PUBLICLY AVAILABLE SPECIFICATION

PAS 108:2007

Specification for the production of tyre bales for use in construction

Material change for a better environment

British Standards

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British Standards Institution
389 Chiswick High Road
London W4 4AL
United Kingdom

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Foreword

This Publicly Available Specification (PAS) has been developed by The Waste & Resources Action Programme (WRAP)[1] in collaboration with the British Standards Institution (BSI). It has been written by Jonathan Simm of HR Wallingford[2] and Dr Mike Winter of TRL Limited[3].

The overall aim of this PAS is to provide a specification that can be adopted by suppliers for producing tyre bales such that potential customers will be assured that they are procuring a construction material of consistent and verifiable quality. Thus the core of this document addresses the production, handling, storage, transport and placement of standardized tyre bales, the dimensions and properties of which are described in this PAS. In addition, guidance is given on engineering properties and typical construction applications.

Acknowledgement is given to the following organizations that were involved in the development of this specification.

- John Barritt, WRAP (The Waste & Resources Action Programme)
- Dr Ken Collins, University of Southampton
- Paul Hallett, Department of Trade and Industry
- Dr John Harris, Scottish Environment Protection Agency (SEPA)
- Steven Mendes, Anglo Environmental
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- Peter Senior, Faber Maunsell
- Andrew Usborne, Environment Agency
- Steve Waite, WRAP

Wider comments from other interested parties were invited by BSI. The expert contributions made by the organizations and individuals consulted in the development of this PAS are gratefully acknowledged.

1) The Waste & Resources Action Programme was created to promote sustainable waste management and to create stable and efficient markets for recycled materials and products. www.wrap.org.uk

2) HR Wallingford is an independent company specialising in consultancy and research in civil engineering hydraulics and the water environment. www.hrwallingford.co.uk

3) TRL Limited undertakes research and specialist consultancy, and provides advice across a broad spectrum of transport, infrastructure, environment, waste and resource concerns. www.trl.co.uk

Introduction

The European Union Landfill Directive (1999/31/EC) [1] is an important driver for used tyre recycling as it bans the disposal of tyres to landfill. Whole tyres were banned as of July 2003 and shredded tyres from July 2006. The ban applies to almost all tyres including car, commercial, motorcycle, aircraft and industrial (including solid tyres).

The disposal of used tyres in the UK is a significant problem; every day over 100,000 worn tyres are taken off cars vans and trucks accounting for a total of around 46 million tyres (460,000 tonnes) per year. Of this figure, about 27 million tyres (260,000 tonnes) are from cars, with truck and van tyres making up the remainder.

The compression of whole tyres into bales offers one of a number of ways of putting post-consumer tyres to good use, at the same time reducing the use of primary materials (typically aggregates).

Conversion of post-consumer tyres into tyre bales is currently a process which is managed under the Waste Management Licensing Regulations 1994 (as amended) [2]. The process of baling is a regulated activity, but Regulators in England and Wales are not actively pursuing licensing applications for tyre baling. In Scotland, subject to limits on the amounts involved, the baling of waste tyres is now an exempt activity. Separately, the transport of whole tyres and tyre bales requires a Waste Transfer Note as specified by the Environmental Protection (Duty of Care) Regulations 1991 (as amended).

The specific use of bales (once manufactured) in construction is generally accepted by the waste regulators in the UK as a low risk activity. Regulators in England and Wales are not actively pursuing licensing applications for use of bales in construction; future amendments to regulations may introduce exemptions to cover this use. In Scotland the use of tyre bales in certain specified works is now an exempt activity. Studies to date have indicated that leachates are well within regulatory limits and fire risks are acceptably small. Tyre bales offer significant advantages in construction projects due to their high permeability and low bulk density, whilst still providing good frictional response and stiffness.

This specification is intended to assist manufacturers of bales of post-consumer tyres to produce a high quality, consistent and traceable product for use in construction by responsible and competent organizations. It is also intended to assist balers in demonstrating that their product is of a high and consistent quality via their Factory Production Control processes (see Annex A).

This specification encompasses the following activities and aspects of tyre bale manufacture, storage and use in construction:

- Receipt, inspection and cleaning of tyres (see Clause 3);

- Handling and storage of tyres (see Clause 4);
- Production of reference bales and both larger and smaller sizes of bale, including a system for measuring and labelling bales manufactured in accordance with this PAS (see Clause 5);
- Handling and storage of the bales (see Clause 6);
- Transport, storage on site and placement of the bales (see Clause 7);
- Factory production control (see Annex A).

This specification is based on reference bales manufactured in a standard width baling machine. The length of bales produced in such machines can be varied from the reference length. In addition this specification permits the production of two prescribed alternative widths of bales, but it is important to note that baling machines to manufacture such modified-width bales may not be commercially available. Whilst the use of reference width bales is encouraged, alternative width bales may be useful in certain specialist applications.

This PAS has been prepared based on current UK practice within the industry and covers the bale sizes specified herein. However, in the future alternative and satisfactory rectilinear shapes of bales and/or forms of tying/wrapping of the bales may be developed to produce bales that are useful for construction purposes. The properties of these bales can be tested using the methods set out in Annex C. For acceptable use in construction, the densities of the new bales (and hence their porosities and permeabilities) should be similar to those indicated in Annex C, Table C1. Care will also be needed over the tyre placing pattern adopted when placing the tyres in the baler to ensure satisfactory structural properties for the bale. Evidence of satisfactory performance derived from such testing will help to make the case for revising this PAS to include new bale types.

Guidance is given to assist construction professionals in formulating preliminary design and construction proposals. This guidance is not intended to cover all aspects of detailed design but to provide key information that could not be sourced from other engineering documents. This information includes:

- The measurement of relevant tyre bale properties (Annex B);
- Engineering properties and behaviours of tyre bales associated with their use in construction (see Annex C);
- Example applications for tyre bales in construction (see Annex D);
- End of service life disposal options for tyre bales (see Annex E).

1 Scope

This Publicly Available Specification specifies the minimum requirements for the manufacture of tyre bales for use in construction, including:

- the receipt, inspection, cleaning, handling and storage of tyres intended for incorporation into bales;
- the process of compressing and baling, handling, transport, and storage of tyre bales intended for use in construction;
- the final placement of tyre bales into construction works;
- a factory production control procedure for tyre bale manufacture;
- the measurement of basic properties (dimensions, mass and density).

Information is also given on the likely engineering properties and behaviours of tyre bales, procedures for measuring the properties, potential applications for tyre bales for use in construction, and end of service life options.

NOTE *Attention is drawn to the following regulations:*

The Management of Health and Safety at Work Regulations 1999 [3].

The Provision and Use of Work Equipment Regulations 1998 [4].

The Personal Protective Equipment Work Regulations 1992 [5].

The Construction (Design and Management) Regulations 1994 [6].

2 Terms and definitions

For the purposes of this PAS, the following terms and definitions apply.

2.1 capping tyre

non-low profile tyre from wheels with a rim diameter of 14 inches or greater

2.2 compressed bale length

final dimension of the bale within the tyre baling machine in the direction of application of the compressive load prior to fixing of tie wires and release of compressive load

2.3 construction works

engineering works designed and executed with due skill and care in a manner appropriate to the purpose of the structure and subject to relevant planning and environmental controls

2.4 depth of bale

the smaller of the two principal dimensions (see Figure 1) of the enclosing cuboid perpendicular to the length dimension as determined in accordance with this PAS

2.5 enclosing cuboid

the smallest cuboid (see Figure 1) which just fits around a completed tyre bale

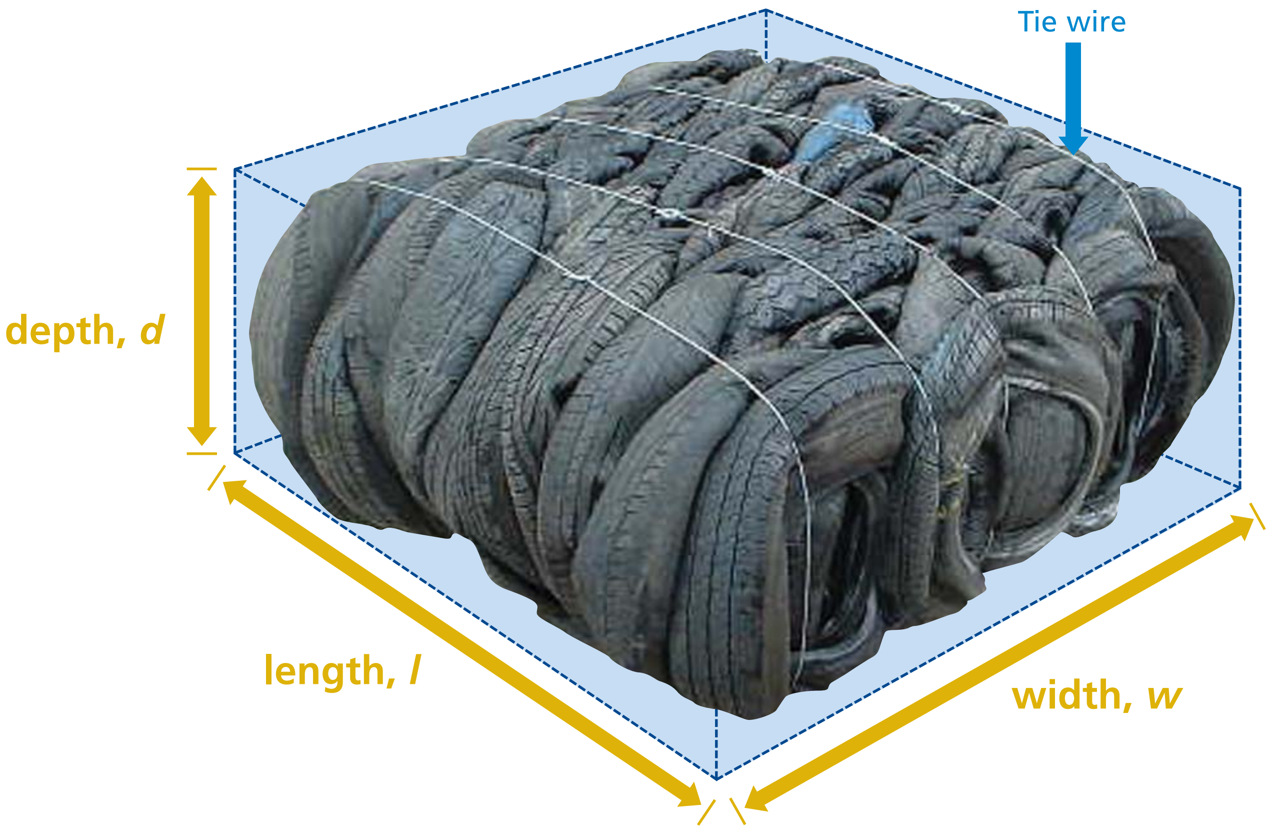
2.6 length of bale

the finished dimension (see Figure 1) of the enclosing cuboid in the direction of application of the compressive load in the tyre baling machine as determined in accordance with this PAS

NOTE 1 *Dotted line in Figure 1 indicates enclosing cuboid.*

NOTE 2 *Configuration of tyres and tie wires in Figure 1 is based on that in a reference bale (see 5.2)*

Figure 1 – Reference sketch of tyre bale



2.7 mass of bale

mass of the completed bale as determined in accordance with this PAS

2.8 nominal mass density of bale

mass of a bale divided by the volume of the enclosing cuboid as determined in accordance with this PAS (see Annex B)

2.9 post-consumer tyre

tyre that has been discarded for vehicular use

2.10 producer

organization that receives and inspects tyres, compresses and bales them and then supplies tyre bales for use in construction

2.11 reference bale

tyre bale of given dimensions which is appropriate for use in many construction applications

NOTE *The dimensions of other tyre bales manufactured in accordance with this PAS are determined with reference to this bale.*

2.12 stretcher bond

placing of tyre bales staggered along their course by half a length of bale (see **2.6**) in relation to the previous course

NOTE *This placing pattern can also be known as running bond.*

2.13 tie wires

galvanised high tensile steel wires, fitted with loops that enable the secure connection of the two ends, used to contain the tyre bale in its compressed size and shape

2.14 true mass density of bale

mass of a bale divided by the true volume of a bale as determined in accordance with this PAS (see Clause C.2.3)

2.15 tyre

untreated whole post-consumer tyre (see **2.9**) of which the principal parts are the casing, the cord, the bead and the tread which consist of elastomers, carbon black and silica, metal and fabric

2.16 tyre bale

result of compressing and securing whole tyres into a bale within dimensional and density limits

2.17 volume of the enclosing cuboid

product of the length, width and depth of the enclosing cuboid as determined in accordance with this PAS

2.18 width of bale

larger of the two principal dimensions (see Figure 1) of the enclosing cuboid perpendicular to the length dimension as determined in accordance with this PAS

3 Receipt, inspection and cleaning of tyres

Tyres received for baling shall be inspected prior to incorporation into bales.

The following tyres shall be rejected for use in tyre bales:

- Tyres whose overall diameter exceeds the depth of the baling chamber (see 5.2);
- Tyres with significant physical damage to the tyre (tears, rips or holes longer than 25 mm in the side wall; any other hole greater than 10 mm);
- Tyres that have been run at speed whilst flat;
- Partially burnt tyres;
- Blow out tyres;
- Tyres with exposed reinforcing material;
- Tyres showing signs of embrittlement or crumbling of the tyre wall.

Other than within the treads, clayey or other soil adhering to tyres shall be removed such that less than 1.0 mm thickness remains on any part of the tyre.

Tyres shall not be contaminated with petrol, diesel, other hydrocarbons or other hazardous substances.

4 Handling and storage of tyres

Tyres shall be baled as soon as practical after arrival at the location of the baling operation and acceptance for inclusion in bales.

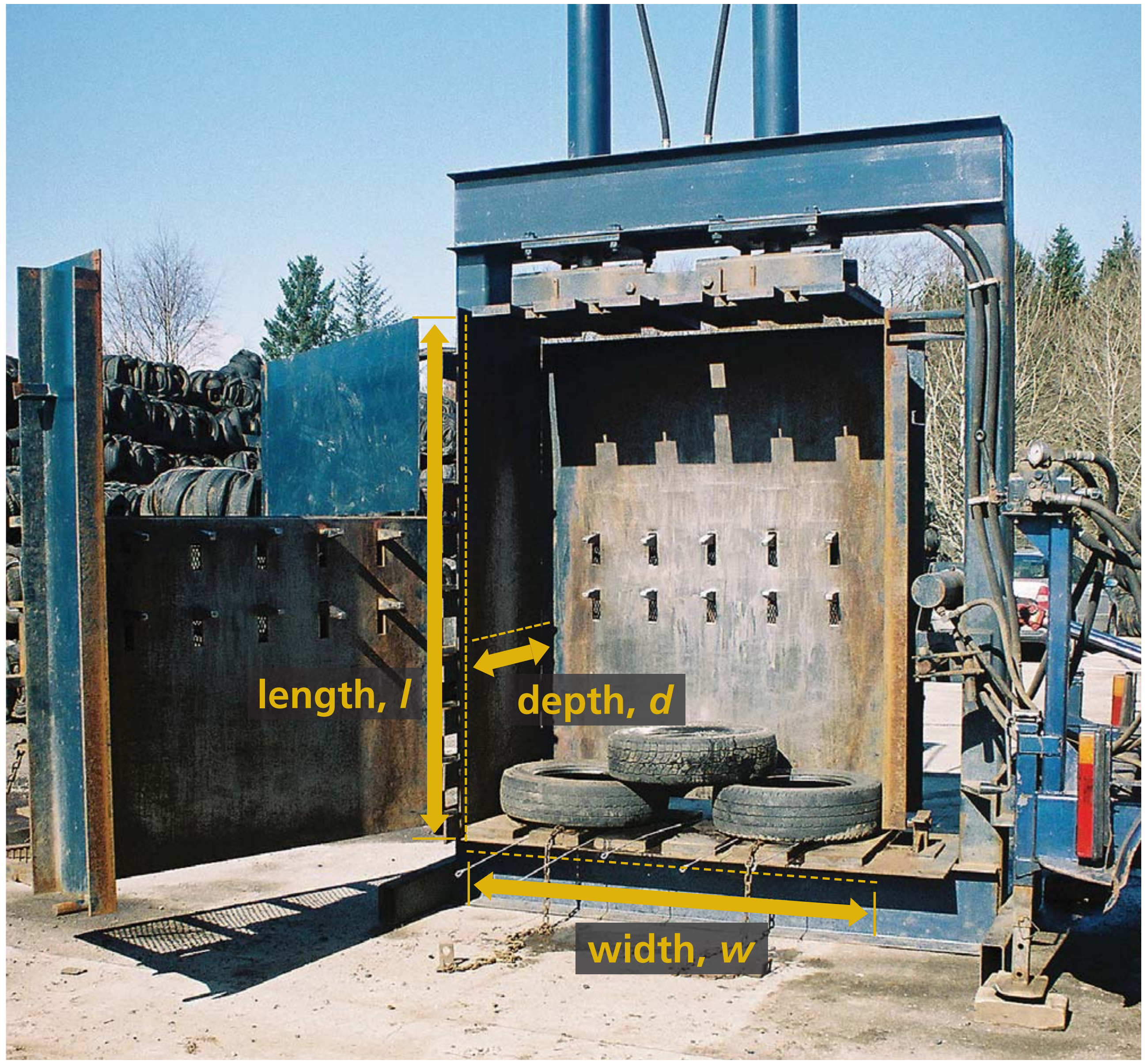
5 Production of bales

5.1 Requirements for all bales

Provision shall be made for compressing tyres in stages in order to build up the entire bale.

The tyres shall be stacked in the baling machine with capping tyres placed flat to form the top and bottom of the eventual bale (Figure 2) and the remainder inserted in a herring-bone arrangement until it is full (Figure 3).

Figure 2 – Commencing filling a typical tyre baler using capping tyres



NOTE *In Figure 2 notice the five tie wires and two bale removal chains at the base of the baler.*

Figure 3 – Filling a typical tyre baler with tyres in a herring-bone pattern

The tyres shall then be compressed in the direction of the application of the load.

This process shall be repeated until the requisite number of tyres has been incorporated and the required compressed bale length has been achieved (see Figures 4 to 7).

The doors of balers shall not be opened during compression operations.

NOTE *The door of the baler shown in Figure 4 was opened especially for the purpose of illustrating this PAS.*

Figure 4 – Tyres compressed in a typical baler prior to locking into position to allow the addition of further tyres

Figure 5 – Further tyres added to the bale ready for further compression. A typical tyre baler is shown

Figure 6 – Filling a typical tyre baler, capping tyres on the top

Figure 7 – A fully compressed bale with tie wires ready to wrap around a bale manufactured in a typical tyre baler

Provision shall be made to wrap tie wires around the reference bale when it is under maximum compression (see Figure 7).

These shall comprise high tensile steel wires of a minimum diameter of 3.8 mm, (tensile strength 1,500 MPa to 1,700 MPa).

All wires supplied for use in bales shall be looped at their ends and then electro-galvanised to a thickness of at least 3 µm or hot dip galvanised to a thickness of at least 6 µm.

The tie wires shall then be fitted to the bale (see Figures 8 and 9) such that they are evenly spaced and approximately parallel around the perimeter of the bale.

Figure 8 – Connecting the ends of the tie wires together (main picture) and after connection (inset)

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Figure 9 – A typical fully compressed bale with ties wires in position and the bale removal chains secured to the front of the top platen

The bale shall be removed from the baling machine (see Figures 10 to 13).

The nominal mass density of any bale, determined in accordance with Annex B, shall not be less than 420 kg/m^3.

Figure 10 – As the platen is raised the slack is taken up in the bale removal chains.

NOTE *A typical tyre baler is shown.*

Figure 11 – The chains tip the bale out of a typical baler

Figure 12 – The bale is removed from a typical baling machine

Figure 13 – Completed tyre bales

__NOTE 1__ Designers should be aware that the output dimensions of all tyre bales will vary from the nominal values depending on the tyres used and the depth will generally be slightly greater than the depth of the chamber. Typical output bale dimensions are given in Annex C.

__NOTE 2__ The number of tyres contained in each bale manufactured in accordance with this specification is likely to depend on the range and proportions of vehicle types from which the tyres originated. Such variations may be significant on a regional basis.

__NOTE 3__ The likely ranges of nominal mass density and true mass density of tyre bales, based on research measurements, may be found in Table C.2 of Annex C.

__NOTE 4__ Due to the degree of compression required (volume compression ratios are typically 4 or 5 to 1), it is normally necessary to compress the bale in more than one stage, securing the part compressed bale temporarily prior to adding additional tyres and completing the compression process.

__NOTE 5__ The advantages of using capping tyres placed flat at the top and bottom of the bale include:

a) The tie wires are less likely to penetrate into the tyre material on the edges of the bales;

b) The resulting bale is of a more rectilinear form.

5.2 Reference bales

Each reference bale shall contain at least 100 tyres selected in accordance with Clause **3**.

Each reference bale shall be formed in a baling machine with a rectilinear cavity measuring 2.0 m (± 0.1 m) in the direction of compression, 1.55 m (± 0.05 m) in width and 0.75 m (± 0.05 m) in depth.

The number of capping tyres to be placed flat adjacent to one another at the top and bottom of the bale in accordance with **5.1** shall be three at the top and three at the bottom of the bale.

Five tie wires shall be used each 3.5 m long including loops.

The compressed bale length prior to fixing of tie wires shall be 1.10 m.

NOTE 1 *The number of tyres within a reference bale will typically vary between about 100 and 115 tyres.*

NOTE 2 *When compressing the bale, typical baling machines are capable of applying forces of the order of 600 kN.*

NOTE 3 *Measurements on 50 bales produced to this specification using two machines gave the following output values:*

- *Length 1.33 m (+ 0.08 m/-0.06 m)*
- *Width 1.55 m (± 0.07 m)*
- *Depth 0.83 m (± 0.04 m)*

A factor influencing the depth of the bales is the mix of tyres used.

NOTE 4 *For some applications bales of sizes different from the reference bale may be more appropriate to the end use but a consistent size of bale should be used for a particular project or application.*

5.3 Reduced length bale

Each reduced length bale shall be formed in a baling machine with a rectilinear cavity measuring 1.55 m (± 0.05 m) in width and 0.75 m (± 0.05 m) in depth.

The number of capping tyres to be placed flat adjacent to one another at the top and bottom of the bale in accordance with **5.1** shall be three at the top and three at the bottom of the bale.

Each reduced length bale shall contain a number of tyres selected in accordance with Clause **3** and appropriate to the selected compressed bale length and achieving the density required by **5.1**.

Five tie wires shall be used.

The length of each tie wire, including loops, shall be of reduced length compared with the length of tie wires used in the production of reference bales.

The reduced length shall be calculated using:

$$l = 3.5 - 2\,(l_{ref} - l)$$

where

l is the length of a reduced length bale and

l_{ref} is the length of a reference bale.

NOTE 1 *The values of both l_{ref} and l are dimensions for the length of a completed bale and not for the compressed length of a bale immediately prior to placement of the tie wires.*

NOTE 2 *If the length of the reduced-length bale, l, which it is desired to use in the reduced-length bale, is known, an estimate of the number of tyres, N, after the final stage of compression prior to fastening the tie wires may be calculated using:*

$$N = \frac{(N_{ref}\,l)}{l_{ref}}$$

where

N_{ref} is the number of tyres in a reference bale, and

l_{ref} is the length of a reference bale.

Or, if the number of tyres, N, which it is desired to use in the reduced-length bale, is known, an estimate of the length of the reduced-length bale, l, after the final stage of compression prior to fastening the tie wires may be calculated using:

$$l = \frac{(l_{ref}\,N)}{N_{ref}}$$

If information on the dimensions and number of tyres used in the manufacture of reference bales with the mix of tyres to be employed in the reduced length bales is available then this should be used in the above equations. If such information is not available then information presented in this specification may be used as a starting point for determining either the length of bale that will be required when a specific number of tyres is used or the number of tyres required to produce a tyre bale of a specific length. Adjustments to the number of tyres (or the length of the bale) can then be made until the required density of bale is achieved.

5.4 Reduced width bales

5.4.1 Full length reduced width bale

Each full length reduced width bale shall contain at least 66 tyres selected in accordance with Clause **3**.

Each bale shall be formed in a baling machine with an equivalent rectilinear cavity measuring 2.0 m (± 0.1 m) in the direction of compression, 1.15 m (± 0.05 m) in width and 0.75 m (± 0.05 m) in depth.

The number of capping tyres to be placed flat adjacent to one another at the top and bottom of the bale in accordance with **5.1** shall be two at the top and two at the bottom of the bale.

Four tie wires shall be used each 3.5 m long including loops.

The compressed bale length prior to fixing of tie wires shall be 1.10 m.

5.4.2 Reduced length reduced width bale

Each reduced length bale shall be formed in a baling machine with a rectilinear cavity measuring 1.15 m (± 0.05 m) in width and 0.75 m (± 0.05 m) in depth.

The number of capping tyres to be placed flat adjacent to one another at the top and bottom of the bale in accordance with **5.1** shall be two at the top and two at the bottom of the bale.

Each reduced length bale shall contain a number of tyres selected in accordance with Clause **3** and appropriate to the selected compressed bale length and achieving the density required by **5.1**.

Four tie wires shall be used.

The length of each tie wire, including loops, shall be of reduced length compared with the length of tie wires used in the production of reference bales.

The reduced length shall be calculated using:

$$l = 3.5 - 2\,(l_{ref} - l)$$

where

l is the length of a reduced length bale and

l_{ref} is the length of a reference bale.

NOTE 1 *The values of both l_{ref} and l are dimensions for the length of a completed bale and not for the compressed length of a bale immediately prior to placement of the tie wires.*

NOTE 2 *The length of tie wires can be estimated using **5.3** including Note 1.*

NOTE 3 *The numbers of tyres required in the bale can be made using the guidance given in the Note 2 to **5.3**, but replacing N_{ref} by the number of tyres in a full length reduced width bale.*

5.5 Increased width bale

5.5.1 Full length increased width bale

Each full length increased width bale shall contain at least 133 tyres selected in accordance with Clause **3**.

Each bale shall be formed in a baling machine with an equivalent rectilinear cavity measuring 2.0 m (± 0.1 m) in the direction of compression, 1.95 m (± 0.05 m) in width and 0.75 m (± 0.05 m) in depth.

The number of capping tyres to be placed flat adjacent to one another at the top and bottom of the bale in accordance with **5.1** shall be four at the top and four at the bottom of the bale.

Six tie wires shall be used each 3.5 m long including loops.

The compressed bale length prior to fixing of tie wires shall be 1.10 m.

5.5.2 Reduced length increased width bale

Each reduced length bale shall be formed in a baling machine with a rectilinear cavity measuring 1.95 m (± 0.05 m) in width and 0.75 m (± 0.05 m) in depth.

The number of capping tyres to be placed flat adjacent to one another at the top and bottom of the bale in accordance with **5.1** shall be four at the top and four at the bottom of the bale.

Each reduced length bale shall contain a number of tyres selected in accordance with Clause **3** and appropriate to the selected compressed bale length and achieving the density required by **5.1**.

Six tie wires shall be used.

The length of each tie wire, including loops, shall be of reduced length compared with the length of tie wires used in the production of reference bales.

The reduced length shall be calculated using:

$$l = 3.5 - 2\,(l_{ref} - l)$$

where

l is the length of a reduced length bale and

l_{ref} is the length of a reference bale.

NOTE 1 *The values of both l_{ref} and l are dimensions for the length of a completed bale and not for the compressed length of a bale immediately prior to placement of the tie wires.*

NOTE 2 *The length of tie wires can be estimated using **5.3** including Note 1.*

NOTE 3 *The numbers of tyres required in the bale can be made using the guidance given in the Note 2 to **5.3**, but replacing N_{ref} by the number of tyres in a full length increased width bale.*

NOTE 4 *Depth of bales dependent on mix of tyre sizes used. Ranges of dimensions given have been based upon extensive measurement of reference bales.*

Table 1 – Likely output dimensions of various bales

Bale type	Length, *l*	Width, *w*	Depth, *d*[1]	Tie wires	
				Number	Length
Reference bale **(REF)**	1.27 – 1.41 m	1.48 – 1.52 m	0.79 – 0.87 m	5	3.5 m
Reduced length bale **(RL)**	0.6 m minimum	1.48 – 1.52 m	0.79 – 0.87 m	5	≈ 2.1 m (for 0.6 m long bale)
Full length reduced width bale **(RW)**	1.27 – 1.41 m	≈ 1.15 m	0.79 – 0.87 m	4	3.5 m
Reduced length reduced width bale **(RL-RW)**	To be specified	≈ 1.15 m	0.79 – 0.87 m	4	≈ 2.1 m (for 0.6 m long bale)
Full length increased width bale **(IW)**	1.27 – 1.41 m	≈ 1.95 m	0.79 – 0.87 m	6	3.5 m
Reduced length increased width bale **(RL-IW)**	To be specified	≈ 1.95 m	0.79 – 0.87 m	6	≈ 2.1 m (for 0.6 m long bale)

5.6 Labelling of bales

A legible, durable and weatherproof label shall be attached securely to each tyre bale immediately after manufacture.

This shall contain the following minimum information:

- The bale reference number;
- The name of the manufacturer;
- The date of manufacture (DD/MM/YY);
- The acronym of the type of bale (see Table 1) with a statement of the length of any reduced length bale;
- The approximate depth of the bale;
- A statement that the bale shall not be lifted by the tie wires;
- A statement that the bale has been manufactured in accordance with this PAS.

NOTE 1 *It is recommended that any information on bale labels be summarized, as appropriate, in any written quotations, supply/delivery notes or invoices.*

NOTE 2 *The labelling system also can be used to ensure proper rotation of stock.*

6 Handling and storage of the bales at the baling facility

Bales shall always be lifted in a manner which avoids damage to the tie wires of the completed bale.

Tyre bales shall never be lifted by the tie wires.

The stacking of tyre bales shall be arranged so as to ensure stability of the stack.

Subsequent layers of bales shall be stacked in a stretcher bond pattern.

Bales shall be organized in such a way as to permit proper rotation of stock.

Bales shall be stored at approved storage locations and subject always to any statutory or licensing restrictions.

If bales need to be stored for more than 12 months, then the producer shall demonstrate the need for the additional storage time on the basis of evidence of orders received and the additional storage time shall be agreed, as necessary, with the regulatory authorities.

NOTE 1 *Wood bolsters under the first layer of bales may be used to lay back the front face of bale stacks as an aid to stability.*

NOTE 2 *A 'loggers'-clam', brick grab or forklift should be used for lifting and handling tyre bales during storage.*

NOTE 3 *The stacking of tyre bales should be organized in such a way as to minimize their exposure of tyres to sunlight and thus the potential further degradation due to UV-exposure.*

7 Transport, storage on site and placement of the bales

Bales shall always be lifted in a manner which avoids damage to the tie wires of the completed bale.

Tyre bales shall never be lifted by the tie wires.

Any stack formed whilst transporting and storing the tyre bales on site shall be stable.

Tyre bales shall be placed within the final construction in an orientation in which, should the tie wires subsequently break, the component tyres in the bales will remain best confined. Tyre bales shall be abutted to one another on completion of placement.

Subsequent layers of bales shall be stacked in a stretcher bond pattern in the longitudinal direction of the course.

Tyre bales shall not be left exposed to ultra-violet light when construction is complete.

Figure 14 – Placing tyre bales using a 'loggers'-clam'

(© Chautauqua County Department of Public Facilities, New York State)

NOTE 1 *Wood bolsters under the first layer of bales may be used to help lay back the front face of bale stacks as an aid to stability.*

NOTE 2 *Experience has shown that a 'loggers'-clam' (Figure 14), brick grab or forklift are effective tools for lifting and handling tyre bales during storage on site. However, when placing bales in their final position in construction works, it is useful to be able to rotate and positively place the bales and, for this purpose, experience shows that a 'loggers'-clam' or brick grab are the most effective tools.*

NOTE 3 *Best confinement of bales will normally be achieved by placing the bales such that the tie wires are parallel to the longer axis of the structure. For example, in the case of a linear structure, such as a road or an embankment, the bales should be placed such that the tie wires are in line with the direction of the chainage. Tight abutting of the bales ensures that the friction between the bales is maximized.*

NOTE 4 *As well as a longitudinal stretcher bond, the form of construction may or may not require a stagger in the bales and/or the joints between the bales in the transverse direction. Examples of both staggered and non-staggered joints between bales in transverse courses are illustrated in Annex D.*

NOTE 5 *Details of uses of bales in construction, including some structure-specific suggestions, are given in Annex D.*

Annex A (normative) Factory production control

A.1 Introduction

This Annex specifies a factory production control system for tyre bales to ensure that they conform to the requirements of this standard.

The performance of the factory production control system shall be assessed according to the principles used in this Annex.

A.2 Organization

A.2.1 Responsibility and authority

The responsibility, authority and the interrelation between all personnel who manage, perform and check work affecting quality shall be defined, including personnel who need organizational freedom and authority to:

a) initiate action to prevent the occurrence of product non-conformity;
b) identify, record and deal with any product quality deviations.

A.2.2 Management representative for factory production control

For every plant producing tyre bales the producer shall appoint a person with appropriate authority to ensure that the requirements given in this Annex are implemented and maintained.

A.2.3 Management review

The factory production control system adopted to satisfy the requirements of this Annex shall be audited and reviewed at appropriate intervals by management to ensure its continuing suitability and effectiveness.

Records of such reviews shall be maintained.

A.3 Control procedures

A.3.1 General

The producer shall establish and maintain a factory production control manual setting out the procedures by which the requirements for factory production control are satisfied.

A.3.2 Document and data control

A procedure concerning the management of documents and data shall be documented in the production control manual covering procedures and responsibilities for approval, issue, distribution and administration of internal and external documentation and data; and the preparation, issue and recording of changes to documentation.

A.3.3 Sub-contract services

If any part of the operation is sub-contracted by the producer a means of control shall be established.

A.4 Management of the production

The factory production control system shall fulfil the following requirements:

a) There shall be procedures to identify and control the materials;
b) There shall be procedures to ensure that bales are put into stock in a controlled manner and the storage locations are identified by bale reference number and date;
c) There shall be procedures to ensure that bales taken from stock have not deteriorated in such a way that their conformity is compromised;
d) Each bale shall be identifiable up to the point of use.

A.5 Inspection and test

A.5.1 General

The producer shall make available all the necessary facilities, equipment and trained personnel to carry out the required inspections and tests.

A.5.2 Equipment

The producer shall be responsible for the control, calibration and maintenance of inspection, measuring and test equipment.

Equipment shall be used in accordance with documented procedures.

Equipment shall be uniquely identified.

Calibration records shall be retained.

A.5.3 Frequency and location of inspection, sampling and tests

The production control document shall describe the frequency and nature of inspections. The frequency of sampling and the tests when required shall be carried out as specified in Table A.1.

NOTE 1 *The requirements for factory production control include visual inspection.*

NOTE 2 Any deviations indicated by these inspections may lead to increased test frequencies.

NOTE 3 When the measured value is close to a specified limit the frequency may need to be increased.

NOTE 4 Under special conditions the test frequencies may be decreased below those given in Table A.1. These conditions could be:

a) Highly automated production equipment.

b) Long-term experience with constancy of special properties.

c) Sources of high conformity.

d) Running a Quality Management System with exceptional measures for surveillance and monitoring of the production process.

The producer shall prepare a schedule of test frequencies taking into account the minimum requirements of Table A.1. All of the measurements described in Table A.1 shall be carried out on all bales sampled.

Reasons for decreasing the test frequencies shall be stated in the factory production control document.

Table A.1 – Minimum test frequencies for general properties

	Property	Clause	Notes/references	Test method	Minimum test frequency
1	Length, width and depth of bale	B.3.1	Dimensions of enclosing cuboid	PAS 108 Annex B	10 bales per 1000 bales produced
2	Mass of bale	B.3.2	Mass of tyres and tie wires comprising the bale	PAS 108 Annex B	10 bales per 1000 bales produced
3	Volume of bale	B.4.1	Volume of enclosing cuboid	PAS 108 Annex B	10 bales per 1000 bales produced
4	Mass density of bale	B.4.2	Mass density related to volume of enclosing cuboid	PAS 108 Annex B	10 bales per 1000 bales produced

A.6 Records

The results of factory production control shall be recorded including sampling locations, dates and times and product tested with any relevant information e.g. weather conditions.

Where the product inspected or tested does not satisfy the requirement laid down in the specification, or if there is an indication that it may not do so, a note shall be made in the records of the steps taken to deal with the situation (e.g. carrying out of a new test and/or measures to correct the production process).

The records required by all the clauses of this Annex shall be included.

The records shall be kept for at least the statutory period.

NOTE "Statutory period" is the period of time records are required to be kept in accordance with Regulations applying at the place of production.

A.7 Control of non-conforming product

Following an inspection or test which indicates that a product does not conform the affected material shall be:

a) reprocessed; or

b diverted to another application for which it is suitable; or

c) rejected and marked as non-conforming.

All cases of non-conformity shall be recorded by the producer, investigated and if necessary corrective action shall be taken.

NOTE Corrective actions could include:

a) investigation of the cause of non-conformity including an examination of the testing procedure and making any necessary adjustments;

b) analysis of processes, operations, quality records, service reports and customer complaints to detect and eliminate potential causes of non-conformity;

c) initiating preventive actions to deal with problems to a level corresponding to the risks encountered;

d) applying controls to ensure that effective corrective actions are taken;

e) implementing and recording changes in procedures resulting from corrective action.

A.8 Handling and storage in production areas

The producer shall make the necessary arrangements to maintain the quality of the product during handling and storage.

A.9 Transport

The producer's factory production control system shall identify the extent of his responsibility in relation to transport, delivery and storage on site.

A.10 Training of personnel

A.10.1 General

The producer shall establish and maintain procedures for the training of all personnel involved in the factory production system.

Records of training shall be maintained.

Operators shall receive practical training in the manufacture of tyre bales under the direct supervision of competent persons before being allowed to manufacture tyre bales for use in construction.

A.10.2 Competent person

A competent person is one who can demonstrate that they have sufficient professional knowledge or technical training, ability, actual experience and authority to enable them to:

a) carry out their assigned duties at the level of responsibility allocated to them;

b) understand any potential hazards to the work (or equipment) under consideration;

c) detect any technical defects or omissions in that work (or equipment), recognize any implications for health and safety, where appropriate, caused by those defects or omissions, and be able to specify a remedial action to mitigate those implications.

NOTE The level of responsibility within an organization will dictate the degree of competence required, e.g. more will be expected of managers/supervisors than a shop floor worker.

Annex B (normative)
The measurement of tyre bale properties

B.1 Principle

The nominal mass density (mass density of the enclosing cuboid) of individual tyre bales shall be determined at the frequency prescribed in Annex **A**.

The principal dimensions of the enclosing cuboid (see Figure 1 in the main text of the PAS): length (l), width (w) and depth (d) shall be determined using straight laths and a tape measure. The mass shall be determined and the mass density computed by dividing the mass by the volume of the enclosed cuboid.

B.2 Apparatus

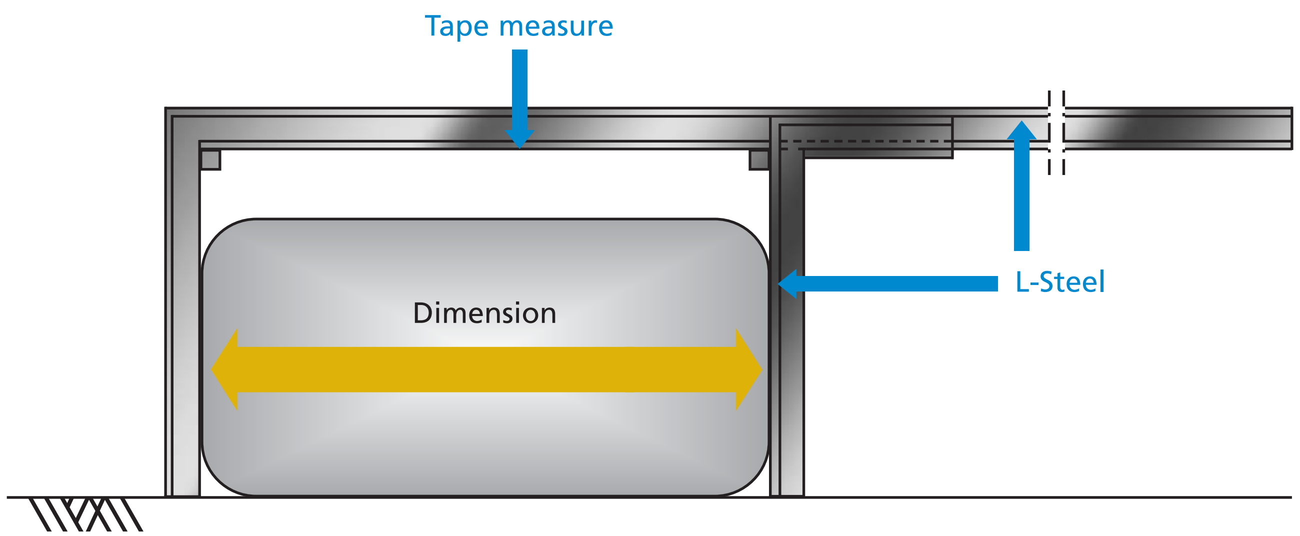
B.2.1 Two straight laths, of length greater than the largest dimension of a tyre bale (l = 1.55 m for a reference bale) to be tested.

B.2.2 Tape measure, readable to ± 25 mm of the largest dimension of the tyre bale to be measured.

B.2.3 Calliper as shown in Figure B.1.

B.2.4 Weighing equipment, accurate to ± 2 % of the mass to be measured (nominally ± 15 kg for a reference bale).

Figure B.1 – Calliper



B.3 Procedure

B.3.1 Dimensions

Position the bale such that its two extremities are between two straight laths positioned parallel to each other, at right angles to the dimension to be measured and coincident with the centreline of the face of the bale being measured. Measure each of the three principle dimensions (l, w and d) at right angles to the laths using the tape measure to ± 25 mm.

If this accuracy cannot be met using the above procedure the calliper (Figure B.1) shall be used.

B.3.2 Mass

The mass of each bale for which the dimensions are measured shall be measured using the weighing equipment.

If the bale needs to be moved or turned during weighing this shall be achieved using suitable lifting plant. The bale shall not be moved by means of manual handling or by the tie wires.

B.4 Calculation and Expression of Results

B.4.1 Volume

For each tyre bale the volume of the bale shall be calculated from the following equation:

$$V = l \times w \times d$$

where

l is the length of the tyre bale in metres;

w is the width of the tyre bale in metres;

d is the depth of the tyre bale in metres;

V is the volume of the tyre bale in m^3.

B.4.2 Nominal Mass Density

For each tyre bale the nominal mass density shall be calculated from the following equation:

$$\rho = \frac{M}{V}$$

where

M is the mass of the tyre bale in kilograms;

ρ is the nominal mass density of the tyre bale in kg/m^3.

V is the volume of the enclosing cuboid containing the tyre bale in m^3.

The dimensions shall be recorded to the nearest 0.01 m, the mass to the nearest 10 kg, and the density to the nearest 10 kg/m^3.

B.5 Test Report

B.5.1 Required data

The test report shall include the following information:

- A statement that the bales have been manufactured and tested in accordance with this PAS;
- Identity and address of the tyre bale manufacturer;
- Identity of the body carrying out the testing;

The test report shall also include the following data:

- The bale reference number;
- The date of manufacture;
- The type of bale (e.g. reference bale, reduced-length bale, reduced width bale);
- The dimensions, volume and mass density as described in **B.4**;
- The date of test.

Annex C (informative)
Engineering properties and behaviours of tyre bales associated with their use in construction

C.1 Summary of Engineering Properties

C.1.1 Introduction

This section provides an overview of engineering properties. More detailed descriptions of the significance of the engineering properties together with an explanation of how tests might be carried out to determine these properties are given in **C.2**. Details of behaviours and environmental risk are given in **C.3**.

C.1.2 Engineering properties

The values in Tables C.1 and C.2 are based on a combination of a limited number of laboratory and field tests, but can be taken to be indicative of the order of magnitude of the relevant property.

Table C.1 – Engineering properties of reference tyre bales

Property	Value(s)
Length (of reference bale)	1.33 m (+ 0.08 m/– 0.06 m)
Width (of reference bale)	1.55 m (± 0.07 m)
Depth (of reference bale)	0.83 m (± 0.04 m)
Volume (of enclosing cuboid of reference bale)	1.70 m^3 (+ 0.24 m^3/– 0.15 m^3)
Mass (of reference bale)	810 kg (± 35 kg)

Table C.2 – Engineering properties of all PAS 108 tyre bales

Property	Value(s)	Comments
Nominal mass density	470 kg/m^3 (± 50 kg/m^3)	Mass density of the cuboid enclosing the tyre bale (see Annex B).
True mass density	500 kg/m^3 (± 70 kg/m^3)	Mass density of bale only (see Clause C.2.3)
Porosity	62 % (± 5 %)	
Shear strength: angle of inter-bale friction, ϕ'	35° to 36°	Tests performed on dry bales. Cohesion is small and can be ignored in design.
Stiffness (expressed as Young's Modulus), *M*	800 MPa to 1,000 MPa	Values increase within range with increasing degree of confinement. Values based on a preliminary interpretation of USA data for arrangements of two and three bales with no joint filling.
Total Creep (35 months)	Up to 1.1 %	Based on measurements of a bale stack in a beach at Pevensey. Measurements indicate creep process now substantially slower and long term creep not expected to exceed 1.5 %.
Permeability through depth (see Figure 1)	0.1 m/s to 0.2 m/s	
Permeability through length (see Figure 1)	0.02 m/s to 0.04 m/s	

C.2 Engineering Properties

C.2.1 General

In this clause more detailed descriptions are given of the significance of the engineering properties summarized in the previous clause, together with an explanation of how tests might be carried out to determine these properties. Each property is dealt with in turn, first explaining its significance and then describing how tests could be carried out to determine that property.

In the event that a manufacturer wishes to promote the widespread use of bales other than reference bales such testing will be of benefit in confirming any variations in their properties. Similarly if a manufacturer wishes to promote a type of bale different to the bale types/sizes described in the PAS (manufacturing process, shape, density, etc) the annex will give guidance on obtaining relevant data for engineering design.

C.2.2 Dimensions, volume, mass, density and porosity

Apart from the practical need to know basic dimensional and mass properties when designing and building structures, density and porosity are also important when assessing the stability of structures for example against sliding and overturning and the volumetric ability of a tyre stack to store water.

The measurement of enclosing cuboid dimensions and tyre bale mass and the calculation of enclosing cuboid volume and density are described in Annex **B**. Once the mass density of the enclosing cuboid, ρ_c, is known, it is possible to infer the porosity, P, of this cuboid by using the known density of tyre material, ρ_{Ty}:

$$P = (1000 - \rho_c) / \rho_{Ty}$$

This porosity can be used for assessing the volume of water that can be stored within a bale stack without granular fill. (For the purposes of this calculation, ρ_{Ty} can be taken as 1,300 ± 40 kg/m^3.)

Should fill be included within the tyre bale stack then it is also important to know the difference between the volume of the tyre bale itself and its enclosing cuboid (estimated as being between 4 % and 8 % for reference bales). This is important both for estimating the amount of fill required and the resultant overall mass density and porosity of the resultant bale/fill mix (see Box D.1). A method for measuring these properties when determining the porosity of the bales is given in **C.2.3**.

C.2.3 True volume, porosity and density of bale mass and density of tyre material

C.2.3.1 Principle

The challenge when measuring the true volume and hence porosity and density of a tyre bale is its uneven external shape. The method therefore makes use of Archimedes' principle, namely that when a body is wholly or partially immersed in a fluid it experiences an upthrust force equal to the mass of liquid displaced. To exclude water from the bales, it is necessary to wrap the bales using flexible plastic wrapping before submerging the bale and measuring its submerged weight.

Subsequently the wrapping is removed and the volume of voids in the bale is determined with the assistance of a further weighing of the unsealed bale in water.

NOTE *A small amount of air will remain trapped in the voids of the bale. Thus, the porosity determined by this test is likely to be a slight underestimate of the true value. However, the difference in porosity is not considered to be significant for most engineering purposes.*

C.2.3.2 Apparatus

C.2.3.2.1 Flexible plastic wrapping and means to make this watertight.

C.2.3.2.2 Lifting equipment, including appropriate straps/shackles, able to lift bale in and out of water without using the tie wires.

C.2.3.2.3 Weighing device (dynamometer, load cell, etc) connected to lifting equipment able to weigh bales to an accuracy of ± 0.5%.

C.2.3.2.4 Tray of steel ingots of total mass at least equivalent to that of the bale, each individual ingot weighing a known mass (e.g. 10 kg).

C.2.3.2.5 Tank of fresh water of sufficient dimensions to hold tyre bale and water displaced by it.

C.2.3.3. Procedure

Weigh the tyre bale in air.

Seal the tyre bale in plastic wrapping and weigh bale again in air.

Fill the tray with ingots to a total weight (including the tray) just smaller than that of the wrapped tyre bale.

Place the tray of steel ingots on top of the tyre bale and measure combined weight of the tyre bale and the tray of ingots.

Lift the tyre bale into tank of water using the lifting device with load cell or dynamometer. Still holding the tyre bale with the lifting device, add further steel ingots until the bale is just submerged, but the tray and weights remain exposed to air. Record the weight of the submerged bale plus tray and ingots.

Lift the bale from the tank and remove the tray of steel weights and plastic wrapping.

Lower the bale back into the tank of water until it is just fully immersed but still held by the lifting device. Note the weight at regular time intervals until measurable changes have ceased. Record the stable weight of the submerged unwrapped tyre bale.

NOTE *A variety of methods may be used to seal the tyre bale in flexible plastic wrapping. These include the use of machines designed to wrap agricultural products, and heat or vacuum sealed plastic wrappers.*

C.2.3.4 Calculation and expression of results

Calculate mass of water displaced by wrapped tyre bale, M_{WDW}, as equivalent to final mass of tray plus ingots, M_{TF} required to submerge wrapped tyre bale as follows:

$$M_{WDW} = M_{TF} = (M_{TBW} + M_{TI}) + M_{AI} - M_{TBW}$$

where

M_{TBW} is the measured mass of wrapped tyre bale

M_{TI} is the measured mass of initial tray of ingots

M_{AI} is the measured mass of additional ingots required to finally submerge bale.

Calculate volume of tyre bale, V_{TB}, as equivalent to the volume of water displaced by the wrapped tyre bale from:

$$V_{TB} = M_{WDW} / \rho_W$$

where

ρ_W is the density of water in tank (assume 1,000 kg/m^3 for fresh water at 20 °C).

Calculate density of the tyre bale from:

$$\rho_{TB} = M_{TB} / V_{TB}$$

where

M_{TB} is the measured mass of unwrapped tyre bale.

Calculate the mass of water displaced by unwrapped tyre bale, M_{WD}, from:

$$M_{WD} = M_{TB} - M_{TBS}$$

where

M_{TBS} is the measured mass of submerged unwrapped tyre bale.F

Calculate volume of solid tyre material in bale, V_{TM}, equivalent to the volume of water displaced from:

$$V_{TM} = M_{WD} / \rho_W$$

where

ρ_W is the density of water in tank (1,000 kg/m³ for fresh water).

Calculate the porosity of the tyre bale from

$$P = (1 - V_{TM}) / V_{TB}$$

Calculate the average density of the tyre bale material, ρ_{TM}, from:

$$P_{TM} = M_{TB} / V_{TM}$$

where

M_{TB} is the mass of the unwrapped tyre bale.

C.2.4 Permeability

C.2.4.1 Significance of engineering property

Permeability is a key parameter when bales are being used with a drainage function, as it determines the rate at which water is able to pass through and escape from the layer. It is also significant in regard to stability under hydraulic loading as it will determine the way in which pore water pressures within the bale mass are able to dissipate. For example, reference bales do not float in steady state conditions, because they are porous and the density of tyre material is greater than that of water. However, under wave action, the bales appear to 'float' because their permeability is too low for the water to enter a significant proportion of the pore space.

C.2.4.2 Principle

Darcy's law is used to determine the permeability of tyre bales. In its simplest form for steady flow through a media, it may be written as:

$$Q = k.A\,(\Delta h / L)$$

where

Q is the discharge (m³/s),

k is the permeability coefficient (m/s),

A is the flow cross sectional area (m²),

Δh is the head difference over flow length (m), and

L is the length of flow path (m).

C.2.4.3 Apparatus

C.2.4.3.1 A hydraulic recirculating discharge flume of width greater than the width of the tyre bale being tested (say not less than 2 m). The flume shall be able to sustain a water depth of about 0.7 m and a measurable steady state water flow discharge of not less than 0.10 m³/s. The flume shall have a means of controlling the downstream water level to allow slow filling of the flume and tyre bale at the start of a test (see C.2.4.4). This is best achieved by a tail gate that can be adjusted to produce free or controlled flow. If free outflow conditions are required, a false floor may need to be installed on which the tyre bale will sit. The flow discharge shall be measured using a flow metering device of high accuracy (typically ± 2 %) such as an electromagnetic flow meter or a calibrated measuring weir.

C.2.4.3.2 Accurately levelled, mounted point gauges or other devices for measurement of water depths in the flume to a repeatable accuracy of ± 1.0 mm.

C.2.4.3.3 Impermeable flume inserts of dimensions able to make up the difference between the width of the bale and the width of the flume.

C.2.4.3.4 Foaming or other waterproof sealant to fill uneven gaps between the sides of the bale and the flume inserts (see Figure C.1)

Figure C.1 – Bale in flume for permeability testing showing (timber) flume inserts and foaming sealant between bale and flume/insert walls

C.2.4.4 Procedure

Measure (using the method of Annex **B**) and report all dimensions of the tyre bale. Record the orientation of the bale in the flume, including the bale dimension in the direction in which flow is to take place and the height of the bale from the (false) floor of the flume.

Install flume inserts.

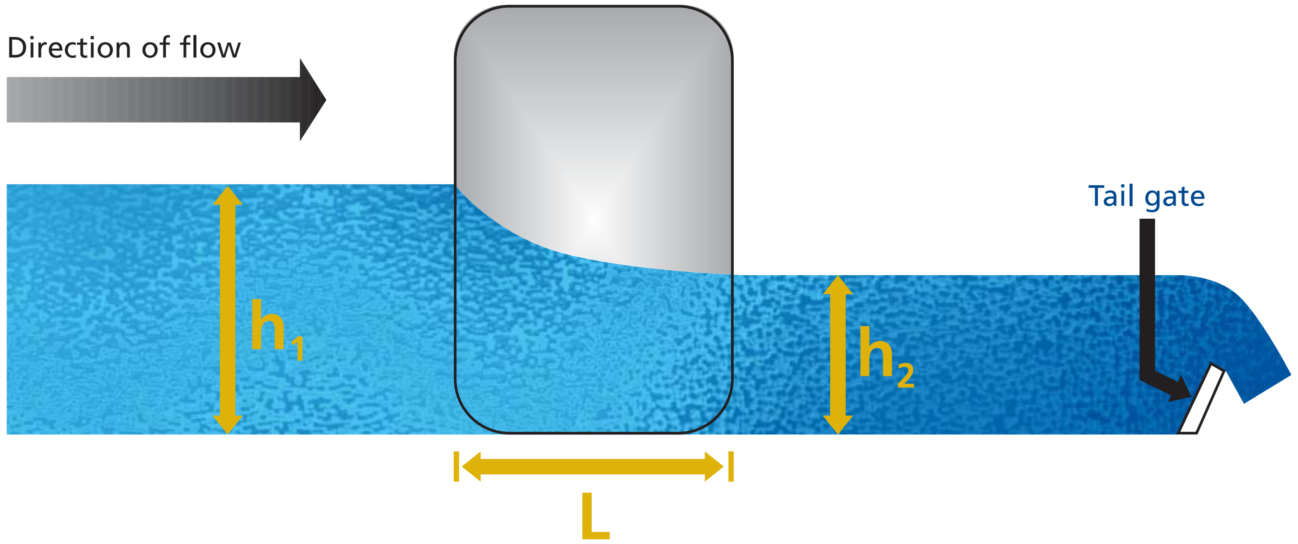
Install bale in flume and secure on downstream side (e.g. with stanchions and bolts).

Using foaming waterproof sealant, seal between bale and sides in contact with flume or insert wall. Also seal bottom edge in contact with floor of flume.

Making use of the tail gate (or other device) fill the downstream end of the flume to allow gradual filling through the tyre bale.

Slowly increase flow though flume increasing the upstream water depth until it appears to be constant, but without overtopping the tyre bale (Figure C.2).

Figure C.2 – Flume set up for bale permeability testing



For each flow rate, take repeated upstream water level measurements over a 15 to 20 minute time period until steady state conditions are obtained. Then take simultaneous measurements of upstream (h_1) and downstream (h_2) water depths and the discharge (Q) over the weir over a further 10 minute time period and determine average values.

C.2.4.5 Calculation and expression of results

Record the length, L, of the flow pathway as the bale dimension in the direction in which flow is to take place.

Calculate the flow cross sectional area, A, through the bale as the product of the other two dimensions of the bale (up to the existing water level).

Calculate the permeability coefficient, k (in m/s), from:

$$k = (Q / A) \,.\, \{L / (h_1 - h_2)\}$$

where

Q is the discharge (m³/s)

A is the flow cross sectional area (m²),

L is the length of flow path (m),

h_1 is the upstream water depth (m), and

h_2 is the upstream water depth (m).

C.2.5 Shear strength

C.2.5.1 Significance of engineering property

One of the key determinants of the stability of a structure is the shear strength of the material(s) from which it is formed. In the case of porous materials two parameters are often used to define a failure line which, at its simplest, is drawn in the plane of the normal and shear stresses. The parameters comprise a fixed element related to cohesion and a, further, frictional element dependent upon the normal stress to which the material is subjected. The parameters are different for drained and undrained conditions – in the case of tyre bales it is highly likely that, subject to competent engineering design and construction procedures being followed, drained conditions will occur. The two parameters that define the drained shear strength are c' and ϕ'. These parameters are respectively the intercept and slope angle of the failure line in the plane of the normal and shear stresses.

C.2.5.2 Principle

The frictional constant, μ (= tan ϕ'), may be estimated from the horizontal force required to move one bale over another divided by the normal force exerted by the mass of the upper bale on the lower bale. For health and safety reasons and to ensure that the contact area is kept constant, the test involves moving the upper bale over two lower bales. Thus three tyre bales of a similar type are required for this test.

Previous investigations have indicated that the value of c' is so small that it should be discounted for design purposes in design estimates and so the test described below does not report the c' value.

Tests are carried out in dry conditions. In real conditions it is unlikely that water, other than at pressure, will substantially affect the measured values of ϕ'.

C.2.5.3 Apparatus

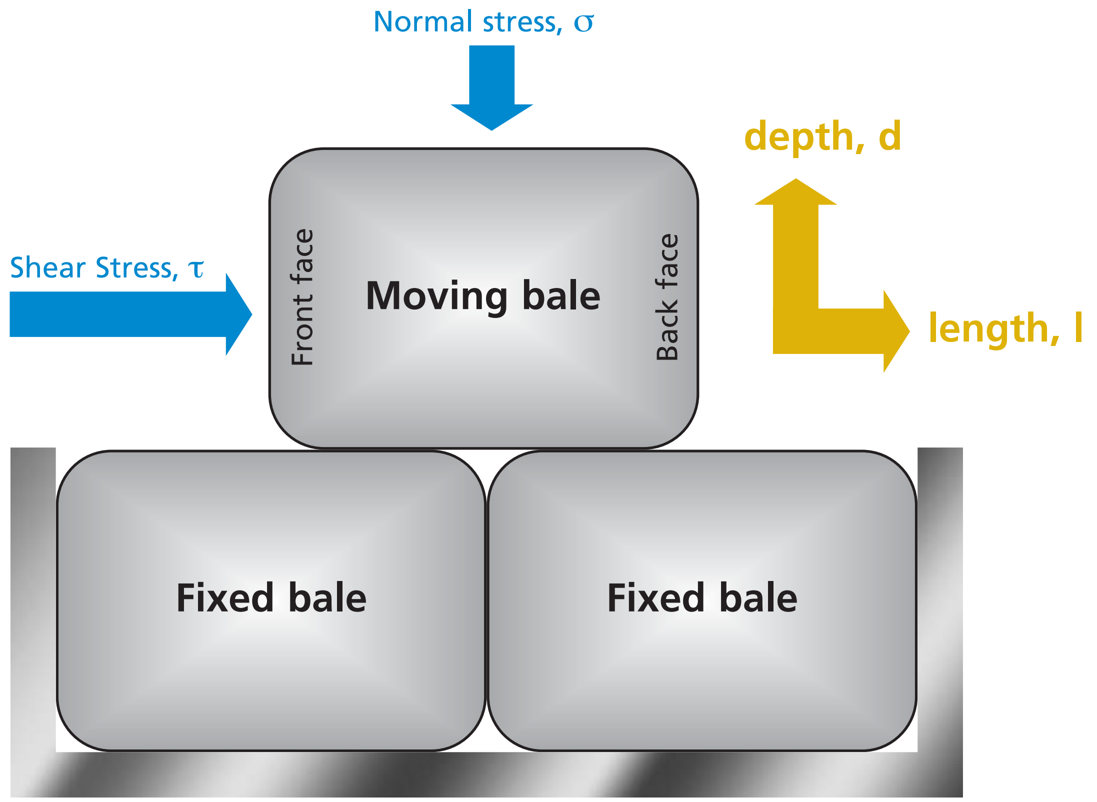
C.2.5.3.1 A flat unyielding floor and a means of restraining the lower two bales against a horizontal force not less than the weight of one bale (see Figure C.3)

C.2.5.3.2 Appropriate mechanical equipment able to apply vertical (normal) and horizontal (shear) forces to the upper bale. Concrete or other hard material may need to be added to some of the faces of the bales to ensure that the applied loads are distributed evenly over the whole of the relevant face of the relevant bales.

C.2.5.3.3 Load cell devices and appropriate recorders for simultaneously measuring the forces applied to the upper bale by the mechanical equipment.

C.2.5.3.4 Devices for measuring the horizontal displacement of the upper bale at both the face at which the compressive pushing force is applied and at the opposite face. These devices must be able to operate simultaneously with the force recorders.

Figure C.3 – Layout for shear tests



C.2.5.4 Procedure

Weigh the upper bale according to Annex **B**.

Install the three bales in the equipment. Measure the contact area between the upper and lower bales. This may be simplified to the product of the length and width of the upper bale as measured in accordance with Annex **B**.

Apply a fixed normal force, and then apply a gradually increasing horizontal force. Measure displacements at the front and back faces of the upper (or moving) bale. Clearly the displacement at the back face indicates bale displacement and that at the front face indicates the sum of bale displacement and any compression of the bale that may occur.

Identify the point of shear failure. This is when the first slippage of the upper bale over the lower bales occurred. Prior to this point the displacements at the two faces will be unequal, indicating that compression of the bale was indeed occurring. After failure the additional displacements will became more or less equal, indicating limited further compression. Note the horizontal force applied to the upper bale at the point of shear failure.

Change the applied normal force and repeat the above procedure.

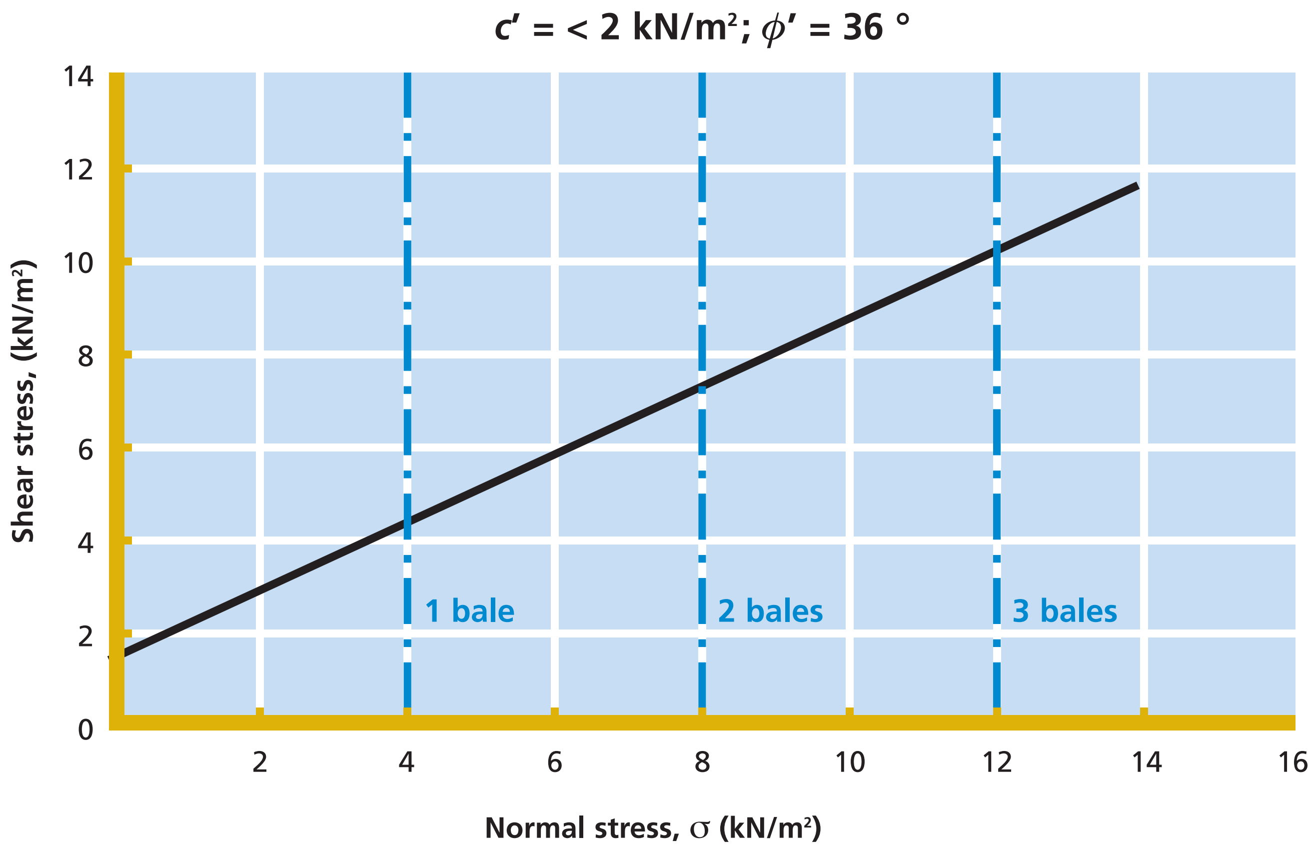
C.2.5.5 Calculation and expression of results

Prepare a table of horizontal stress recorded at the point of shear failure against the total normal force arising at the interface between upper and lower bales. Note that this total normal force is the addition of the compressive force applied to the top of the upper bale plus the weight of the upper bale and any concrete or other facing material applied to its surfaces.

Convert the forces into stresses by dividing these values by the contact area between upper and lower bales.

Plot the results on a graph of normal force (horizontal axis) against shear force (vertical axis). The output will look similar to that in Figure C.4. Determine and report the gradient of the line, μ, and the intercept, c'. Calculate and report the internal angle of friction at the shear interface, $\phi' = \tan^{-1}(\mu)$.

Figure C.4 – Typical shear test results based on data from the USA. Lines representing the normal stress imposed by the self weight of 1, 2 and 3 bales are shown



C.2.6 Stiffness (stress-strain response)

C.2.6.1 Significance of engineering property

The stiffness or stress-strain response of the tyre bales is important because it determines the way the structures, of which the bales form part, deform under loading, including both self weight and live loads. As such it is normally most important when assessing serviceability limit state conditions.

C.2.6.2 Principle

The stiffness of tyre bales, E (MN/m^2), describes the extent to which the bales resist compression under load and is effectively the gradient of the stress/deformation curve.

Stiffness tests should ideally be in confined conditions representing those existing in most construction works. However, full confinement is difficult to achieve in the laboratory, and simple unconfined tests are clearly much more straightforward, and will (conservatively) underestimate the stiffness. An analysis of work carried out in the USA suggests that the underestimate is only of the order of 5 % to 15 % and should not be critical for most engineering applications.

The number of bales to be stacked and compressed is clearly a balance between maximising deflection in order to minimise errors in measuring the compressive strain and minimising the effects of lack of confinement. Experience suggests that two bales stacked vertically is the best compromise.

C.2.6.3 Apparatus

C.2.6.3.1 A flat unyielding floor.

C.2.6.3.2 Appropriate mechanical equipment able to apply vertical (normal) forces to the upper bale up to a maximum of between 50 kN and 100 kN. Concrete or other hard material may need to be added to some of the faces of the bales to ensure that the applied loads are distributed evenly over the whole of the relevant face of the relevant bale.

C.2.6.3.3 Load cell device and deflection recorders for simultaneously measuring the force applied to the upper bale by the mechanical equipment and the deflection of the top of the upper bale.

C.2.6.4 Procedure

Measure the contact area between lower bale and the floor. This may be simplified to the product of the length and width of the upper bale as measured in accordance with Annex **B**.

Place the two tyre bales on top of one another on the floor.

Measure the height of the two bale stack following the principles in Annex **B**.

Apply increasing vertical forces to the stack of bales up to the capacity of the mechanical equipment.

Measure and record forces and displacements simultaneously.

NOTE *Failure of the tyre bale is unlikely in this test.*

C.2.6.5 Calculation and expression of results

Convert the applied forces to stresses by dividing by the area of contact of the bale with the floor.

Convert the deflections to strains, by dividing by the deflections by the height of the two bale stack.

Plot the stresses against the strains and determine the gradient of the resulting line. Report the gradient as the tyre bale stiffness.

C.2.7 Creep

Creep response of a material or structure describes its strain under constant stress and environmental conditions. In the context of tyre bales such tests will be carried out in compression, rather than in tension as described in many textbooks, and as such failure of the element under test is unlikely to be experienced. Creep tests must almost always be carried out over a long period of time. Whilst the strain immediately following the application of stress may be significant, continued observation yields a very slow decline in the rate of strain to zero over a period of days, weeks, months or even years depending upon the material.

Such tests may be carried out in either the laboratory or in the field. The use of dead weights for the application of stress is usually preferred as variable load apparatus are seldom stable over the periods under consideration.

The time period of the test also has bearing on where the test will be undertaken. Only rarely is it practical to conduct such tests in advance of construction, nor is it often affordable to tie-up expensive laboratory space for such long time periods. Accordingly such tests are most often carried out in the field and upon specific structural arrangements. In such circumstances the tests must be seen as confirming the behaviour within expected limits. It is also important to note that creep tests conducted in the field will not experience constant environmental conditions, although for buried elements the all important temperature may well vary less than might at first be thought.

Field tests conducted at Pevensey Beach indicate that for a 3.71 m deep buried bale mass the creep strains after 35 months were 0.7 % of filled bales and 1.1 % for wrapped (but not filled) bales. These figures are not expected to increase beyond 1.1 % and 1.5 % respectively over a period of more than 10 years.

C.3 Behaviours and environmental risk

C.3.1 General assessment of environmental risk from using tyre bales

Data amassed over more than 30 years concerning the potential impacts of used tyre materials on human health and the environment indicates that they are neither hazardous nor dangerous. They do not appear on any EU or Basel Convention list of hazardous materials. It can be concluded that used tyres and related materials do not pose a threat to the environment or to human health so long as normal precautions are followed for treatment, processing, storage and use.

This clause summarizes the issues in connection with the use of tyre bales in regard to:

- The risk of fire;
- The potential leaching of chemicals and compounds into local water courses and potable supplies;
- Human health and safety issues.

C.3.2 Resistance to fire

The spontaneous combustion of whole tyres is unknown although calculations indicate that theoretically it can occur if their temperature exceeds about 180 °C. The risk of spontaneous combustion is therefore low for typical construction works.

The main risk of fire arises from arson, either as whole or semi-processed tyres.[4] However, igniting bales deliberately is difficult and only possible whilst bales are being stored prior to being buried in construction works; appropriate safety and security measures will minimize this risk.

4) Environment Agency licensed storage sites are required to follow the Home Office guidance on fire safety for tyre sites, 1995.

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Research carried out at BRE Fire and Risk Sciences Division indicated that ignition of tyre bales was much more difficult than for granular tyre product and that burning rates were much slower than for loose tyre casings or granular product. The evidence suggests that tyre bales pose the lowest fire risk of all tyre products.

Further, for a fire to propagate within a mass of tyre bales after ignition (either spontaneous or deliberate) a temperature of at least 350 °C must be reached and maintained.

There are no known explosive hazards associated with any tyre material.

The risk of tyre fires started by arson are significantly diminished with the proper consideration and application of security provisions.

C.3.3 Chemical leaching

Laboratory and field measurements (to date) on leachates indicate that levels of all regulated metals and organics fall well below current UK regulatory limits.

The principal leachates that might be of concern from tyres are metals and metallic compounds and benzothiazole and its derivatives.

Of a range of potential metallic leachates (chromium, lead, nickel, copper, cadmium, and zinc) zinc has been identified as the most significant, totalling 10 mg/tyre after three months. The reason for this seemingly low leachate concentration (the total zinc content is in the region of 200 g/tyre) is that the chemicals are only leaching from the outer 2 mm of the tyre previously affected by ultra-violet.

Test results indicate that tyres do not leach volatile organic compounds. Research into long term safety indicates that most of the compounds detected in water samples are at, or near lower detection limits at only trace levels: 10 to 100 times less than regulatory limits for drinking water. They should not, therefore, pose a threat to health or the environment.

The pH level has been shown in field and laboratory tests to affect leaching. Organic materials may leach more freely under neutral conditions while metals leach more freely under acidic conditions. In proper applications though, used tyres are not considered a soil contaminant as the leached amount of Poly-Aromatic Hydrocarbons (PAHs) and metals under laboratory conditions is negligible.

PAHs have not been produced in leachate at significant concentrations when tyres are placed below the water table, and appear to be even less of a problem when tyres are placed above the water table.

Normal pH in soil will generally limit the mobilisation of zinc. However, the use of tyres in aquatic applications may permit leaching of chemicals. However, it is unlikely that the pollution load from a tyre-based structure will have any significant effect on the environment; leachate levels are low in comparison with leachate in rainwater run-off from roads, which has been received in watercourses for many years without adverse impact.

Leachate laboratory and field studies indicate that for all regulated metals and organics the results for used tyres are well below regulatory levels. Substances which could potentially leach from post-consumer tyre materials are already present at low levels in groundwater in developed areas. Studies suggest that leachate levels for the majority of determinants fall below acceptable regulatory limits and have negligible impacts on the general quality of water in close proximity to tyres. Benzothiazole and its derivatives have to be present in very high concentrations (> 1,000 μg/L) to be toxic. From the evidence, one could conclude that in an open aquatic system (relevant to the natural environment around most storage or construction works), the flushing rate will be high and benzothiazole toxicity would not be a problem.

Box C.1 – Construction projects involving tyres or tyre bales with data on effects of tyre leachates on receptors

In July 1998 tyre modules and concrete control modules were deployed alongside an existing cement stabilized coal ash reef study site in 12 m of water off the South Coast of England near Poole in Dorset. Five hundred scrap tyres were used in various configurations. Organisms sampled from both the concrete units and the tyres were routinely analysed for heavy metals and organic compounds. No evidence of significant uptake of zinc was detected. Benzothiazoles or PAHs were not detected in the reef epibiota. The lack of effect on the development of the artificial reef organisms can be explained by the limited release of leachates from the tyres. Tyres in the stable pH conditions of seawater and away from the deleterious effects of UV in sunlight, are very stable and leaching is confined to a 2 mm surface layer. This leaching decreases exponentially with a time scale of days. A review of toxicity studies shows decreasing effect with time of immersion. In a coastal environment, leachates are quickly dispersed by tidal currents. Tyres recovered from a World War II wreck off Scotland after 42 years immersion were found to be in excellent physical condition.

In 1997 a 200 m wall of lorry tyres was built along the shore of Copperas Wood Farm, Wrabness in a north Essex estuary to stop erosion of the clay cliffs. This was formed of stacks of tyres four high and two deep, tied together with polypropylene rope and filled with stone and soil. Seaweed *(Fucus vesiculosus)* was sampled from the tyre wall along with control specimens growing on stones and concrete blocks 50m further along the beach. No difference in levels of zinc were found between the two populations.

In November 2002, some 350 tyre bales (each containing 100 car tyres compressed to form a block 150 by 125 by 75 cm) were placed in a beach at Pevensey Bay in the South East of England and surrounded by a number of sampling wells to monitor water quality in the shingle. Water inundation is restricted to tide induced percolation through the beach. Whilst the base of the tyres are at the level of mean neap tide high water, the limited permeability of the beach material only allows sea water to reach the base of the tyre bales during the higher spring tides. Detailed monitoring of this trial demonstrated that levels of zinc leachates in beach interstitial water were below EQS levels and declined with time. It was possible to model the levels of zinc observed within the tyre bales. In addition, no evidence of cadmium contamination was found even within the tyre bales.

Between October 2003 and May 2004 some 10,000 tyre bales were used in almost 2 km of flood defence embankment on the River Witham in Lincolnshire. Monitoring has been carried out since construction (2004) and to date there have been no unexpected leachate effects on the adjoining water bodies.

C.3.4 Durability

Tyres degrade if exposed to ultra-violet light and the binding wires corrode if the galvanising is breached. However, adoption of good practice as set out in this PAS will minimize any adverse impact on engineering performance.

C.3.5 Human health and safety

There are no permanent effects from physical contact with whole tyres or tyre bales. There are no known health effects due to short term exposure to the material. Prolonged dermal contact can create skin irritation, sensitisation or disorders with repeated exposure. The material contains untreated naphthenic or aromatic oils, which are classified as carcinogenic and could be released from the surface through skin contact. Prolonged contact has caused skin cancer in studies with animals. Normal protective wear (steel reinforced boots, eye, ear and head protection, protective gloves and dust masks) together with long sleeves and trousers has proven sufficient against any potential irritations from the handling of tyres and tyre based rubber materials, should they arise.

When subjected to heat potentially carcinogenic materials (e.g. nitrosamines), carbon oxides (CO, CO_2), acrid fumes, and flammable hydrocarbons may be liberated due to thermal decomposition/combustion. Precautions against fire will minimize this risk.

The most enduring known risks arising from tyres in the workplace are from manual handling operations leading to strains and sprains. There is an added risk of injury that pertains particularly to tyre bales during storage and/or loading and unloading; tyre bales weigh around one tonne and there is a risk of injury to staff if not handled with the correct machinery or stacked appropriately.

Annex D (informative)
Applications of tyre bales in construction

Applications of tyre bales in construction are based upon wide experience of such works and relate to reference bales. Some applications have been developed and used more extensively than others. There is little experience of the use of reduced length or varied width bales.

Tyre bales are a relatively inert, durable, free draining, low density construction material. Their application should adopt accepted engineering design and construction principles.

This Annex first deals with some generally applicable issues (see D.1) and then moves on to highlight some example applications which make good use of tyre bale properties (see D.2 to D.7).

D.1 General construction issues

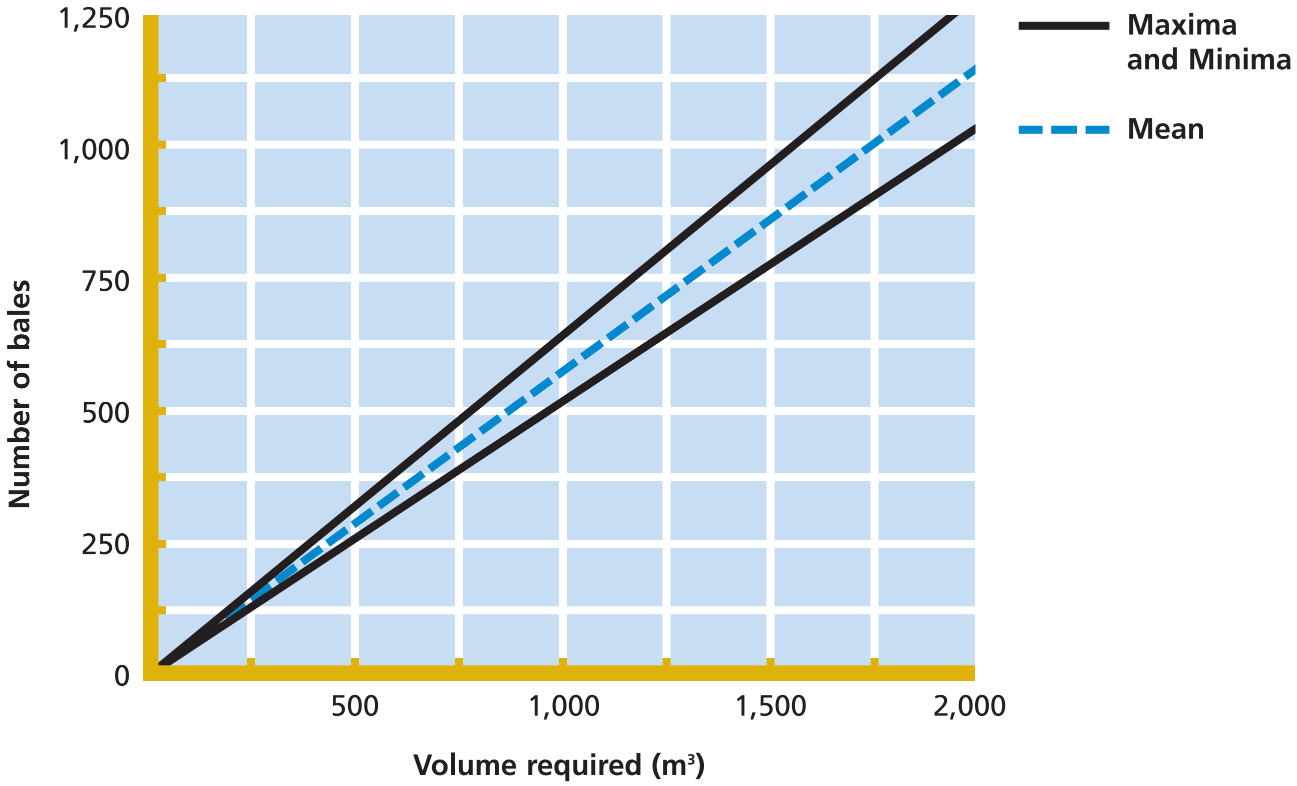
D.1.1 Supply and production

The availability and costs of bales all need to be considered prior to making a decision to use these materials in construction. This is not just a practical decision but is also important for assessing the extent to which the proximity principle (waste materials should be reused, recycled or disposed as close as possible to their point of arising) can be maintained. Alternatively, transport of the bales to site should endeavour to be carbon neutral.

Availability. Figure D.1 may be used to assess the number of bales required for the required volume. Figure D.2 may then be used to assess the equivalent number of tyres likely to be utilised in their manufacture. Maxima and minima are given based upon the variation in tyre bale sizes for the number of bales required and on the number of tyres in each bale.

Figure D.1 – Number of reference bales required to fill a given volume

Maximum, mean and minimum values are given to allow for variations in bale dimensions and thus volume.



Cost. The manufacturing cost is a function of material, plant and labour at the point of production. Material quantities can be assessed as above. Plant costs are specific to the balers being used. An initial assessment of labour costs can be made using Figure D.3 which is based on a typical production rate of four bales per hour during a two man shift. The figure gives the number of eight hour (two man) shifts required to manufacture tyre bales of a given volume.

To the production costs need to be added transport and construction costs. The former are minimized by locating the point of tyre collection and bale production as close to the site as possible. However this may not always be practicable and so alternative modes of transport should be considered to minimize the carbon footprint. Unit construction costs are generally found to be low due to the simplicity of placing the bales.

Figure D.2 – Number of tyres required in the manufacture of reference bales to fill a given volume

Maximum, mean and minimum values are given to allow for variations in bale dimensions, and thus volume, as well as allowing for the variation in the number of tyres.

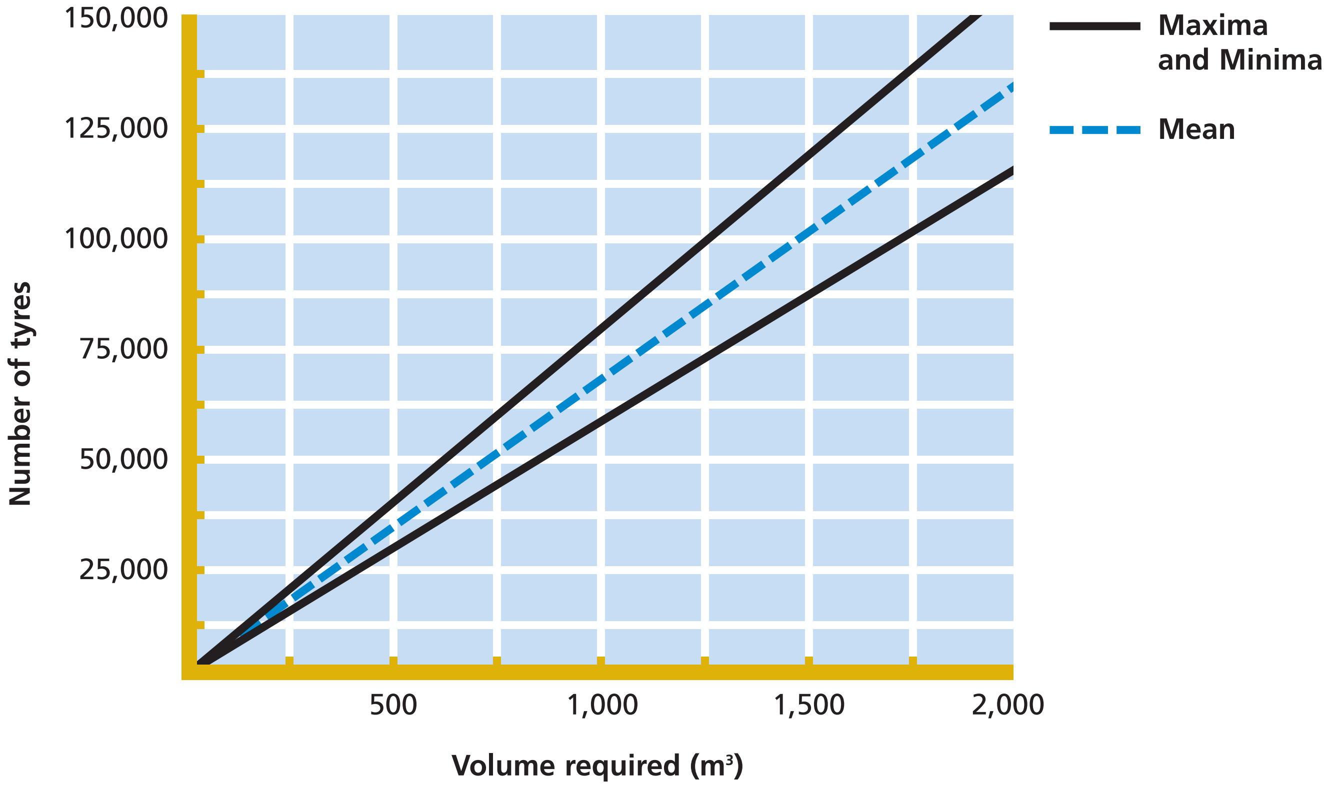
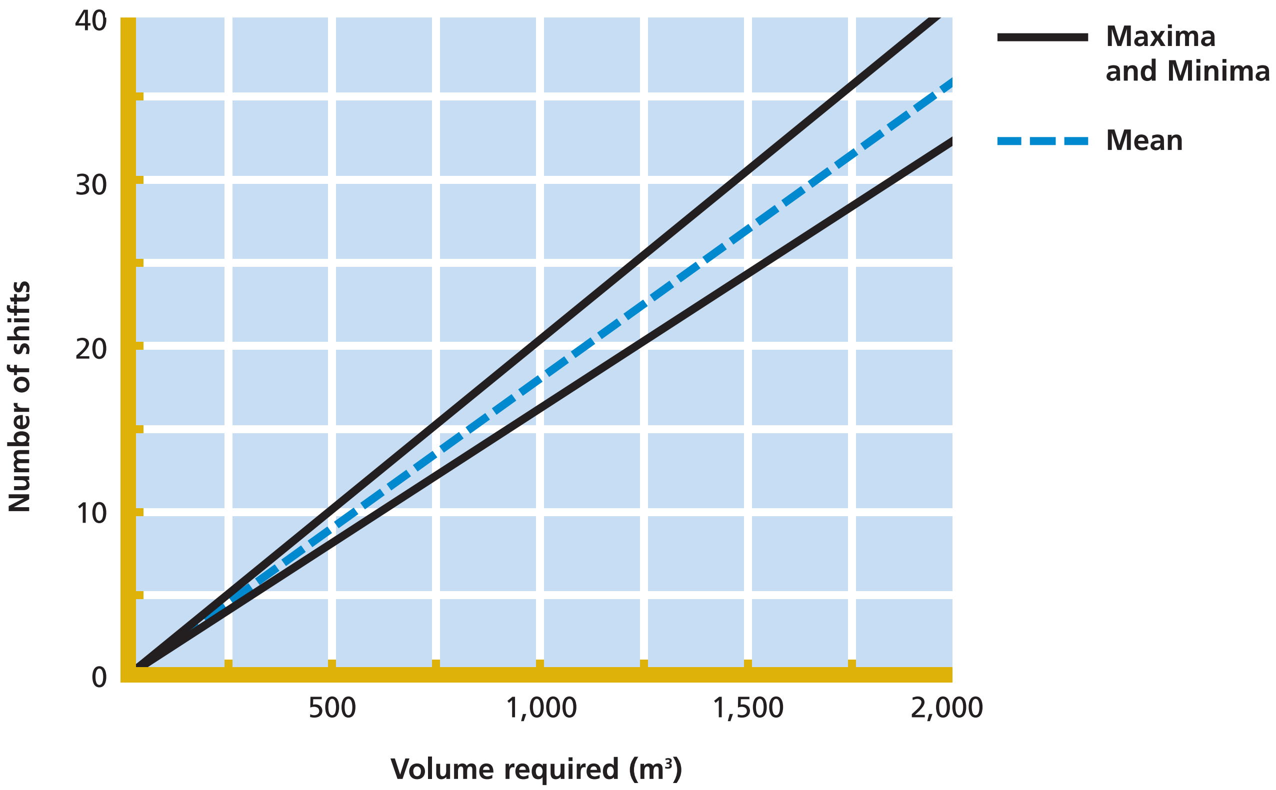


Figure D.3 – Number of 8 hour (two-man) shifts required to manufacture reference bales to fill a given volume

Maximum and minimum values are given to allow for variations in bale dimensions and thus volume.



D.1.2 Alignment and layout (patterns of placing)

Alignment

Tyre bales have different properties in different directions and so orientating them correctly in the works is important.

Bales have their highest stiffness through their depth and therefore should be installed such that this direction is in line with the maximum load. In most applications, this will mean that the bales will be installed "flat" (depth dimension vertical).

Bales should also be placed such that the direction of original compression (through the length, which is also the direction of the tie wires) is aligned with the direction of maximum confinement in the structure. Hence, the tie-wires should always lie in line with the direction of a road or flood defence embankment, for example. Bursting of the galvanised tie-wires should not occur if construction is carried out in accordance with this PAS, but should the tie wires fail at some point in the future due to corrosion the tyres will then remain confined within the structure.

NOTE *It is not recommended to cut the tie-wires once the tyre bales are in place as this will affect the behaviour and properties of the bales, not least in the all important areas of frictional resistance and permeability. If there are concerns about any gaps between bales then these should be filled with dry sand or similar material to close the gaps between the bales.*

Layout within a layer of tyre bales

There are various options for laying out tyre bales within a given layer. However, as the main threat to the integrity of layers of bales is from differential vertical, rather than lateral, movement a simple chessboard pattern is recommended as providing a compromise between interlock and simplicity of construction.

NOTE *There may be specific construction reasons for requiring a stagger of the bale joints in one or the other direction.*

Layer to layer layout

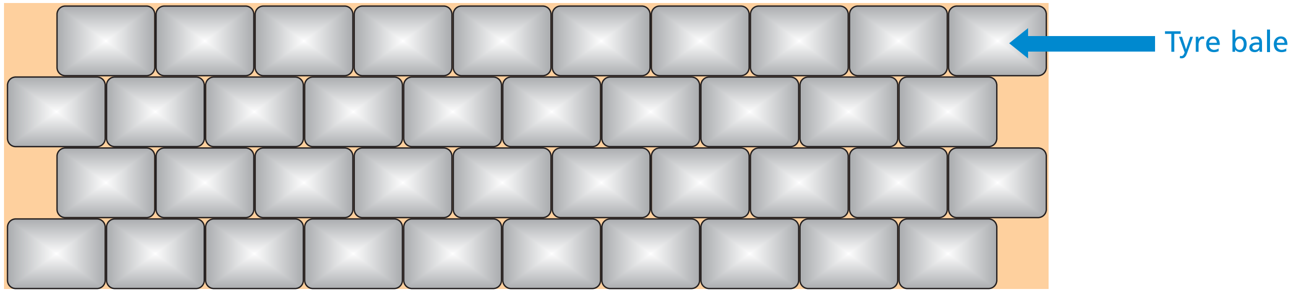
Clause **7** of this PAS requires subsequent layers of bales to be placed in a stretcher bond fashion along their course. Figure D.4 (a) illustrates this.

Note 4 of Clause **7** indicates that as well as a longitudinal stretcher bond, the form of construction may or may not require a stagger in the joints between the bales in the transverse direction. In most applications such as embankments and slope repairs, some degree of stagger of the bale joints will also occur almost by default in the other direction (see Figure D.4b). Examples of staggered joints are shown in Figures D.4 and D.11 (see **D.3**), while those without stagger are illustrated in Figures D.12 (see **D.4**) and D.13 (see **D.5**). The amount of stagger will depend to a marked degree upon the required slope of the front face and, to some extent, that of the rear face where applicable. Figure D.4 illustrates a typical arrangement for a repair to a failure in a cutting slope.

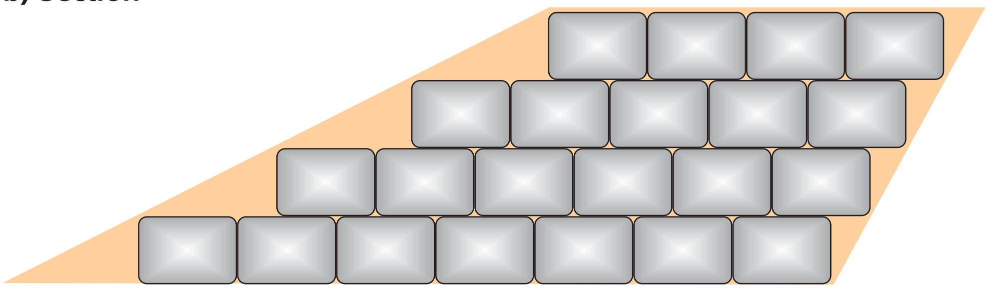
Figure D.4 – A typical tyre bale repair to a failure in a cutting slope (prior to placement of cover)

The tyre bales are shown in grey and all other areas comprise fill.

a) Front elevation (stretcher bond pattern)



b) Section



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D.1.3 Filling between bales

Bales have been placed successfully with, and, without fill between the bales. Whether fill should be introduced depends on the application and the design criteria.

Omitting filling between bales can be advantageous when structural rigidity is not critical and has the advantages of:

- Maximizing the permeability of the tyre bale layer which can be useful in layers with a drainage function.
- Minimizing the load imposed on the underlying ground which can be important when total settlement of the embankment is critical. For example when flood defence embankments are constructed on soft ground the value of limiting gross settlement may outweigh the disadvantage of any increased differential settlement (see below).

However, if the gaps between the bales are not filled then the entire bale structure should be encapsulated within a geosynthetic of suitable form to prevent the ingress of the surrounding soil into the bale mass. This approach was adopted on a project on the River Witham (see Figure D.5).

Figure D.5 – Placing tyre bales (using a pallet grab) within a wrapping of geosynthetic

(© Environment Agency)

Filling between bales has several advantages which are important when total and differential settlement is to be minimised (including that under vertical loading):

- Maximising the friction between the bales by minimising the effect of the joint gaps between the bales caused by the slight curvature at the edges and corners of the bales. This has the dual benefits of:
  - Maximising the internal stability of the bale mass, and
  - Helping to reduce differential settlement between adjacent bales.
- Minimising the potential for the surrounding soil to be washed into these same gaps.
- Reducing any long term creep settlement of the bale stack (see **C.2.8**).

For these reasons filling between the bales is particularly important for structural applications in which the friction and interlock between the bales must be optimised (usually maximised), for example in transport infrastructure embankments.

Guidance on the amount of material required to fill these gaps is given in Box D.1.

The material used to fill the gaps must be a compromise in terms of its properties between being able to flow freely into the gaps, exhibiting frictional strength and being able to drain freely. Coarse sand and fine gravel have been found to be good materials for this use. The addition of water in excess of the optimum moisture content is sometimes useful to promote the free flow of the material into the gaps, provided that suitable drainage exists for excess water to escape. Placement of fill between layers of tyre bales should be avoided (except for the occasional regulating layers described below). This avoids the potential to create a preferential slip plane between the layers of bales (and also minimises the amount of fill required).

Depending on the form of structure, the key design considerations, and the grading of both the fill and the adjacent soil, the entire bale structure may need to be encapsulated within a geosynthetic of suitable form to prevent the ingress of the surrounding soil into the bale mass and to further limit differential settlement.

Regulating layers take up the cumulative minor irregularities which develop in the surface of the tyre bale layer when a significant number of bale layers are involved. It is therefore suggested that if filling between bales within layers is acceptable, an additional regulating layer of 200 mm to 400 mm depth should be placed between each "lift" of 3 or 4 tyre bale layers.

Box D.1 – Filling gaps between bales: quantity and density implications

It is estimated that the gaps between the bales take up between 4 % and 8 % of the volume of a mass of bales.

The density of the resultant bale mass, ρ_M, with void filling will be different to that of the bales themselves and, given the above, lies between:

$$\rho_M = (0.96\ \rho_{Tr}) + (0.04\ \rho_F)$$

and

$$\rho_M = (0.92\ \rho_{Tr}) + (0.08\ \rho_F)$$

where

ρ_{Tr} the true bale mass density (as opposed to that of the enclosing cuboid) varies between 430 kg/m^3 and 570 kg/m^3,

and

ρ_F is the mass density of the fill used.

Thus taking the density of the fill between the bales, ρ_F, to be 1,600 kg/m^3 the density of the tyre bale mass, ρ_M, will increase to between 480 kg/m^3 and 650 kg/m^3.

Clearly this does not take account of any additional fill placed in regulating layers. However, similar principles may be used to calculate the bale-fill density in these circumstances.

D.1.4 Covering of bales (depth and stability of cover)

As required by Clause **7** of this PAS, tyre bales should always be covered at the end of the construction period in order to avoid degradation due to exposure to ultra-violet light. It is also likely that tyre bales will be covered for reasons of aesthetics. A minimum cover depth of 0.5 m of inert fill is recommended. Fine-grained material may be used to help reduce the ingress of water.

The stability of the cover soil should be addressed; where the slope is steep erosion can be a particular problem, albeit that the stepped nature of an uncovered tyre bale slope aids stability of the cover, limiting the likelihood of larger areas failing. Geosynthetic materials that contain growth media, often described as biosynthetics, can be particularly useful in this respect. The range of such materials is considerable and independent advice should be sought in terms of making such a selection. Hessian mats in conjunction with seed mulch have been successfully used on slopes of up to 1:2. The successful use of such materials on slopes much steeper than this may require the use of sacrificial staples to pin the Hessian mat to the topsoil.

Such systems are unlikely to be effective for slopes in which the soil is placed at angles greater than that of repose. Where greater angles are required systems comprising a steel mesh incorporating a seeded biosynthetic in order to promote vegetation growth may offer a solution. These are generally formed from a sheet of a horizontal steel mesh attached to a similar sheet set at an angle to the first corresponding to the desired slope angle. These pre-formed steel mesh elements are then placed in layers with the tyre bales in order to form a smooth slope. The same material used to fill around the bales, with the addition of a small amount (< 10 %) of organic matter, may then be used to fill the void between the tyre bales and the steel mesh behind the face of the slope. The vertical dimension of the steel mesh can be specified to match the dimensions of tyre bales making construction simpler.

D.1.5 Construction breaks

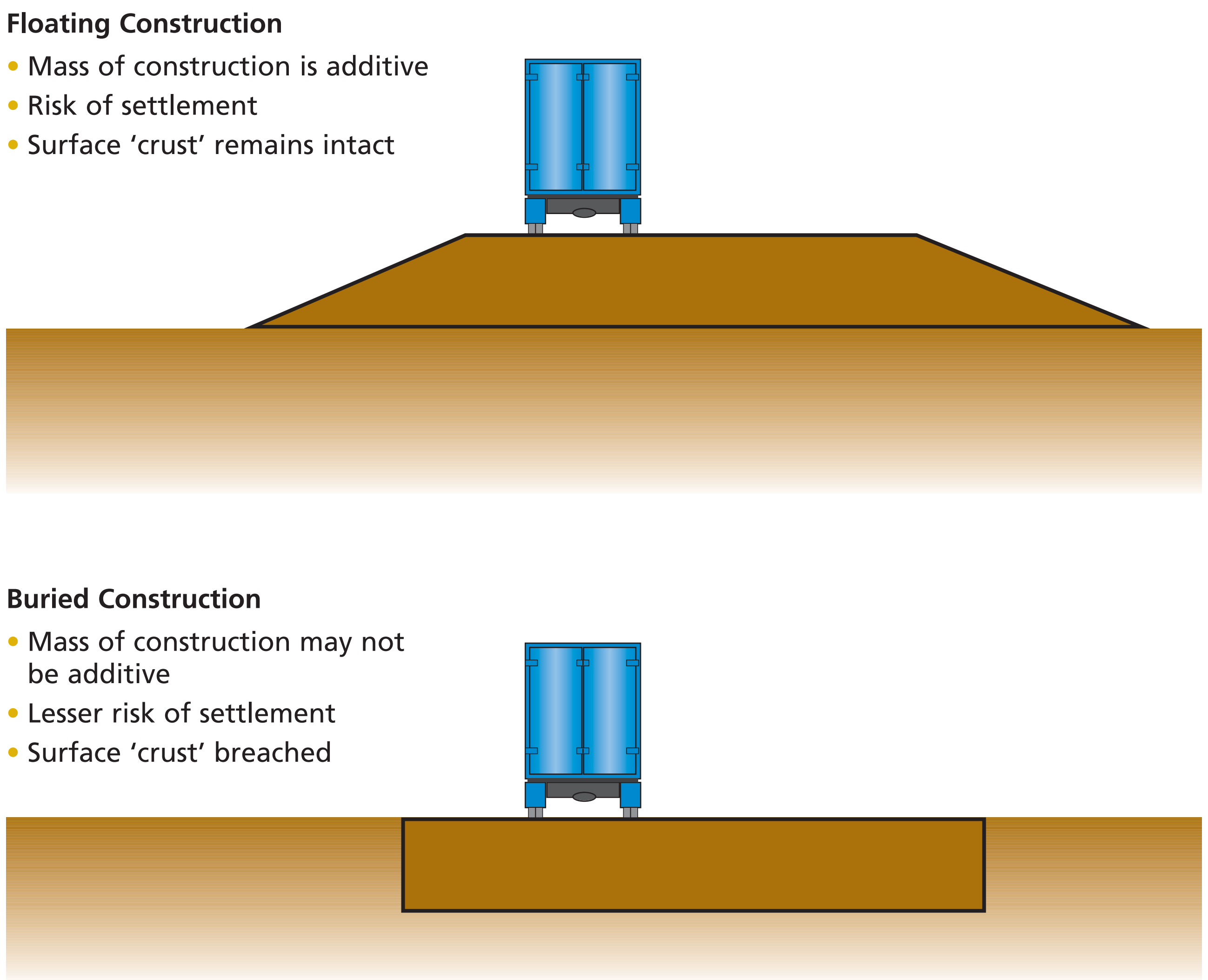
When placing bales without filling of the gaps between them, it may be appropriate to consider the placement of short breaks in the longitudinal bale courses formed using frictional fill. The fill is to be placed with each course in such a way as to maintain the stretcher bond pattern and typically will be of longitudinal dimension half to one times the length of a tyre bale. The reasons for considering this break are partly to correct unevenness in the stretcher bond pattern that may have developed over a length of, say, 100 m. They can also provide reassurance to those concerned about the potential for arson during construction as they will provide a natural fire break.

D.2 Road foundations over soft ground

Tyre bales can provide lightweight foundations to roads over soft ground. They can be particularly effective in situations where the layer of soft material is sufficiently thick that solutions involving the removal and replacement of its full depth are impractical or uneconomic. Many roads over soft ground allow access to remote and relatively under-populated regions and as a result carry relatively little traffic and must therefore be constructed and maintained within limited budgets.

There are essentially two approaches to construction of roads over soft ground: above ground or 'floating' construction and below ground construction (Figure D.6). Both conventionally use large volumes of granular fill.

Figure D.6 – Schematic illustrating the differences between 'floating' and buried construction



D.2.1 Floating versus buried construction

In areas of deep soft soil, full replacement techniques are unattractive as large volumes of material must be excavated, transported and disposed of with the consequential effect on costs. Additionally, 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. Historically, various materials have been used to enhance the 'crust' effect and spread loads. The shallow embankment on which the Airedale Railway runs through Bingley in Yorkshire is constructed over a peat bog with bundles of faggots and sheep pelts placed on top of the peat to spread the load of the embankment.

Above ground construction has often utilized bundles of twigs, called fascines, placed at subgrade level to provide resistance to differential movement. Often these were orientated at 90° to one another in two layers. On constructions designed to take higher traffic flows logs and timber grillages 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 allows the applied load to be minimized.

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.

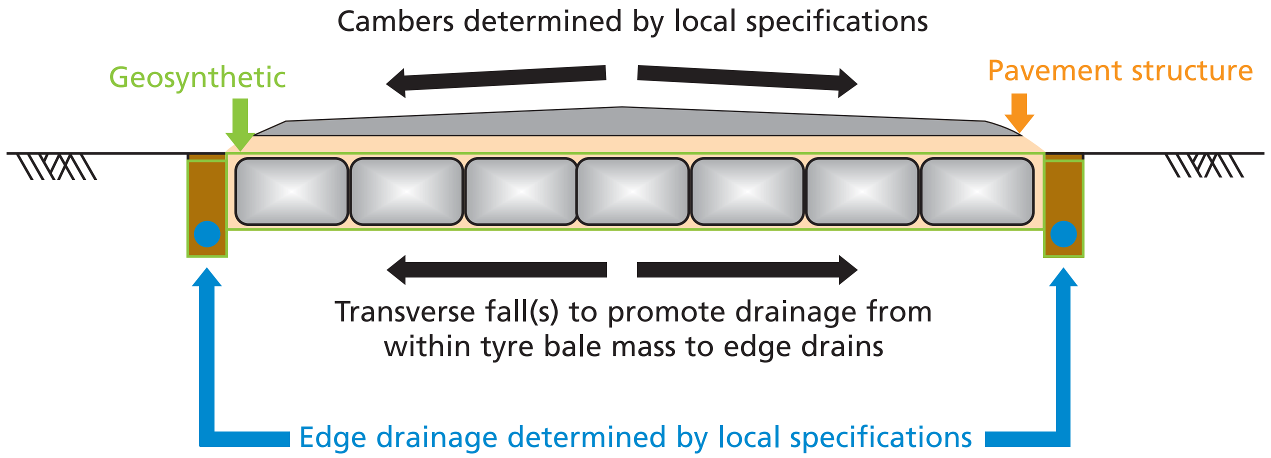
Buried construction may be preferred in more competent materials, or shallow poor materials for which removal is an option. Such materials include normally consolidated silts and clays, and soft predominately mineral soils for example. A geotextile is a key element in ensuring that the subsoil is separated from the tyre bale construction, thus preventing pumping, and the potential for differential settlement between adjacent bales is minimized, in particular under construction loads.

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.

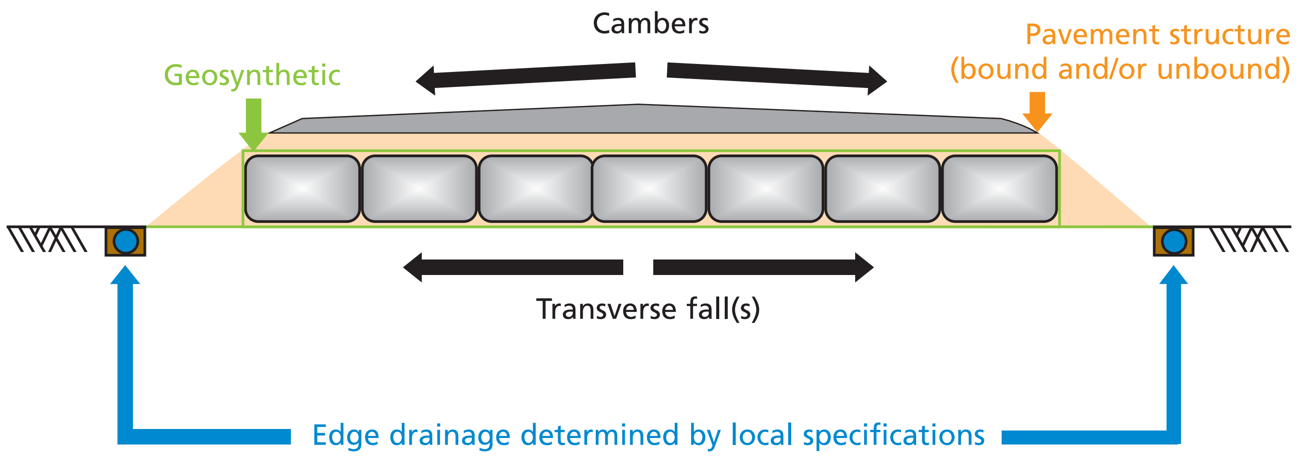
Typical cross-sections for buried and floating construction are illustrated schematically in Figure D.7.

Figure D.7 – Schematic cross-section showing typical layouts of road construction utilizing tyre bale foundations: (a) buried construction; and (b) floating construction

a) Buried construction



b) Floating construction



D.2.2 Other design and construction considerations

Experience of tyre bale road foundations is limited to annual average daily traffic (two-way) levels of 200 to 1,600 vehicles per day. However there seems little reason to restrict their use in carefully engineered, low risk projects subject to traffic levels of < 5,000 vehicles per day.

Whether floating or buried construction is adopted it is important that the bales are properly aligned and laid out as described in **D.1.2**. Filling between the bales is required in order to provide maximum stability and resistance to differential settlement (**D.1.3**), as is the use of a suitable geosynthetic beneath the bales. Consideration should also be given to wrapping the geosynthetic around the entire bale mass.

The required form of road pavement construction will be constructed on top of the bales; typically this may be between 250 mm and 450 mm thick.

The design of the surface and subsurface drainage of the construction will be determined by the prevailing climate and construction specifications in the location in which the road is constructed. In the case of fully bound surfaces local specifications will determine both types of drainage. In the case of unbound surfaces less information may be available and as the custom is often to construct such road pavements wider than their bound equivalents this must be taken account of in the design of the edge drainage, the subsurface transverse fall and the surface cambers or crossfall.

D.3 Slope failure repair

Slope failures and landslides occur in five basic modes: falls, topples, slides, flows and spreads. A sixth mode, 'complex failures', involves one of the five types of movement following another type (or types), rock fall-debris flow for example.

Typical approaches to the remediation of failed soil slopes include:

- The placement of mass at the toe;
- The placement of soil nails, anchors or piles to strengthen the in-situ material;
- Construction of a retaining wall (including gabion and crib walls) to resist further movement of the in-situ material;
- The use of geosynthetics to strengthen either the in-situ material or replacement fill;
- Stabilisation, or solidification, of the in-situ material;
- Drainage improvement;
- Replacement of the in-situ material with stronger, better draining fill.

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 D.8). 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 (Figure D.9) and hence free-draining tyre bales offer a natural alternative.

Figure D.8 – Excavated slide failure

(© Texas Department of Transportation)

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 (Figure D.8). The object of such excavation and replacement works is to reform the slope using a higher strength, freer-draining material. Flows may also produce large voids as gullies may be formed or enlarged during their erosional phase (Figure D.9). 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.

Figure D.9 – A gully eroded by the action of a debris flow

The boundary details are particularly important in terms of promoting the appropriate flow of water into and out of the tyre bale mass and also in ensuring that the high permeability bales do not cause ponding and consequent softening of the adjacent soil materials.

The base, sidewalls and back wall of the excavation must be constructed so as to promote both stability and the flow of water out of the mass of tyre bales in a controlled manner so as not to introduce further problems elsewhere.

The base of the excavation should be constructed so as to slope downwards toward the toe of the slope and the shape of the excavation can be relied upon to provide passive drainage (Figure D.10). Whilst a base sloping towards the toe of the slope is likely to yield a slightly less stable repair compared to an inward sloping base, the drainage arrangement is considerably less complex and will require much less maintenance in the longer term. The precise angle of the slope of the base of the excavation will be dictated by the needs of each situation and it is likely that a number of angles will be analysed to assess the influence of excavation base angle on the overall stability of the slope.

The lateral gradient of the base of the excavation should be constructed so as to ensure that water flows to one end. This water needs to be collected and removed so as not to promote instability in the adjacent slope. At the low end of the excavation a perforated pipe should be used to collect the water and provide gravity drainage to the main road drainage system. This approach largely avoids the need for a 'water stop' at the end of the excavation.

Typically the boundaries will be formed by a suitable geosynthetic fabric overlain by a minimum of around 150 mm of free-draining fill between the bales and each boundary. These materials should be selected to minimize the migration of in-situ soil into the repair.

A typical solution involves the stacking of tyre bales within the void (Figure D.11). The directional dependence of their permeability indicates that care is required in placing bales to ensure that the flow is optimised. It should also be noted that while the permeability of tyre bales is somewhat lower than for rockfill the porosity is likely to be equivalent or higher.

The maximum permeability will usually be oriented vertically and the depth of the bale placed vertically. This also means that the tie wires will be parallel to the face of the slope, so as to maximize confinement. However, if drainage is critical then consideration to aligning the bales with the tie-wires perpendicular to the slope can be given in order to maximize the flow of water out of the slope.

Filling of the gaps between the bales is strongly recommended in order to maximise the stability of the bale mass. Before completing the surface protection, it is also recommended that the face of the tyre bale fill is covered with a suitable geosynthetic fabric to help prevent the penetration of roots into the tyre bale mass.

Figure D.10 – Schematic diagram of excavation showing the drainage paths for the base of the excavation sloping towards the toe of the slope

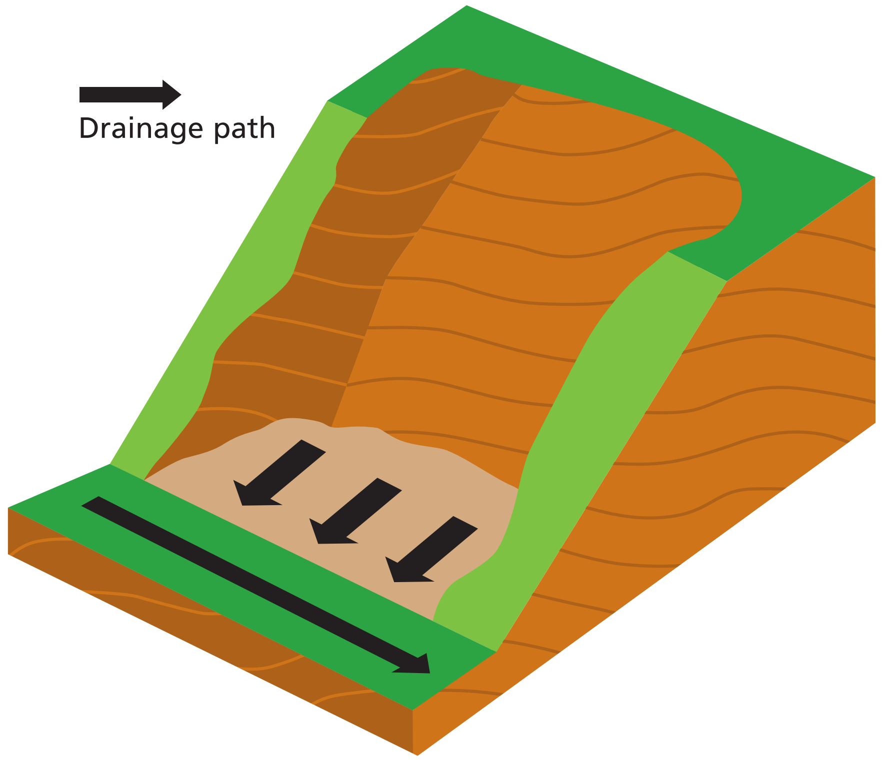
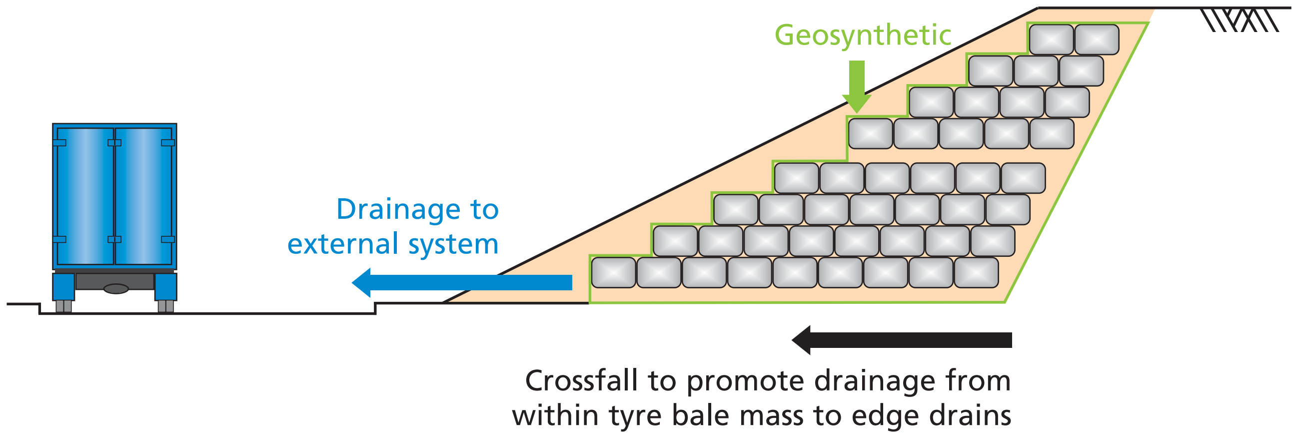


Figure D.11 – Schematic cross-section showing a typical layout of a slope failure repair



D.4 Lightweight embankment fill

Embankments across low-lying soft ground are commonly required for transport, services and flood defence. Their height means that they apply a significant loading to the underlying soft ground, which can lead to significant total and differential settlements and potential failures of either the ground or the embankment and resulting ongoing maintenance expenditure.

There are a number of ways in which settlement may be limited, including the following:

- Reducing the weight of the embankment.
- Staged construction and/or pre-loading of the embankment to allow subsoil consolidation.
- Reinforcing the base of the embankment to help spread the load better.
- Constructing the embankment on piles, or stone or lime/cement columns.
- Improving the foundation soil by mechanical or chemical means, by accelerating the drainage, by pre-loading, or by dewatering.

Whichever solution is adopted, 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.

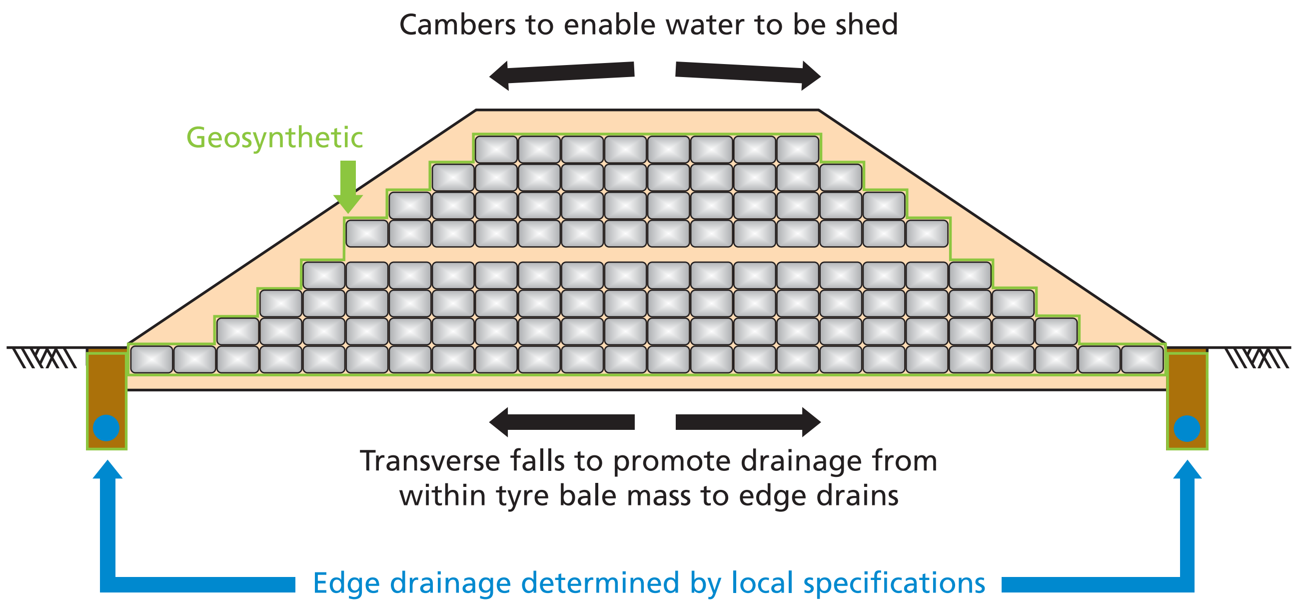
Tyre bales can be used in both new construction and in repairs or modifications to existing embankments (see **D.3** for slope repair). In the design and construction, full account should be taken of the foundation conditions and the requirements for free drainage of the tyre bales. Construction will typically commence with a geosynthetic fabric overlain about 150 mm of free-draining fill between the bales and each boundary. After placement of the bales, the gaps between them are filled with gravel. Before completing the surface protection, the resulting bale stack is covered with a further geosynthetic fabric.

Many of the key issues discussed in **D.2** in relation to road foundations over soft ground are also important to the design and construction of embankments. In particular, the issue of floating versus buried construction is still more critical for embankments constructed on soft ground. Burying the first layer of tyre bales has the potential to provide some lateral support and this approach is reflected in Figure D.12. Implicit within the assumptions under-pinning this approach is that the side walls of the excavation will not fail during the brief construction period. However, embankments are likely to impart significantly higher loads than roads constructed more or less at grade and in many cases buried construction may be inappropriate. Geosynthetics should be specified in order to provide separation between the existing ground and to provide resistance to the tendency of the bales to separate under load whether buried or floating construction is used. This will help to resist the lateral stresses developed at the base of the embankment during the consolidation stage and will resist the formation of 'slips' within the embankment.

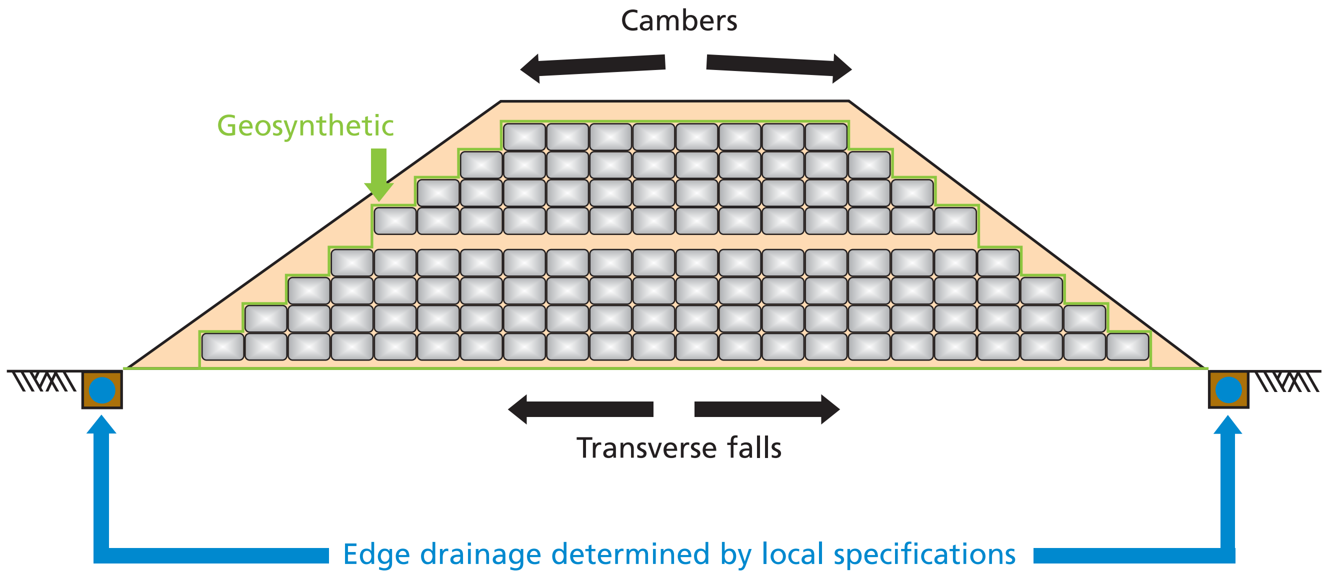
Designs of embankments must assess both internal and external stability – that is, they must consider both the stability of the embankment itself and the magnitude of the settlement induced by the loads applied by the embankment in the underlying formation. The provision of basal reinforcement also should be a key consideration.

Figure D.12 – Schematic cross-section showing typical layouts of tyre bale embankments: (a) buried construction; and (b) floating construction.

a) Buried construction



b) Floating construction



Provision for drainage of the subsoil will probably be required, and may be achieved using band drains and/or by utilising the lowest layer of tyre bales as a drainage layer beneath the embankment.

Fill to the gaps between bales is likely to be required if the embankment is designed to carry infrastructure such as road and other elements that will impose serviceability limits on differential settlements. For flood embankments where the serviceability criteria for differential settlements are more relaxed, minimising the loads applied to the subsoil may be a more important issue and in such cases it may be desirable to omit the fill around the bales.

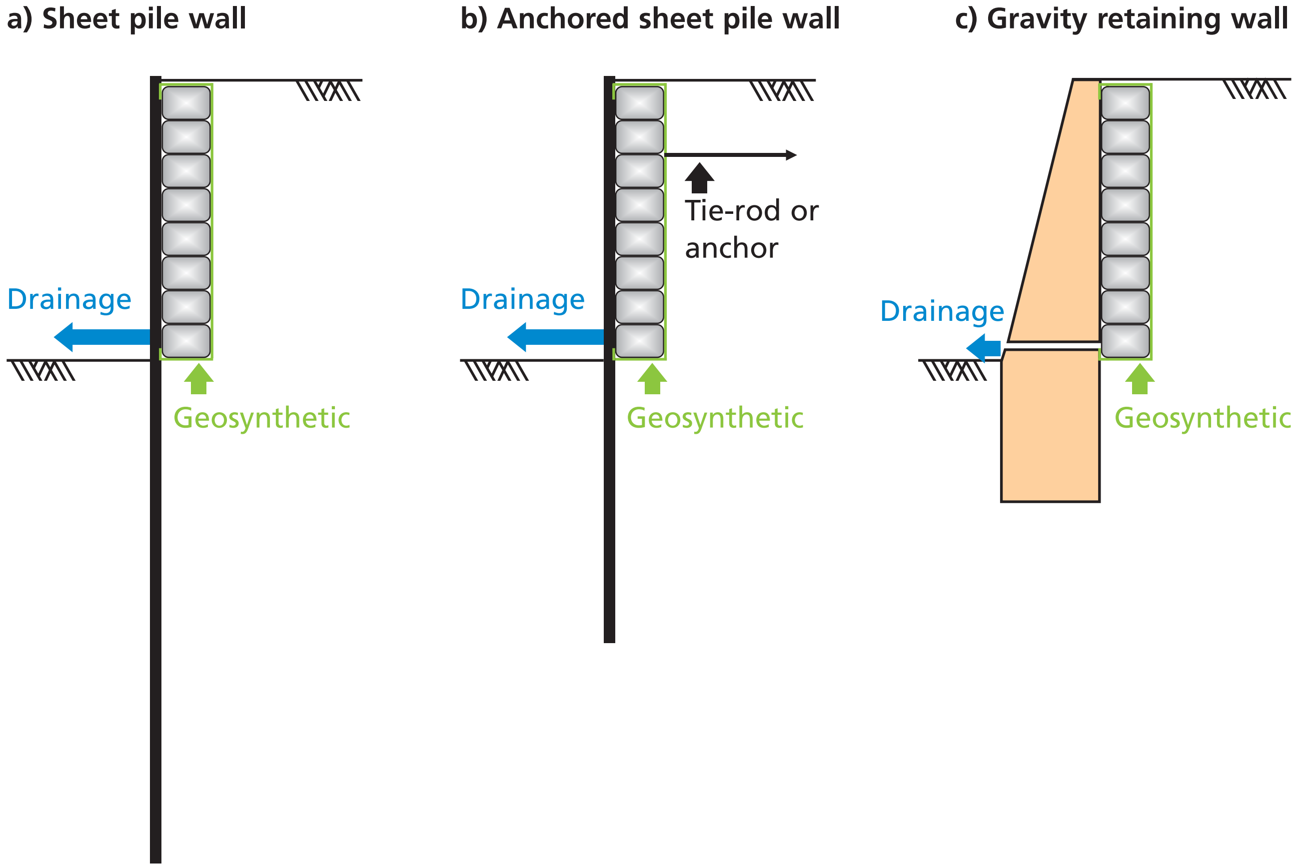
D.5 Free-draining layers behind retaining walls

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 avoids excessive water pressures from 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, providing a geosynthetic filter between the bales and the subsequent backfill. Careful consideration is needed as to whether it is appropriate to allow imposed loading at the level of the top of the wall, given the impact this may have on settlement and drainage behaviour.

Figure D.13 illustrates possible arrangements for tyre bales for three widely used retaining wall types. The use of an appropriate geosynthetic material wrapped around the tyre bale mass is essential to act as a filter to the ingress of fines from the surrounding material.

Figure D.13 – Schematic cross-sections showing typical layouts for free-draining tyre bale layers behind retaining walls: (a) sheet pile wall; (b) anchored sheet pile wall; and (c) gravity retaining wall



As for all retaining walls it is essential that particular attention is paid to the design and construction of the drainage from the back to front faces of the wall. For most walls this takes the form of weep holes, but in tidally affected locations flap-valves may be required to prevent the ingress of tidal water.

The installation of tyre bales does not obviate the need for the designer to consider whether a wedge of granular material will be needed behind the bales to further relieve the active pressures behind the wall.

D.6 Drainage layers, including in landfill engineering

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.

Figures D.7, D.11 and D.12, illustrating road foundations, slope repairs and embankments all incorporate and illustrate the use of drainage layers, particularly in the form of the lowest layer in the case of slope repair and embankments. For many applications the information provided in **D.2**, **D.3** and **D.4** will be relevant.

When using the bales attention should be given to the anisotropic nature of their permeability, the greatest permeability arising through the depth of the bales.

Filling of the gaps between the bales will depend upon the design requirements of the structure under consideration; situations in which the gaps between bales would either need to be filled or left open can be envisaged for drainage layers. Geosynthetic fabrics will generally be placed above and below the drainage layers to limit ingress and subsequent blockage of the tyre bales by fine material.

Tyre bales are beginning to be used in the basal drainage layer for landfill sites. For landfill applications the loads on the basal drainage can be significant with many metres of fill albeit of lower density than soils. These represent probably the largest loads under which tyre bales are being used to date. Figure D.14 illustrates tyre bales being placed in a landfill drainage layer.

Figure D.14 – Tyre bales being placed in a leachate drainage layer at the base of a landfill cell at Bryn Posteg

(© Potters Waste Management)

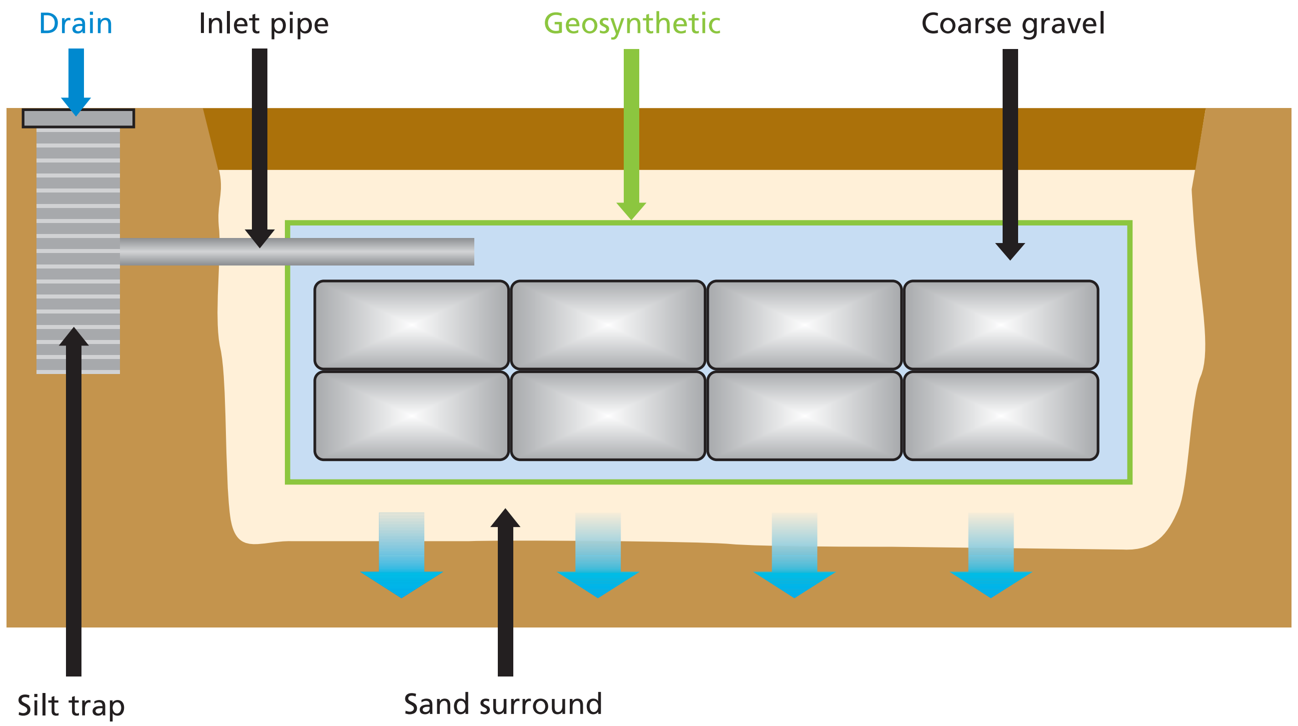
D.7 Sustainable Urban Drainage Systems (incl. soakaways)

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 applications to SUDS can be envisaged, such as soakaways, French drains and under 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.

Figure D.15 illustrates a typical layout for a tyre bale soakaway.

Figure D.15 – Schematic cross-section showing a typical layout a tyre bale soakaway



Annex E (informative) Applications of tyre bales in construction

E.1 General

The issue of what happens to tyre bales at the end of the service life of the structure of which they form a part is as important as for any other material. Clearly any disposal at a later date due to demolition for example will be determined by the prevailing legislation, regulation and interpretation thereof at that time. As with all construction components the presence of tyre bales should be noted in the Health and Safety file required by the Construction (Design and Management) Regulations 1994 and any anticipated approaches to reincorporation and/or removal noted. The management of any bales emerging at the end of service life must be appropriate but clearly forms of recovery involving both engineering and non-engineering uses could be considered.

There is no evidence of significant deterioration of tyres buried in the ground, even after many years. However effective reuse will be more conveniently achieved if the bales are uncontaminated with fine or clayey material. This is most readily achieved where the bale stacks or layers have been covered with a suitable geosynthetic fabric as part of the original construction. The bales can then be reused in any application in other structures, so long as the tie wires are intact. Should the tie wires not be intact then consideration could be given to re-baling the tyres on site, albeit that this will add to the overall cost of the operation.

However, incorporating the bales into any reconstruction in the same location is likely to be the most attractive and cost-effective option. Some options are briefly discussed below:

E.2 Road foundations over soft ground

In the example of a road construction that is to be refurbished the existing bales could be used as a construction platform for the reconstruction. Such an approach is most likely to succeed if the tyre bales are placed lower in the original carriageway so that they can form the foundation in the reconstruction.

E.3 Slope failure repair and lightweight embankment fill

Tyre bales incorporated into slope failure repairs or lightweight embankment fill are only likely to be removed in the event of failures, where widening or realignment of any associated infrastructure is required, or there is a need to remove part or all of an embankment. Leaving the bales in place is likely to be the preferred option, but if they have to be removed they can be re-employed in the further slope or embankment construction that will inevitably be required in such situations.

E.4 Free-draining lightweight layers behind retaining walls

Retaining walls are rarely demolished, it being more common to install additional walls in front if strengthening or height increases are required. In such situations the bales can be left in place. Where walls are demolished, it will commonly be in the context of construction of further infrastructure and the bales should be reused therein.

E.5 Drainage layers and Sustainable Urban Drainage Systems (SUDS)

The decommissioning of drainage and SUDS infrastructure is likely to be highly specific to the type of works originally installed. As a starting point the management of such decommissioning works should assume that the tyre bales will be reused without being removed form their present location. However, in a significant number of cases this is unlikely to be feasible, but they should be reused in further works in the vicinity.

Bibliography

Standards publications

BS EN 10244-2: 2001, *Steel wire and wire products – Non-ferrous metallic coatings on steel wire – Part 2: Zinc or zinc alloy coatings.*

BS EN 10270-1: 2001, *Steel wire for mechanical springs – Part 1: Patented cold drawn unalloyed spring steel wire.*

Other publications

[1] The European Union Landfill Directive (1999/31/EC)

[2] GREAT BRITAIN. *Waste Management Licensing Regulations 1994 (as amended).* London: The Stationery Office.

[3] GREAT BRITAIN. *The Management of Health and Safety at Work Regulations 1999* London: The Stationery Office.

[4] GREAT BRITAIN. *The Provision and Use of Work Equipment Regulations 1998.* London: The Stationery Office.

[5] GREAT BRITAIN. *The Personal Protective Equipment Work Regulations 1992.* London: The Stationery Office.

[6] GREAT BRITAIN. *The Construction (Design and Management) Regulations 1994.* London: The Stationery Office.

Additional Reading

Aaboe, R, Haoya, A-O, Edeskar, T (2004). Leaching of Phenol from tire shreds in a noise barrier. *Used/Post-Consumer Tyres,* 251-260. Thomas Telford, London.

Anon (2003). Geotechnical investigation and analyses – slope failure repair utilizing baled tire fill, Interstate Highway 30 west of Oakland Blvd., Fort Worth, Tarrant County, Texas. Report by TEAM Consultant Inc to Fort Worth District, Texas Department of Transportation. Forth Worth, TX: Texas Department of Transportation (www.dot.state.tx.us/).

Collins, K J, Howell, D and Fisher, N (2004). Tyres in coastal and flood defence engineering – environmental monitoring. *Sustainable Waste Management*. Thomas Telford, London

Collins, K J, Jensen, A C, Mallinson, J J, Roenelle, V and Smith, I P (2002). Environmental impact assessment of a scrap tyre artificial reef. *ICES Journal of Marine Science,* **59**: S243-S249.

Collins, K J, Jensen, A C, Mallinson, J J, Smith, I P, Mudge, S M and Russel, A (2001) Scrap tyres for marine construction: Environmental impact. *Recycling and Reuse of Used Tyres*, 149-162. Thomas Telford, London.

Hylands, K N and V Shulman (2003). Civil engineering applications of tyres. *Viridis Report VR5*. Crowthorne: TRL Limited.

Prikryl, W, R Williammee and M G Winter (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.

Reid, J M and M G Winter (2004). The use of post-consumer tyres in civil engineering. *Used/Post-Consumer Tyres*, 195-202. London Thomas Telford.

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

Simm, J D, M J Wallis, K J Collins and R Atkins (2004). Reuse of materials in coastal and river engineering. *Proceedings, Institution of Civil Engineers (Engineering Sustainability)*, **157**(ES3). 113-121.

Winter, M G (2005). Report on a Technical Visit to the United States of America: May 2004. *The Delegate*, Issue 45 (March) London: Royal Academy of Engineering (www.raeng.org.uk/).

Winter, M G, P E Johnson and J M Reid (2005). Construction of road foundations on soft ground using lightweight tyre bales. *Problematic Soils*, 2, 775-783. Famagusta, N Cyprus: Eastern Mediterranean University Press.

Winter, M G, J M Reid and P I J Griffiths (2005). Tyre bales in Construction: Case Studies. *TRL Published Project Report PPR 045*. Crowthorne: TRL Limited.

Winter, M G, G R A Watts and P E Johnson (2006). Tyre bales in Construction. *TRL Published Project Report PPR 080*. Crowthorne: TRL Limited.

Zornberg, J G, B R Christopher and C J LaRocque (2004). Applications of tire bales in transportation projects. *Recycled Materials in Geotechnics* (Eds: A H Aydilek and J Wartman). Geotechnical Special Publication No 127, 42-60. Baltimore, MA: American Society of Civil Engineers.

Zornberg, J G, B R Christopher and M D Oosterbaan (2005). Tire bales in highway applications: feasibility and properties evaluation. *Research Branch Report No. CDOT-DTD-R-2002-2 (in two volumes)*. Denver, CO: Colorado Department of Transportation (www.dot.state.co.us/).

In addition to these references, The Waste Resources & Action Programme (WRAP) websites for aggregates (www.aggregain.org.uk/) and tyres (www.wrap.org.uk/materials/tyres/) contain a large number of case studies of practical construction projects utilising tyre bales.

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