THE USE OF TYRE BALES WITH CONVENTIONAL FORMS OF GEOSYNTHETIC

M G Winter[1] J D Simm[2] & G R A Watts[3]

[1] *Transport Research Laboratory. (e-mail: mwinter@trl.co.uk)*
[2] *HR Wallingford. (e-mail: j.simm@hrwallingford.co.uk)*
[3] *Transport Research Laboratory. (e-mail: gwatts@trl.co.uk)*

Abstract: The disposal of used tyres is a problem of international significance. In the European Community nations sending whole tyres and shredded tyres to landfill were banned in 2003 and 2006 respectively. A range of sustainable solutions that allow the reuse and recycling of used tyres is urgently required. One such solution is the manufacture of tyre bales which comprise approximately 100 whole tyres compressed into a rectilinear block. The bales are lightweight/low density, high permeability, high porosity and high friction and thus ideally suited to many construction applications. Most tyre bale applications in construction are best achieved in tandem with the use of a conventional planar geosynthetic to aid separation, reinforcement and/or filtration. This paper examines a number of tyre bale applications highlighting the use of conventional planar geosynthetics as part of the construction system. Such applications include road foundations over soft ground, slope failure repair, lightweight embankment fill and drainage layers amongst others.

Keywords: Cellular system, construction, design, waste.

INTRODUCTION

Around 40M tyres (450,000 tonnes) are scrapped in the UK each year. However, the generation of scrap tyres is by no means a problem unique to the UK and Europe. In the USA it has been estimated that more than 2 billion used tyres are stockpiled, and that an additional 285M are added each year. In the state of Texas alone 69M scrap tyres are estimated to be stockpiled and a further 24M added each year.

In the recent past by far the bulk of these have been sent for energy recovery, stockpiled, disposed of in landfill or disposed of illegally (Hird *et al*. 2001). The disposal of tyres is a recognised problem around the world.

In Europe the EC Landfill Directive outlawed the disposal of whole tyres in landfill in 2003 and that of shredded tyres in 2006, albeit exceptions are made on a case-by-case basis for use in engineered landfill works. 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.

Unsurprisingly the focus on means of reusing and recycling used tyres has increased in recent years in Europe. However, by far the majority of research work has been aimed at the use of tyre shred, chip and crumb in construction works. A relatively new process is the baling of around 100 whole tyres to produce a rectilinear bale. The resulting bales are lightweight/low density, permeable, porous and of high friction.

These properties are favourable for many types of construction, in particular those relating to geotechnical engineering and the bales are likely to play an increasing part in future construction works. Construction applications include road foundations over soft ground, slope failure remediation, lightweight embankment fill and drainage layers.

This paper reviews some of the possible approaches to the design and construction of a wide range of construction applications and includes an overview of the key properties of tyre bales. In particular the need to use geosynthetics in conjunction with tyre bales is highlighted. One of the main purposes of the work reported here was to assist the tyre baling industry in achieving increases to the volume of tyre bales used in construction and, at the same time, to help raise the utility (or value) of those applications. There are strong signs that the work reported here, in combination with other work conducted in the UK and USA, has made a strong contribution to the potential future use of tyre bales in construction.

It is concluded that tyre bales are a valuable addition to the range of materials available to engineers. In addition, the incorporation of tyres into bales and their subsequent use in construction makes a positive contribution to the sustainable recycling of an otherwise problematic waste material.

PROPERTIES AND BEHAVIOURS

The British Standard Publicly Available Specification (BS PAS 108 – Anon, 2007; Winter *et al*. In Press) deals with the receipt, inspection, cleaning, handling and storage of tyres; the manufacture of tyre bales; and their handling, storage, transport and placement on site. In addition a factory production protocol is given as well as details on the engineering properties of tyre bales and their measurement, detailed explanation of behaviour, construction applications, and guidance on end of life service options.

Properties

Tyre bales are formed by compressing approximately 100 to 115 whole tyres into a rectangular block of approximate dimensions 1.3m by 1.55m by 0.8m (Figure 1) and an enclosing volume of around 1.7m^3. The completed blocks have a mass of around 800kg and a density of around 0.5Mg/m^3, indicating a truly lightweight/low density material.

Bales are secured by five galvanized steel tie-wires running around the length and depth of the bale. They have considerable potential for use in construction particularly where their low density and ease of handling places them at a premium.

In addition, the bales are free-draining with a permeability broadly corresponding to that of gravel (0.1m/s to 0.2m/s) in the shorter dimension and to that of coarse sand (0.02m/s to 0.04m/s) through the middle (1.3m) dimension. The porosity of tyre bales is around 62% (Simm *et al*. 2005). These properties make the bales ideal for drainage applications.

The bale-to-bale friction angle is around 35° in dry conditions (Zornberg, 2004). Other relevant properties of the bales include a stiffness (expressed as Young's Modulus) of between 800MPa and 1000MPa (Winter *et al*., 2006a) and a total creep under load of 1.1% over 35 months with long term creep not expected to exceed 1.5% (Anon, 2007).

Figure 1. A typical tyre bale with dimensions.

Behaviour

Potential leachates 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 viewed as extremely low. Incidents of the spontaneous combustion of whole tyres are not known to the authors and baling tyres further reduces the available oxygen by a factor of four to five and also decreases the exposed rubber surface area, by the creation of tyre-to-tyre contacts, without exposing any steel, thus reducing the exothermic oxidation reaction potential. Simm *et al*. (2005) 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.

Tyres can degrade under the action of the ultra-violet (UV) component of sunlight although carbon black, which is used to strengthen the rubber in tyres and aid abrasion resistance, serves to block the damaging UV rays. The rate of degradation is dependent upon a range of factors and is largely unpredictable. However, for temperate climates there appears to be a broad consensus that five to ten years of exposure of tyres in direct sunlight would be required before significant deterioration, which might threaten the mechanical integrity of the tyre, would be encountered. It is important to note that such exposure is typical of neither the situation in which tyres are used in-service on vehicles or of post-consumer tyre dumps where tyres at the surface are usually covered up rapidly by additional tyres.

Notwithstanding this, procedures for the exclusion of tyres adversely affected by UV-light are given in PAS 108 (Anon, 2007). Additionally, it is recommended that tyre bales be stored such that exposure to UV-light is limited and that once incorporated into a construction they are buried (see also Winter *et al*. 2006a).

Issues in relation to manufacture, construction and end of life are dealt with elsewhere (Anon 2007; Simm *et al*. 2005; Winter *et al*. 2006a, 2007a)

CONSTRUCTION APPLICATIONS

Construction applications are briefly described in this section. Further details on port, coastal and river engineering applications are given by Simm *et al*. (2005); further details of the applications described in this paper are given by Winter *et al*. (2006a) as well as details for environmental barrier applications. Many of the foregoing applications are also described in PAS 108 (Anon, 2007), which also gives additional details of tyre bale applications in drainage layers behind retaining walls. Additionally, Winter *et al*. (2005a) give details of a wide range of case studies.

It is important to note that construction with tyre bales can be a rapid and efficient process, provided that appropriate handling plant is utilized. Experience has shown that loggers-clams and brick-grabs are particularly suited to handling tyre bales; placement can be achieved quickly with minimal expenditure on plant and labour.

The information presented here is in summary form. However, both it and information given elsewhere is generally specific to the design, specification and construction of works using tyre bales. The reader is referred to local codes, standards and specifications for areas that are not specific to tyre bales. It is essential that design is undertaken, and construction overviewed, by appropriately qualified and experienced engineering personnel.

Road Foundations Over Soft Ground

The construction of roads over soft ground such as peat has long presented technical challenges (Figure 2). 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 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 paved. The success of such an approach is often limited in very soft soils such as peat due to the likelihood of long-term (secondary and tertiary) consolidation (Winter *et al*. 2005b).

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.

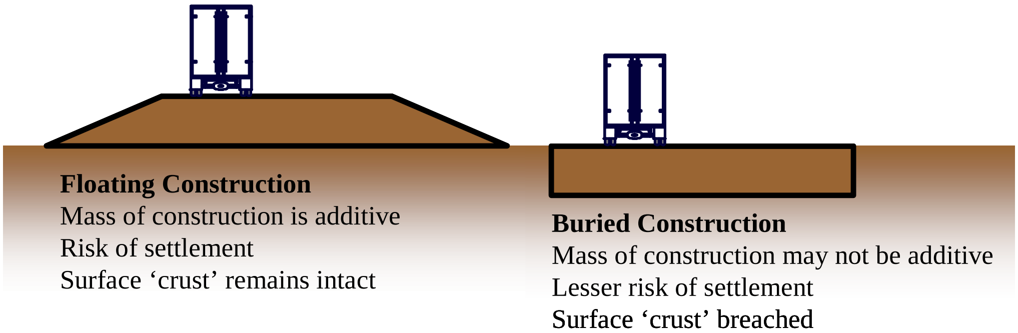

Figure 2. Road construction over soft ground using a tyre bale foundation.

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. One of the primary design considerations is whether the construction should be floating or buried (Winter *et al*. 2005b) and there are advantages and disadvantages to each approach (Figure 2).

There has been a wide variety of successful applications of tyre bale road foundation construction in both the USA and in the UK, as well as other parts of Europe (Figures 3 and 4) and such applications are described by Winter *et al*. (2005a, 2005b).

Whether floating or above ground construction is used there is a need to use a geosynthetic layer to limit differential settlement and, in the case of buried construction, to provide a degree of separation between the tyre bales and the surrounding construction media and the subsoil as described in both PAS 108 (Anon 2007) and by Winter *et al*. (2005b, 2006a).

Figure 3. Road construction over soft ground using a tyre bale foundation: Condin Road, Ellery, NY, USA. (Courtesy of Chautauqua County Department of Public Facilities.)

Slope Failure Repair

The key issues in relation to slope repair are addressed by Winter *et al*. (2007b). Much of the information that they present is derived from case studies in the UK and the USA. One of those case studies involved the repair of a cutting slope adjacent to Interstate Highway (IH) 30 between Dallas and Fort Worth (Figure 5); Prikryl *et al*. (2005) and Winter *et al*. (2005a) present an extended case study of the earlier works at IH30 in Texas.

Figure 4. Road constructed over soft ground with a tyre bale foundation: Kabob Road, Stockton, Chautauqua County, NY, USA four years after construction.

Figure 5. Slope failure repair at IH30, TX, USA around two years after completion.

Lessons learned were reported by Prikryl *et al*. (2005) and include the following:

- The need to ensure adequate supplies of tyres, and thus tyre bales (see Winter *et al*. In Press), prior to commencing a project – volume reductions of around four to five times are achieved by the tyre bale manufacturing process. Detailed advice on this matter is given by Winter *et al*. (2006a) and Anon (2007).
- Layers of fill placed between each layer of tyre bales are not necessary. These can potentially, especially if fine-grained fill is used, introduce potential slip-planes to the repair. If many layers of tyre bales are to be placed then regulating layers of high friction fill may be required (see Winter *et al*. 2007b).
- A water stop at the down slope end of a repair will not be necessary if the effective inflow and outflow of water is catered for correctly.

These lessons were not only incorporated into the guidance given by Winter *et al*. (2007b), but also into a second repair in the same area of IH30.

Not all types of slope failure lend themselves to remediation using tyre bales. The essential feature that determines the suitability of tyre bales for use in slope failure remediation is the presence of a large void, usually created by the movement of the failed material. Often this material will need to be excavated to fully reveal the extent and shape of the failure (e.g. Figure 6). The role of water is usually critical in the creation of failures and, thus, the voids that result from the excavation of the failed material. This is demonstrated by the fact that free-draining rockfill is often used to improve the subsequent drainage and hence free-draining tyre bales offer a natural alternative (Prikryl *et al*. 2005). Geosynthetic layers usually form a critical part of the filter between the tyre bale mass, the surrounding construction and the subsoil ensuring that migration of fines and clogging of the drainage pathways are minimised.

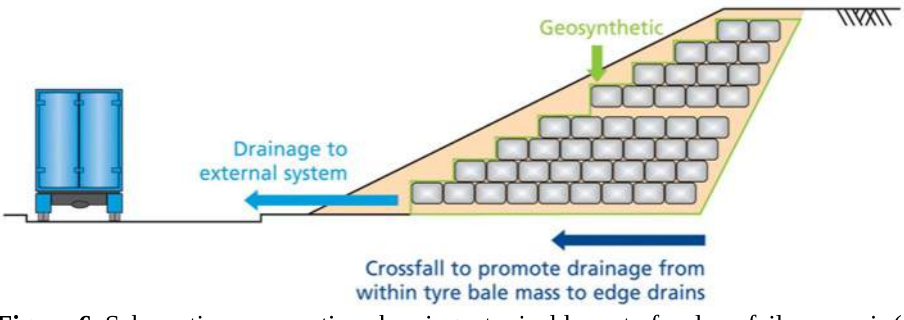

Figure 6. Schematic cross-section showing a typical layout of a slope failure repair (after Anon 2007).

Typically, slides (in circular, translational or wedge form) will involve the movement of relatively large volumes of material. Such volumes of failed material will often be removed to create a large void which is then filled as part of the remediation works. The object of such excavation and replacement works is to reform the slope using a higher strength, more freely-draining material. Flows may also produce large voids as gullies may be formed or enlarged during their erosional phase (Winter *et al*. 2005c, 2006b). Slides and flows are therefore most likely to provide an environment in which the high inter-bale friction angle and high permeability of tyre bales may be exploited in slope failure remediation. In general failures in rock slopes are much less likely to lead to situations favouring the use of tyre bales in their remediation.

Successful applications of slope failure repair using tyre bales are described elsewhere (Winter *et al*. 2007b; Prikryl *et al*. 2005).

Lightweight Embankment Fill

Embankments across low-lying soft ground are commonly required for transport, services and flood defence. Typically they are required to achieve a satisfactory vertical alignment, and raise the infrastructure above potential flood waters, or to provide an effective freeboard as part of flood defence works. In either case their consequent height means that they apply a significant loading to the underlying soft ground. The use of conventional fill can lead to significant settlements, either internal to the embankment or globally as the entire structure settles, potentially generating serviceability problems and may also lead to the potential failures of either the ground or the embankment, resulting in ongoing maintenance expenditure.

There are a number of ways in which consolidation may be limited. These generally involve either strengthening the foundation, by the addition of strengthening materials or by staged construction to allow consolidation and thus improve the strength of the in-situ material, or by reducing the weight of the embankment by the use of lightweight materials.

Drainage, especially at the base of the embankment, remains a critical issue in ensuring stability of both the embankment itself and the underlying soft ground, such as flood plains, marshes and peat bogs. Tyre bales, being both lightweight and free-draining, have considerable potential to form a critical construction material for embankments both on soft ground and more widely. The bulk unit weight of an embankment comprising a tyre bale core may reduce the vertical stress on the subsoil by a considerable amount (well in excess of 50% in many instances), and their use provides a valuable advantage to the engineer.

Successful applications of tyre bales in flood defence embankments are described elsewhere (Simm *et al*. 2005; Bo & Yarde 2006). The most significant use of bales in flood defences to date is in a major reconstruction of a 1500 metre stretch of river embankment for the Environment Agencies defences on the Lower River Witham system. Over a million tyres were placed over a peat foundation in baled form (see Figure 7) and, in a constrained site, the bales permitted steeper side slopes to the embankment and a smaller ground-take than would otherwise have been possible.

Figure 7. Design and construction of modification to flood embankment on River Witham using tyre bales.

Many of the key issues discussed in relation to road foundations over soft ground are important to the design and construction of embankments (Winter *et al*. 2005b, 2006a). The analysis of the stability of the embankment itself can be undertaken using methodologies similar to those relevant to slope failure remediation (e.g. Prikryl *et al*. 2005).

The key issues to be addressed in the design of tyre bale embankments are those of the settlement and stability of the underlying subsoil under the embankment load. Typically a geosynthetic will be used as a basal reinforcement, also playing a key role in drainage and separation. A typical form of construction is illustrated in Figure 8.

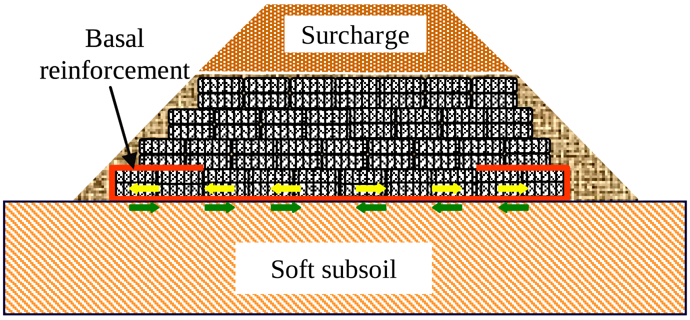

Figure 8. Schematic cross-section of tyre bale embankment showing the action of horizontal basal reinforcement (not to scale).

Drainage Layers (or Drainage Paths)

Drainage layers are required in many types of structures including embankments and landfill cells. The high permeability and easy handling of tyre bales makes them ideally suited to such applications. Where they are used in the basal drainage layer for landfill sites, the loads on the bales can be significant with many metres of fill, albeit of lower density than soils. Such applications probably involve the highest loads to which tyre bales have been subject in construction works to date.

The primary objective of all drainage systems is the removal of excess moisture. Typically, drainage measures may be required to perform one or more of the following functions:

- Lower ground water levels.
- Intercept flows to protect important earthworks.
- Reduce softening of cohesive soils by reducing pore-water pressures and increasing shear strength (i.e. consolidation).
- Reduce lateral stresses that could result in the failure of the earthwork or structure.
- Removal of moisture away from areas of potential or pre-existing slip failures.
- Reduce potential for piping or loss of fines.

In geotechnical applications a successful drainage system may make the difference between a fully stable soil structure/earthwork and one that undergoes deformation throughout its service life, or in the extreme event failure. The stability of a soil mass is dependent on the shear strength, which in turn depends on the density, angularity of the particles, grading and moisture content. Shear strength decreases with increasing moisture content; for in situ materials the moisture content may be controlled by the application of suitable drainage measures. Such control is particularly important for soils that are wholly or partially cohesive in nature as even small changes in moisture content can make the difference between stability and collapse. In uncontrolled areas a wide variation in moisture content can occur in soils throughout their service life and adequate drainage measures should be provided to maximise stability.

Figure 9 illustrates just one drainage layer system that might be constructed using tyre bales to aid the drainage of an embankment constructed form relatively wet fill. If the structure is to be permanent then a geosynthetic filter will be required to prevent the ingress of fines to the tyre bale layer and thus also preventing consequent clogging.

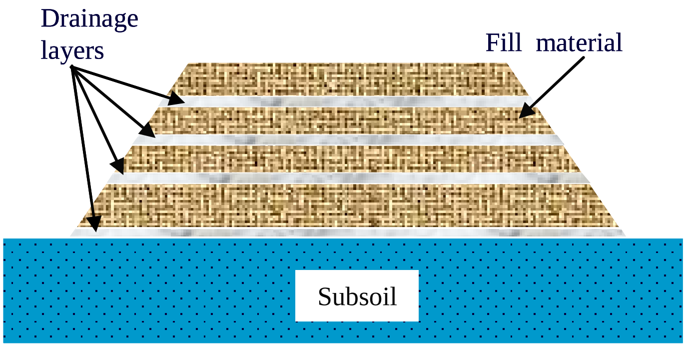

Figure 9. Schematic representation of horizontal tyre bale drainage layers used to remove excess water form embankment fill (not to scale).

Retaining Walls

Retaining walls can be a challenge to design where substantial heights of ground or fill have to be supported (e.g. in port construction). When placed behind the wall, tyre bales can provide a free-draining layer which helps to prevent excessive water pressures building up behind the wall. They may also assist by reducing the load applied to some forms of wall construction. The form of construction will involve stacking bales directly behind the wall, and the provision of a geosynthetic filter between the bales and the subsequent backfill.

Sustainable Urban Drainage Systems

Sustainable Urban Drainage Systems (SUDS) are those which limit amounts and rates of discharge of water from housing and industrial developments into water courses, encouraging recharge of water back into aquifers. Tyre bales are suited to some SUDS systems because of their permeability and porosity. In such applications, the high porosity of the bales is important as it permits storage of significant quantities of water, slowing eventual discharge and encouraging filtration into the surrounding ground.

Many tyre bale applications to SUDS can be envisaged, such as soakaways, French drains and placement beneath permeable car park paving for temporary water storage. Geosynthetics will be needed to limit ingress and subsequent blockage of the tyre bales by fine material.

SUMMARY

Tyre bales are a lightweight, free-draining, high porosity, high friction construction material. Additionally their shape, size and mass mean that, provided appropriate handling plant are used, construction can proceed rapidly and with relatively low expenditure on plant and labour. In many construction applications these factors can provide a real advantage.

Many such applications relate to geotechnical engineering and foundations for roads over soft ground, slope failure repair, lightweight embankment fill and drainage have been briefly highlighted in this paper. Detailed information on these and other applications is available elsewhere as set out in the sections describing each application in this paper and in the references cited therein.

Tyre bales are a valuable addition to the range of materials available to engineers. In addition, the incorporation of tyres into bales and the subsequent use of the bales in construction make a positive contribution to the sustainable recycling of an otherwise problematic waste material. However, one of the key requirements for their successful use in construction applications is the provision of appropriately specified geosynthetic layers. These are usually required for drainage and separation purposes, primarily to prevent clogging by fines migrating form the surrounding subsoil, but may also be required to aid in limiting differential settlement and to provide a degree of basal reinforcement.

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Corresponding author: Dr M G Winter, Transport Research Laboratory, Craighouse Campus, Craighouse Road, Edinburgh, EH10 5LG, United Kingdom. Tel: +44 1314555043. Email: mwinter@trl.co.uk.

REFERENCES

Anon. 2007. Specification for the production of tyre bales for use in construction, *PAS 108*. London: British Standards Institution.

Bo, M. W. & Yarde, A. 2006. Use of waste tyre bales to construct a flood embankment. Proceedings, Institution of Civil Engineers (Waste and Resource Management), 159(2), 57-64.

Hird, A. B., Griffiths, P. J. & Smith, R. A. 2001. Tyre waste and resource management: a mass balance approach. *Viridis Report VR2*. Crowthorne: Transport Research Laboratory.

Hylands, K. N. & Shulman, V. 2003. Civil engineering applications of tyres. *Viridis Report VR5*. Crowthorne: Transport Research Laboratory.

Prikryl, W., Williammee, R. & Winter, M. G. 2005. Slope Failure Repair using Tyre Bales at Interstate Highway 30, Tarrant County, Texas, USA. *Quarterly Journal of Engineering Geology and Hydrogeology*, **38**(4), 377-386.

Simm, J. D., Wallis, M. J. & Collins, K. (Editors) 2005. Sustainable re-use of tyres in port, coastal and river engineering: guidance for planning, implementation and maintenance. *SR 669*. Wallingford: HR Wallingford.

Sonti, K., Senadheera, K., Jayawickrama, P. W., Nash, P. T. & Gransberg, D. D. 2000. Evaluate the uses for scrap tires in transportation facilities. *Research Study No 0-1808, Centre for Multidisciplinary Research in Transportation*. Lubbock, TX: Texas Tech University.

Winter, M G, Reid, J. M. & Griffiths, P. I. J. 2005a. Tyre bales in Construction: Case Studies. *TRL Published Project Report PPR 045*. Crowthorne: Transport Research Laboratory.

Winter, M. G., Johnson, P. E. & Reid, J. M. 2005b. Construction of road foundations on soft ground using lightweight tyre bales. *Proceedings, International Conference on Problematic Soils, GeoProb2005*, Eastern Mediterranean University, Famagusta, N Cyprus, 25-27 May 2005.

Winter, M. G., Macgregor, F. & Shackman, L. (Editors) 2005c. *Scottish road network landslides study*. 119p. Trunk Roads: Network Management Division Published Report Series. Edinburgh: The Scottish Executive.

Winter, M. G., Watts. G. R. A. & Johnson, P. E. 2006a. Tyre bales in Construction. *TRL Published Project Report PPR080*. Crowthorne: Transport Research Laboratory.

Winter, M. G., Heald, A., Parsons, J., Shackman, & L. Macgregor, F. 2006b. Scottish debris flow events of August 2004. *Quarterly Journal of Engineering Geology and Hydrogeology*. **39**(1), 73-78.

Winter, M. G., Watts G. R. A. & Simm, J. D. 2007a. Tyre bale applications in geotechnical engineering. Proceedings, XIV European Conference on Soil Mechanics and Geotechnical Engineering: Geotechnical Engineering in Urban Environments (Eds: Cuéllar, V, Dapena, E, Alonso, A, Echave, E, Gens, A, de Justo, JL, Oteo, C, Rodríguez-Ortiz, JM, Sageseta, C, Sola, P and Soriano, P), **3**, 1579-1585. Rotterdam: Millpress.

Winter, M. G., Williammee, R. & Prikryl, W. 2007b. Landslide remediation using tyre bales. *Proceedings, First North American Landslides Conference: Landslides and Society* (Eds: Schaefer, VR, Schuster, RL & Turner, AK), 1763-1772. Association of Environmental & Engineering Geologists Special Publication 23. Wisconsin, USA: OMNI Press.

Winter, M. G., Simm, J. D. & Waite, S. In Press. The British Standard Publicly Available Specification for tyre bales. Proceedings, Fourth European Conference on Geosynthetics. (This Volume.)

Zornberg, J. 2004. Validation of the effectiveness of tire bale use in slope repairs and embankment construction – report of laboratory results. *Semi-Annual Progress Report*, Project 5-9023-01. Fort Worth, TX: Texas Department of Transportation.