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Construction of Road Foundations on Soft Ground Using Lightweight Tyre Bales

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Abstract

Road construction over soft ground presents technical challenges. When traffic flows and the consequent need to construct and maintain the roads within limited budgets are factored in such challenges can be substantial. There are two broad approaches to such construction: above ground, or floating, construction and below ground construction. Above ground construction has often employed bundles of twigs, called fascines, to provide a degree of resistance to differential settlement. This approach generally works best where a relatively stiff material, such as fibrous peat, overlies a less competent material, such as amorphous peat. Below ground construction is generally preferable in less incompetent materials, or in poor materials of shallower depth such that removal is a viable option. The use of modern geotextile materials in combination with lightweight tyre bales allows both construction and service loads to be effectively spread as described in this paper.

Keywords: *Soft ground, roads, embankments, peat, waste management.*

1 Introduction

The construction of roads over soft ground such as peat has long presented technical challenges. These are often magnified by the fact that many such roads carry only low levels of traffic and must therefore be constructed and maintained within limited budgets.

Temporary surcharging of newly constructed roads has been employed in an attempt to consolidate and strengthen the subsoil in both Scandinavia and parts of Sutherland in Scotland. Typically two metres of fill material has been placed to surcharge the road for several weeks and after some consolidation of the subsoil, the fill is removed and the surface regulated and repaved. The success of such an approach is often limited in very soft soils such as peat due to the likelihood of long-term secondary consolidation.

If the depth of peat or other soft material is shallow then removal may be an option. The excavated material is then replaced by more competent materials which may include tyre bales. However, this does leave the issues of disposing of the excavated material and preventing the adjacent material from flowing into the excavation. The resolution of either or both of these issues can prove costly, and such costs will increase rapidly with the depth of material excavated.

Where the layer of soft material is sufficiently thick to preclude complete removal alternative solutions using lightweight materials are needed. The use of lightweight tyre bales as a foundation material has the potential to provide such solutions.

2 Tyre Bales

The disposal of tyres is a recognised problem around the world. In the USA a number of fires in waste dumps comprising whole tyres and concerns regarding the potential flammability of tyre shreds and chips led the drive towards alternative solutions. In the Europe Union the landfilling of whole tyres was banned in 2003 and that of tyre shred will be banned in 2006.

Tyre bales comprise around 110 to 120 car tyres (slightly fewer in the USA due to the larger vehicles/tyres prevalent) compressed into a lightweight block (*circa* 0.7Mg/m^3). The bales measure 60" by 50" by 30" (1.52m by 1.27m by 0.76m), Figure 1. Bales are secured by five galvanized steel tie-wires running in the Y and Z directions. They have considerable potential for use in construction particularly where their light weight and ease of handling places them at a premium. A porosity of around 50% or more and a permeability of approximately 0.4m/s (Simm *et al*., 2004) makes them ideal for drainage applications. The bale-to-bale φ' is around 35^o in dry conditions (Zornberg, 2004). Furthermore, the process of tyre bale manufacture consumes around 1/16 of the energy required to shred a similar mass of tyres.

The amount of materials required by a project is a critical consideration for any construction. For a volume of 100m^3 approximately 8,000 tyres in the form of 70 tyre bales are required. These are likely to require slightly over two 8 hour two-man shifts to manufacture.

Figure 1. A typical tyre bale with dimensions.

Substances which could potentially leach from tyres are already present in groundwater in developed areas. Studies suggest that leachate levels generally fall below allowable regulatory limits and will have negligible impact on the water quality in close proximity to tyres (e.g., Hylands and Shulman, 2003).

The risk of spontaneous combustion from tyre bales is thus generally viewed as extremely low. Baling tyres reduces the available oxygen by a factor of four to five compared to whole tyres while decreasing the exposed rubber surface area by the creation of tyre-to-tyre contacts without exposing any steel. The exothermic oxidation reaction potential is thus greatly reduced. Simm *et al*. (2004) reported on a modelled storage condition in which a 17.5m by 6.0m by 3.0m volume of bales reached and maintained a temperature of 188^{o}C for 39 days before spontaneous combustion became possible. In contrast Sonti *et al*. (2000) report apparently spontaneously combusted fires in large volume of tyre shred in the USA.

3 Methods of Construction

There are two broad construction approaches for roads over soft ground: above ground ('floating'); and below ground. Both conventionally use large volumes of granular fill.

3.1 'Floating' Construction

In areas of deep soft soil replacement techniques are unattractive as large volumes of material must be excavated, transported and disposed of with the consequential effect on costs. The surrounding soft material may create technical difficulties related to excavation support, basal heave and other factors, making the proposed project difficult if not uneconomic.

Where the natural surface 'crust' is stiffer than the lower layers due to vegetation, desiccation, compaction and other factors the surface may be suitable for use as the road foundation. Care is needed to ensure that the crust is not broken or otherwise compromised during construction and that as the road is built the imposed loads are spread over as wide an area as practical.

Above ground construction has often utilised bundles of twigs, called fascines, placed at subgrade level to provide resistance to differential movement. Often these were orientated at 90^o to one another in two layers. On constructions designed to take higher traffic flows logs were used above the fascines. This generally worked best where a stiffer material, such as fibrous peat, overlay less competent material, such as amorphous peat. The modern equivalent is a geosynthetic material often with a sand regulating layer. The use of tyre bales on top of the geosynthetic/sand layer further allows the applied load to be lessened.

3.2 Buried Construction

The removal of in-situ materials and replacement with new, preferably lightweight, materials is undoubtedly a more expensive option. However, due to the lateral restraint provided by the excavation boundaries a more durable construction is likely. The key to such construction lies in ensuring that the new material adds as little load as possible.

Buried construction may be preferred in more competent materials, or shallow poor materials for which removal is an option. Such materials include normally consolidated silts and clays, and soft predominately mineral soils for example. A geotextile is a key element in spreading the foundation load as for above ground construction.

The repair or reconstruction of an existing road over soft ground presents particular problems. Often the repair is required as a result of differential settlement. The road materials will have settled giving an uneven surface, poor ride quality and an increased risk of flooding. The placement of additional material to raise and regulate the pavement surface is simple but will increase the loading on the formation and almost certainly cause additional differential settlement. The replacement of the existing material is thus a necessity.

4 Construction Approach

The construction and rehabilitation of low-volume roads over soft ground represents one of the most promising applications for tyre bales. There is currently insufficient information to justify their use with higher traffic levels (in excess of a few hundred vehicles 24 hour, 2-way Annual Average Daily Traffic). When more information and greater experience are available it may be possible to incorporate tyre bales in foundations for higher traffic flows.

Low-volume tyre bale roads have been successfully constructed both above and below ground. A geotextile separator has been used between the in-situ soil and the tyre bales, often with a regulating layer of sand. The geotextile is particularly important to prevent differential movement of the bales during and after construction.

One of the key design decisions is whether the construction should be above ground (floating) or below ground (buried). The former exploits any stiffer layer that may exist close to the surface, while the latter exploits the lateral support available from the in-situ materials and has the potential to limit the additional loads placed on the subgrade. Thus the designer needs to consider which approach is most suitable for the given circumstances.

Analytical input for low-volume road design on soft ground is usually limited. Setting aside economic factors, this is because the strength and stiffness properties of the soil involved are usually at or close to the lower limit of what can be measured, rendering the analytical input parameters subject to wide error ranges. In addition the sampling process tends to disrupt the soils structure leading to lower values than might exist in the field situation. Accordingly many such roads are designed on the basis of experience and on a specification-led basis.

The following sections describe the main construction steps and offer guidance based upon experience of successful projects of emerging good practice in constructing low-volume roads over soft ground using tyre bales.

4.1 Excavation and Preparation

If the construction is to be buried then excavation is the first construction activity.

Low ground-pressure, tracked plant are to be preferred as is working in dryer weather when the moisture content of the soil is at a minimum and strength and stiffness are maximised. The plant should be driven carefully to the start of the excavation to ensure that the surrounding soil formation is not unnecessarily damaged.

A suitable geotextile should be installed either at ground surface level or in the excavation followed by a regulating layer of sand if required. Provision should be made so that all geotextile-to-geotextile interfaces incorporate an overlap of 1m. The use of a geotextile is considered good practice and has a number of advantages including aiding working conditions in soft soils, strengthening the structure by tying together the assembly of bales, and separating the bales from the subsoil and thus preventing the ingress of fines.

Construction in cells is recommended to minimise the size of the excavation as is rapid construction of each cell. The exposure to of the soil to the weather and the likelihood of side slope failure are thus minimised. Bale sizes mean that excavations are unlikely to exceed 1m but close attention should be paid to the possibility of sidewall collapse and associated hazards to workers during the risk assessment and the execution of such operations.

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.

4.2 Placement and Alignment of Bales

Tyre bale handling must incur the minimum risk of damage to the steel tie-wires. Approaches that have been tried include webbing straps wrapped around the bale and lifting ropes formed as part of the bale. However, the most successful was the use of a ‘loggers-clam’ (Figure 2). The clam can be attached to a variety of hydraulic equipment and provides an appropriate lift-and-place methodology while allowing the bale to be rotated to the correct alignment.

Figure 2. Use of a ‘loggers-clam’ to handle tyre bales.

The manufacturing process renders tyre bales inherently heterogeneous. Information on the relative stiffness in each of the three directions is not currently available.

The Z-X plane (Figure 1) is likely to have a high stiffness and should be installed such that it attracts the maximum load, horizontal for a road. The X-Y plane is perpendicular to the loads applied during manufacture and it is recommended that it is aligned perpendicular to the longitudinal confining stresses (i.e., with the tie-wires in line with the road).

Three different options for the two-dimensional placement of tyre bales (i.e., in a single layer) are illustrated in Figure 3. Each layout has advantages and disadvantages.

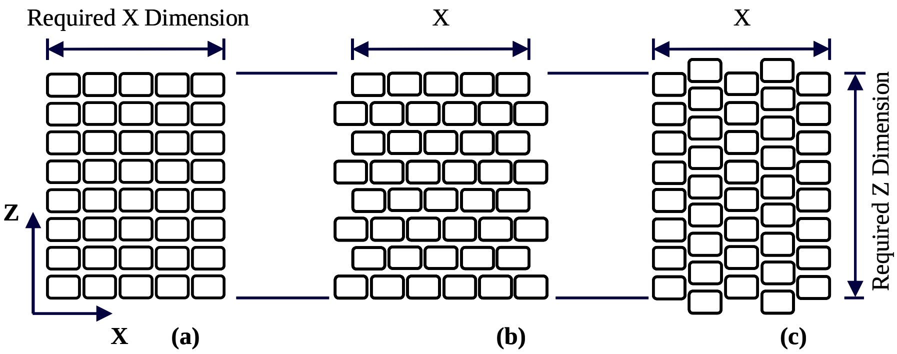

Figure 3. Two-dimensional tyre bale layouts: (a) chessboard; (b) stretcher bond; (c) staggered.

The chessboard layout (Figure 3a) is simple to construct and has been used successfully. It does not however provide mechanical interlock to resist differential lateral movement. Such resistance must come from friction and passive resistance between adjacent bales and the inter-bale fill material. However, the main threat to the integrity of a two-dimensional tyre bale layout is from differential vertical, rather than lateral, movement.

The stretcher bond layout (Figure 3b) affords improved resistance to lateral movement. However, it also uses more tyre bales (10% in Figure 3b) for a given plan area and the castellations create additional resource needs and construction and operational difficulties.
The comments made for the stretcher bond layout apply to the staggered layout (Figure 3c). However, the castellations are more problematic being formed at either end of the construction over which traffic will pass.

The chessboard pattern (tie-wires in line with the road; shortest dimension vertical) is recommended. In general, the bales should be placed as close together as possible in order to minimise any potential deformation under load and also the amount of inter-bale fill needed.

The width of the foundation should be at least two bales wider than the completed road surface to maximize load spreading. Other considerations (land availability, cost, soil strength, etc) may encourage greater or lesser widths based on engineering judgement. Six bales yield a 9m nominal width. It is customary in many parts of the world to construct unbound roads wider than normal.

The rows of bales should be placed across the width of the road. When the rows reach to about 1m from the far edge of the geotextile a second geotextile sheet should be overlapped beneath the first. More rows of bales should be added until they rest on the second sheet.

The foregoing assumes a single layer of bales is to support the road. If two or more layers are required then the second layer should be placed on top of the first, stepped in at either side to provide around half a bale width of overlap. This is similar to constructing a shallow embankment for which design and construction procedures are currently being developed.

4.3 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. In practice small gaps are usually left between adjacent bales. To maximise the stiffness and stability of the structure the voids must be filled. Coarse sand has been used successfully as have single-sized aggregate pellets. Crushed glass of a suitable grading may be less likely to clog or arch than sand when wet.

The most effective method of ensuring that the voids are filled has been found to be to use a bulldozer to apply a 150mm to 300mm layer of the material to the upper surface of the bale layer and then to apply a vibrating roller to the layer to vibrate the fill into the voids.

If the fill becomes wet or clogs the voids applying water using a bowser may unclog such areas. Note that both very dry and very wet sand will generally flow efficiently, but that it is generally easier to add than remove water, at least in a temperate climate.

The fill material will affect the density of the structure. The voids have been estimated to take up 20% to 25% of the nominal rectangular bale volume. This must be allowed for in calculations of, for example, bearing capacity. The effects of regulating layer(s) above or below the tyre bale layer must also be taken into account.

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. A crushed rock 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 sub-base must be assessed to ensure sufficient capacity during normal use and should be the subject of site-specific design.

After the completion of these operations the construction may proceed to the next cell to continue the process described above until the required length of road has been completed.

4.4 Pavement Construction

Pavement thicknesses must be determined from traffic flows and type, foundation conditions and the material used to form the pavement layers. Experience in the USA is of tyre bale roads with AADT 2-way flows of between 200 and 1600 vehicles per day. Local methods of determining pavement thickness are likely to prove most suitable.

Total pavement thicknesses between 250mm and 450mm have been employed. The 250mm thick pavement employed an A252 welded reinforcing mesh (8mm bars at 200mm centres) to help stiffen and strengthen the pavement. Bituminous layers, where required, are usually added at a later date after initial differential settlement of the unbound layers under traffic has occurred and suitable adjustments have been made to the profile.

The low traffic flows associated with such pavements yield an excellent opportunity to maximise the use of reused and recycled materials.

4.5 Drainage

Cross falls and drainage provision should be in line with local climatic conditions and standards. Cross falls shallower than 1 in 24 are unlikely to be effective on unbound surfaces.

Drainage provision should take account of both current needs and emerging needs in terms of perceived climate change. In Scotland, for example, the current design return period for rainfall events is likely to be increased by a factor of two. Additionally the high porosity and permeability of tyre bales needs to be taken into account. Care is however needed especially with roads founded in peat that the drainage is of the road and not of the surrounding wetlands which may be damaged if drained excessively.

5 Successful Applications

Successful applications involving the construction of tyre bale road foundations have been achieved in both the USA (New York State) and the UK.

Chautauqua Co. Dept. of Public Facilities has completed five projects using tyre bales as a lightweight subgrade replacement for roads over soft ground (Figure 4). The tyres result from the clean up of a tyre dump and from a tyre amnesty programme. A further project is planned for 2005. Future projects of this nature will depend upon the availability of tyres for baling (Anon, 1998; 2001).

Figure 4. CR342 under construction (left) and in May 2004 after five years in service (right).

The geology of the County is characterised by sands and gravels in the river valleys with glacially deposited fine silty clays elsewhere, primarily on the hilltops which are often depressed forming high level swamps. These materials are stable if kept dry but are very sensitive to moisture and more so to the freeze thaw cycle which can turn them to a material not dissimilar to pottery slip and are capable of turning conventional roads constructed on them into impassable quagmires. It is on these relatively high level roads that the County Authorities have targeted tyre bale road construction.

To date with the roads having been in service for up to six years no major signs of distress have been observed that could be attributed to the presence of tyre bales (Figure 4).

A public road has been constructed by Highland Council in the far north of the UK (Anon, 2003). It was completed in late-2002 and performance to date has been broadly satisfactory despite extreme loadings imposed by a very high proportion of logging trucks using the route.

6 Summary

This paper has described the lightweight tyre bales that are seeing increasing use on a wide range of low-cost construction projects.

An outline approach to the construction of low-volume tyre bale road foundations on soft ground has been presented. The construction stages considered are: excavation and preparation; placement and alignment of bales; filling of voids; pavement construction and drainage. Particular attention has been paid to the stages that deviate most from conventional construction, namely placing and alignment of the bales and filling of the voids between.

Research in the UK and USA is developing design and construction methods for a wide range of potential tyre bale applications including lightweight embankments and retaining walls.

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