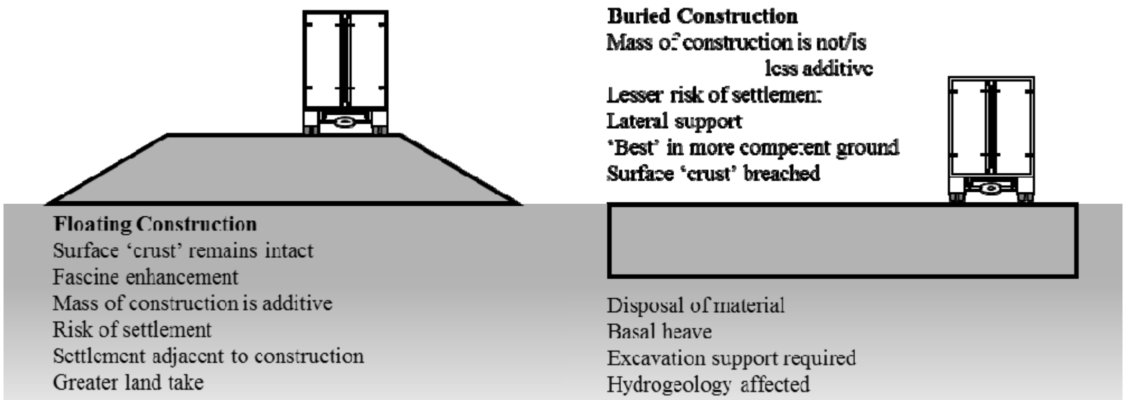

FIG. 3. Advantages and disadvantages of floating construction and buried construction.

The construction and rehabilitation of low-volume roads over soft ground is an ideal tyre bale application. While there is currently little information to prove their use with traffic levels in excess of a few hundred vehicles/day AADT there are no over-riding reasons why such uses should not be successful.

The following sections summarises the main construction steps and issues, and gives guidance based upon experience of successful projects and established good practice in constructing low-volume roads over soft ground. Further details are given by Winter et al. (2006) and Anon. (2007).

Excavation and Preparation

For buried construction, excavation is the first construction activity. Low ground-pressure, tracked plant is preferred as is working in drier weather when the moisture content of the soil is at its lowest and strength and stiffness are at their highest.

A suitable geotextile should be installed either at ground surface level or at the base of the excavation, followed by a regulating layer of sand. Geotextile-to-geotextile interfaces should have an overlap of 1m. The use of a geotextile has a number of advantages including aiding working conditions in soft soils, strengthening the structure by tying together the assembly of bales, and providing separation between the bales and the subsoil thus preventing the ingress of fines. Randomly orientated, bonded, non-woven geotextiles have been found to be effective. Their main function is separation, with strength and resistance to clogging the most important properties. Geotextile design procedures should reflect local standards. Sufficient excess should be allowed at either side to allow the bale assembly to be completely wrapped in the geotextile with a 1m overlap.

Rapid cellular construction reduces the size of the excavation, the exposure of the soil to weather and the likelihood of side slope failure. Bale sizes mean that excavations are unlikely to exceed 1m, when constructing a single layer of tyre bales, but an assessment of the possibility of sidewall collapse and the associated risks to workers and others during the execution of such operations is essential.

Placement and Alignment

Tyre bales should be handled so as to minimise the risk of damage to the steel tie-wires; 'loggers'-clams' and brick-grabs have been particularly successful.

Tyre bales exhibit a high stiffness when loads are applied vertically to the 1.3m by 1.55m plane (Figure 1); they are usually installed as in Figure 1 for high vertical load applications such as road foundations. The 1.55m by 0.8m plane is perpendicular to the load applied during manufacture and provides restraint when aligned perpendicular to the longitudinal confining stresses (i.e. with the tie-wires in line with the road). This renders the tie-wires largely sacrificial as after a period of months the bales generally retain their shape when de-stressed.

While there are different layout options for the two-dimensional placement of tyre bales (i.e. in a single layer) a straightforward 'chessboard' pattern, as viewed in plan, is generally the easiest to construct and is recommended. A regulating layer of sand is normally required between the top of the tyre bales and the geotextile wrapped over the bales to help eliminate variations in level. If two or more layers are required then the second layer should be stepped in to provide around half a bale width of overlap.

Filling of Voids

The sub-rectangular shape of tyre bales means that voids remain at the corners of each bale even when they are butted up against one other. The design generally requires the stiffness and stability of the structure to be maximised and thus the voids should be filled (Figure 4). Coarse sand and single-sized aggregate pellets have been used for filling such voids, usually by bulldozing a 150mm to 300mm layer on top of the bale layer and vibrating the fill into the voids with a roller (Figure 4**).**

The fill material affects the density of the structure – the voids take up an estimated 4% to 8% (Anon. 2007) of the nominal rectangular bale volume – and must be allowed for in design calculations as must the regulating layers above/below the bales.

Once the fill operation for a cell has been completed for a section of road, the geotextile should be wrapped around the bale-fill composite with an overlap of around 1m. The sub-base should be placed and compacted on top of the completed section. A thickness of 150mm is likely to be sufficient to provide a construction platform for the works to continue without damaging the geotextile. The final thickness of the sub-base must be subject to site-specific design. Construction then proceeds to the next cell, repeating the process described above until the road has been completed.