Building With Tire Bales -

Addressing Some Engineering Concerns

Acres and Acres of Tires – small part of a tire dump located near Fountain, Colorado. [1]

ITS Innovative Technical Solutions

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[1] All photos, drawings and sketches in this paper are by Leonard Jones or Michael Shealy except where otherwise noted and are used by their permission.

The U.S. Environmental Protection Agency's website states that approximately 281 million used or scrap tires were generated in 2001.[2] This is a vast, even incredible, amount of waste that no doubt continues to increase. The sheer quantity is aggravated by the fact that tires are low density items requiring much disposal volume unless processed by shredding or compaction.

Fortunately, per the EPA web page, many of the tires generated in 2001 were beneficially re-used in various ways:

- 115 million were used as industrial fuel
- 40 million were used in civil engineering projects (retaining walls, sound attenuation projects, flood control, etc.)
- 34 million were ground up and recycled into products
- 16 million were re-treaded for continued use.
- 15 million were exported, mainly to third world countries
- 8 million were recycled into cut/stamped/punched rubber products
- 7 million were used in agricultural and misc. uses

This leaves approximately 46 million. 25 million of these are known or estimated to be disposed of in landfills; the remaining 21 million, or nearly 10% of the total, are unaccounted for despite increased regulatory attention since the 2001 EPA report.

It is possible that the number of tires going to landfills or unaccounted for could be reduced by utilizing the tires beneficially as construction material in residential or commercial projects. Some scrap tires are being used now to construct earthship[3] residential buildings. In the earthship building process, scrap tires rammed full of compacted earth are used to construct building walls. It is also possible to construct building walls from compacted bales of scrap tires, or tire bales, although some engineering issues might seem to arise. These issues will be addressed in this paper.

Figure 1 – A Typical Tire Bale

[2] HTTP://WWW.EPA.GOV/EPAOSWER/NON-HW/MUNCPL/TIRES/BASIC.HTM
[3] "Earthship" is a term coined by Michael Reynolds of Earthship Biotecture, Taos, NM, to describe his designs for "dwelling units made from materials that are indigenous to the entire planet" including scrap tires filled with compacted earth. For more details, please see: http://www.earthship.com

1. Tire Bales – The Nature Of The Material

   Tire bales are made by compressing waste tires into a rectangular shape with a large hydraulic press and banding them with with 5 or more, .115 inch diameter, galvanized or stainless steel wires. The bales are typically 5 feet wide x 5 feet long x 2.5 feet high, although sizes can vary depending on the particular press that is used. Smaller half bales are also available. One bale requires approximately 100 passenger car and/or recreational vehicle tires. Each full bale weighs approximately one ton. The bales, when stacked in running bond and finished with a cement-based grout and plaster/stucco have the potential of forming a strong, stable wall. Pictures of a typical tire bale and a tire bale press are shown at Figures 1 and 2.

Figure 2 – Hydraulic Tire Press

2. Strength of Tire Bales

   Tire bales are quite strong. A study of tire bales conducted by undergraduate students at the Colorado School of Mines (CSM)[4] concluded that about 150,000 pounds of compressive force were required before the first steel wire band broke. Even with a single broken wire, the tire bale did not entirely fail, but continued to support its load, albeit with more deformation, up to a force of 600,000 lbs. No ultimate failure was observed, as one would see in concrete, wood, or many other conventional building materials.

   Let's put this into perspective with regard to residential or commercial building:

   Assume that a tire bale is supporting an overhead roof load. Assume also that the roof load from the roof beams, rafters, or trusses is transmitted to the tire bale by a spreader beam or bond beam sufficient to ensure that the roof load is transmitted uniformly across the tire bale. Then the load per linear foot of wall required to "break" the first band of the tire bale is about:

   150,000 lbs / 5 feet = 30,000 lbs / linear foot

[4] "Recycled Tire-Bales for Wall Construction" Final Report submitted to The Multi-Disciplinary Senior Design Program, Colorado School of Mines, Davis et al, Arthur Lakes Library, Colorado School of Mines, Golden, Colorado, 2000.

This is nearly an order of magnitude greater than one could expect in a usual residential or commercial application, even in an area where severe snow loads could be expected.

These characteristics relate, of course, to a single tire bale in a testing machine rather to the strength of an assembled and finished wall. An additional factor that has not been considered with respect to the strength of completed walls is that tire bale building walls are typically grouted with pneumatically applied cement-based material (i.e., gunnite or shotcrete), stabilized earthen (adobe) plasters or other stucco materials. Then the walls are faced with stucco wire and surfaced with the same material. This material fills the voids between the bales as well as many of the voids within the bales and provides a thick, even surface on the walls. Although no laboratory or field tests have been done, addition of the grouting and surfacing to the assembled bales is certain to improve the strength and stability of the completed wall.

3. Deformation Under Load

The same CSM study referenced above indicates that tire bale deformation is near-linear under compressive loads from zero to at least around 70 PSI (equivalent to a force of around 250,000 lbs). After this point, the deformation per unit of load increases in a more-or-less exponential fashion. A portion of the deformation appears to be plastic, as the tire bale does not completely return to its original shape when the load is removed.

Some, including the authors of the CSM study, would say that the deformation was indicative of “failure” and that tire bales are not suitable as construction material on that account. On the other hand, and in my opinion, this is not so. The compressive loads used in the CSM testing are, again, nearly an order of magnitude greater than wall loadings that can be reasonably expected in single story residential or commercial use. Moreover, the CSM study seemed to indicate little possibility of a precipitous failure like those occasionally seen in conventional wall building materials such as wood, concrete, or masonry, even under much greater loads than would be expected.

Additionally a stack of tire bales, 10 high, at the Tire Disposal Facility located near Fountain, Colorado was examined and measured. It is worth noting that there was no measurable difference in size or shape of the heavily loaded bottom layer bales compared to the size and shape of the not loaded top layer. In this case, the bottom bales were bearing much more weight than could be expected in any reasonable building design.

An additional factor, which has not been tested in the laboratory or in practice, is the cement-based grout and stucco/plaster that is applied to tire bale walls, as described above in paragraph 2. The addition of this material will reduce deformation of tire bale walls as well as improve their strength.

4. Soil Bearing Capacity

Some have questioned how the soil underlying a tire bale wall topped with a roof structure could support such a heavy load. It is true that the tire bales are very heavy, at about one ton each. However, it is also true that the bales have a very large "footprint," approximately 25 square feet each, or 5 square feet per running foot of wall. Here's how it works out:

Assume that the tire bale wall is made from tire bales, stacked 4 bales high. This yields a bearing pressure of approximately:

4 bales x 2000 lbs per bale / 25 square feet = ~320 lbs / SF, or about 1600 lbs per running foot of wall

If we assume that our wall supports a 30 foot wide roof with a total load (live load + dead load) of 100 lbs / SF, the we get an additional load of:

30 feet x 100 lbs / square foot = 3000 lbs per running foot, or about 600 lbs per square foot

In addition to the weight of the wall and the roof, the wall must also support the weight of the bond beam and the grout/plaster that is applied to the wall. These weights are estimated as follows:

Bond beam	150 lbs per LF or 30 PSF
Grout/plaster	1000 lbs per LF or 200 PSF

The sum of the wall load plus the roof load yields a total of:

320 PSF + 600 PSF + 30 PSF + 200 PSF = 1150 lbs per square foot, or

1600 PLF + 3000 PLF + 150 PLF + 1000 PLF = 5750 lbs per linear (running) foot of wall

Soil conditions can vary widely from one site to another and even between one location and another on the same site. It is, therefore, unwise to make generalizations regarding the load bearing capacity of soils in a particular site and situation. Nevertheless, a variety of authorities, including the US Army Corps of Engineers[5], have published

[5] US Army Corps of Engineers, Engineer Manual 1110-1-1905, Table 4-8, page 15 of 30, 30 Oct 1992, available at: http://www.usace.army.mil/inet/usace-docs/eng-manuals/em1110-1-1905/c-4.pdf

generalized soil bearing capacities for commonly-found soils that might be required to support a tire bale wall ranging from around 3000 lbs per square foot for poorly compacted and graded silty, sandy, and gravely soil to around 20,000 lbs per square foot for well-compacted, well-graded sandy and gravely soils. These nominal bearing capacities substantially exceed the bearing pressures calculated above for tire bale walls.

It can be said, therefore, that tire bale walls can be adequately supported with a reasonable safety factor directly on many commonly-found soils. It would be inadvisable to place a tire bale wall on organic soils, expansive clays, highly frost-susceptible soils (in cold areas) or other poor soils that may not be able to bear the weight of the tire bale wall. Any case that is questionable should be referred to a qualified soils engineer. In situations where weak soils underlie the wall location, it may be advisable to over-excavate the weak soil and to backfill with an engineered fill – typically a well-graded road base sand/gravel mix. Efforts to design and build a footer to support a tire bale wall should be discouraged. The 5-foot-wide tire bale wall already provides widely distributed soil pressure; it would probably be more fruitful to seek a more suitable site for the structure than to make an extraordinary effort to improve a site with poor soils.

5. <u>Bond Beam</u>

An adequate bond beam is required to support the roof beams, trusses, or rafters and to secure them to the walls. Experience suggests that this bond beam be constructed of reinforced concrete (3000 psi or greater) formed and poured in place on top of the wall. A nominal 6" x 24" or equivalent bond beam with 3 #4 rebars 10" on center all around is suggested. An alternative bond beam configuration is shown at Figure 3. Low slump concrete should be used so as to avoid losing too much concrete into the porous tire bales beneath the bond beam. The near-complete fit of the concrete into the bales will lock the bond beam into place. This may be supplemented by additional #4 rebars wired into the tire bales on 4 foot centers and tied into the horizontal reinforcing or by field fabricated anchors extending from beneath the final layer of tire bales.

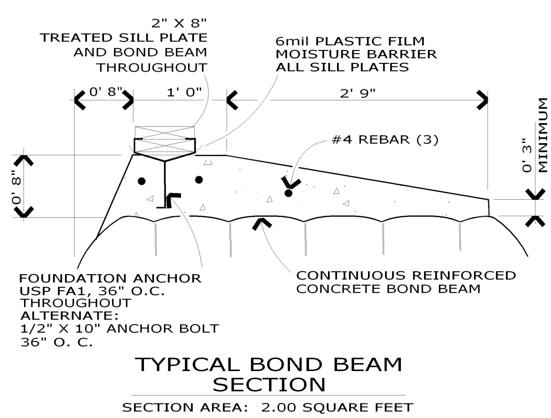

Figure 3 – Bond Beam Alternative

6. <u>Door and Window Installation, Lintels, etc</u>.

Due to the massive size and weight of tire bales, the installation of doors, windows, and other openings in them should be avoided. Typical passive solar design features with tire bale walls include a solid North tire bale wall. East and West walls may be constructed entirely from tire bales or may be part tire bale and part frame. The South wall is usually a conventional frame wall. Doors and windows should be installed in the South wall or in frame portions of East and West walls. This will avoid the necessity of creating breaks in the tire bale walls, installing large door and window bucks, constructing and installing lintels, etc.

7. Wall Buttresses

The large (25 square foot, more or less) footprint, the massive (one ton, more or less) weight, and the irregular surface of tire bales makes them stable once placed. Mismatching irregularities may cause them to rock a bit initially, but after the spaces between the bales are filled with cement-based grout, they become very stable, virtually immobile unless heavy equipment is used to break them apart and move them. Therefore, buttresses are not recommended for tire bale walls that are four or less bales high unless eccentric loads or some other unusual circumstance makes them necessary.

8. Bale Placement

Tire bales should be laid in running bond, as if they were very large bricks, as shown in Figure 4. Wire straps wrapping bales shall be located running with the length of the wall, so as to butt end to end. Corners, where necessary, should be made at even block spacing, with half-blocks every other course to maintain the running bond pattern. For passive solar house designs, it may be preferable to construct the North wall as a single unit with staggered ends, butting N-S walls up against the North wall. Where this is done, the N-S wall should be joined to the North wall with a pattern of 3 - #4 rebars each way at each course of tire bales. These details are shown in attached Figure 5 below:

Figure 4 – Four-High Bale Wall

To my knowledge, experience with tire bales to date has only included single story structures with walls not exceeding 4 bales. I would not recommend higher walls or multi-story structures unless additional testing demonstrates that higher structures are practical to construct and safe for occupants.

Some possible tire bale layout features are shown in the sketch below:

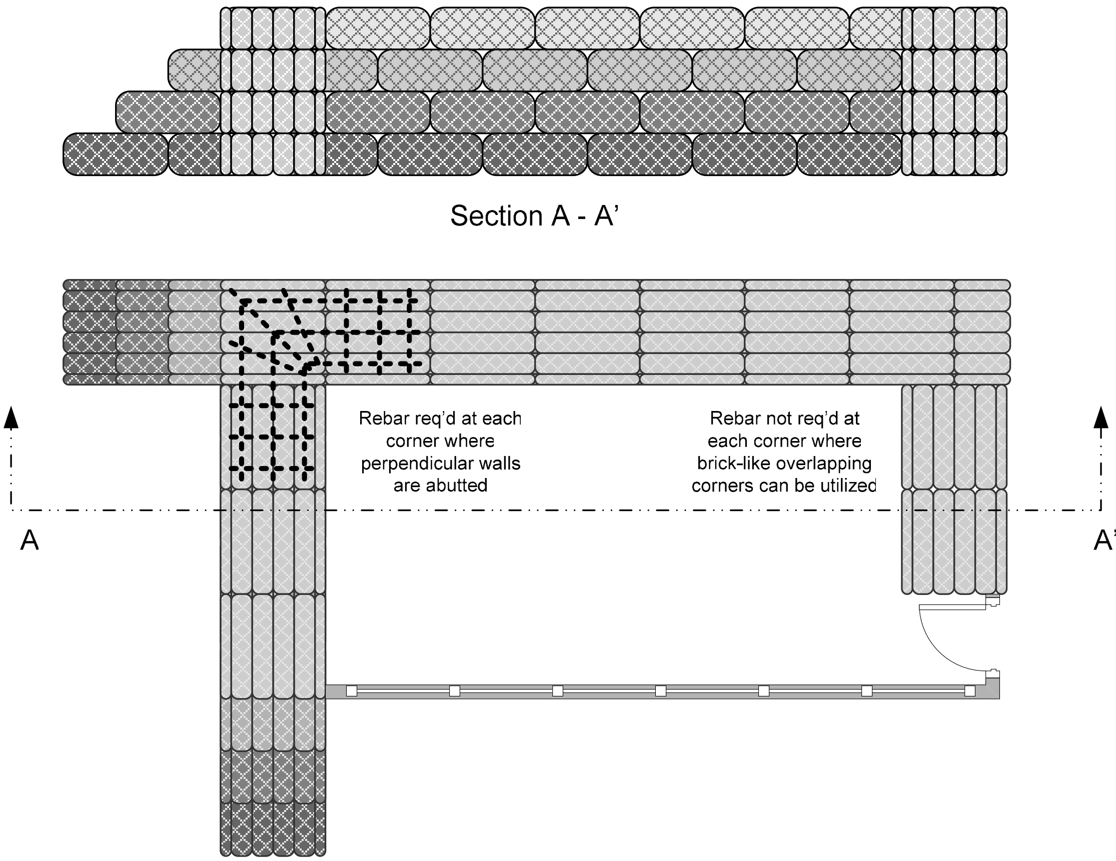

Figure 5 – Some Possible Tire Bale Wall Layout Features

9. Drainage and Waterproofing

This is a major factor on ALL projects, not just tire bale wall projects; engineers, builders, and owners should pay attention to it before during and after any work. The best way to deal with drainage problems is to avoid them in the first place with effective site selection and design. Sites that are in or near significant drainage ways should be avoided, and the building should be sited so that it will stay high and dry insofar as possible. Where this is not possible, adequate perforated pipe drains, dry wells, etc. should be provided.

Most residential tire bale designs are intended to be passive solar, high thermal mass buildings. As a result, the buildings will often have earthen berms on the West, North, and East sides or, alternatively, the buildings will be located in level excavations on South-facing hillsides. Moreover, to obtain the required South-facing condition, designers and owners may have to compromise on a variety of factors, including optimal site selection for drainage.

In any case, the opportunity for water to infiltrate behind the north tire bale wall exists. As a matter of routine practice, I suggest that a 4" perforated pipe drain covered with landscaping cloth and bedded in clean ¾" gravel be installed at or just below grade at the rear of the West, North, and East tire walls. This drain should be sloped to drain to "daylight" or to an adequately sized dry well distant from the building. Additionally, the grouted and plastered back of the tire wall above the drain should be treated with an appropriate waterproof membrane or waterproofing compound from the top of the wall down to the level of the drain. Permeable material, such as single-graded gravel or sand, should be installed behind the waterproofing to ensure that any water reaching this area can easily drain down and out of the area behind the wall.

In addition to providing the perforated pipe drainage described above, designers, builders, and owners should ensure that the area around the building is sloped so as to direct rain and snow-melt water away from the building. In frequently-seen south-facing hillside sites, this may mean providing diversion ditches behind the building to move water out and away from the building.

10. <u>Outgassing From Tires</u>

When a tire bale building is initially enclosed, the tires may be left uncovered for a time. During this period it is possible that occupants may be able to smell the "rubbery" odor of the tires. However, when the walls are completed, they are covered with a 2 - 4 inch thick coating of cement-based plaster. The tires are completely covered and sealed away from the occupied space. It seems very unlikely that any out-gassing would reach the occupied space once the plaster is in place. Any residual odor will slowly but steadily be reduced by continuing ventilation of the enclosed space.

This issue has been studied and commented upon extensively by designers, builders, and owners (as well as detractors) of related rammed tire earthship buildings, previously referred to. I have done much reading in this area and I have been unable to find a single case where any human or animal sickness occurred that was attributable to outgassing tires. The use of discarded tires for occupied structures is relatively new compared to other building technologies, and it is possible that long-term problems may arise. However, other outgassing issues inherent in conventional buildings, like the chemicals used in commercial glues, carpets and engineered wood, seem to be at least as serious.

11. <u>Fire Protection Issues</u>

Concerns have also been expressed regarding the use of tires in residential structures. Tires are flammable, can emit toxic smoke and fumes when burning, and can be very difficult to extinguish when loosely stacked. The method of construction used for tire bale walls allays these concerns. First, coating the tire bales with a thick layer of non-combustible cement-based or earthen plaster or stucco eliminates their exposure to sources of ignition and insulates them from the heat of a nearby fire. Also, compaction of the tires into a tight, dense bale reduces the amount of oxygen that would be readily available for combustion. Finally, grouting the voids between the bales will further reduce the available oxygen in the wall as well as reduce the possibility of ignition. These measures reduce the possibility of a tire bale wall fire and the associated hazards to a reasonable level.

I have not heard of a situation where compacted tire bales, treated with a non-combustible coating, were involved in a fire. Fire situations have occurred with rammed earth tire earthship residential buildings. In these cases, earthships in remote areas were involved in forest and/or brush fires. Conventional stick frame houses and the wood frame parts of the earthships (roofs and front walls) in the involved areas typically burned to the ground; but the rammed tire walls, treated with non-combustible stucco or plaster, remained intact. After remediation of smoke damage and removal of ash and other residue the walls were capable of being re-used.

As far as I know, only ad hoc fire protection-related testing has been conducted on tire bale walls, but given the information at hand, it seems unlikely that the level of hazard would be greater than that of a conventional frame house.

In cases where a tire bale wall based house is distant from fire fighting resources (water, fire department, etc.) it would be appropriate to reduce or eliminate combustible vegetation around the building, to reduce or eliminate combustible exterior building materials in areas such as trim, fascia, soffits, and roof, and to provide a local source of firefighting water, such as a well or cistern. (These measures apply to all types of construction, not just tire bale wall buildings.) Fortunately, a variety of non-combustible products, such as HardieBoard™ cement board and sheet metal products are available for these applications.

12. <u>Potential Seismic Issues</u>

I have never practiced in an area considered highly prone to seismic activity, so my knowledge of this subject is quite limited. However, gravity is the primary force holding a tire bale wall together; it seems likely, therefore, that the various types of motion that are induced by earthquakes could cause a tire bale wall to topple. If the wall toppled, the weight of the massive tire bales would certainly crush human beings, animals, and a wide variety of other objects. The use of tire bale walls in structures for human habitation in seismic areas is therefore NOT recommended at this point.

It would be interesting to assemble a complete tire bale wall with grouting and bond beam on a large shaker table for testing to see how it compares with other forms of construction. Alternatively, or in addition, tire bale structures for non-habitation use, such as sound abatement walls or storage dividers for aggregate or landscaping materials could be assembled in earthquake-prone areas and their performance could be observed over time as earthquake events occur.

Conclusions

After examining several tire bale structures and the issues that have been raised concerning tire bale walls, I can find no substantial reason why they should not be used for walls in residential and commercial structures in non-seismic areas as long as they are assembled and finished as described above. Using tire bales in this way has the potential for reducing landfill utilization, waste, and inappropriate/illegal disposal of scrap tires in a way that results in a product that can have positive societal impact.

Figure 6 – Southwest View of Tire Bale House near Fountain, Colorado

Only a few structures have been built with tire bale walls thus far. Our knowledge about the character of the material, the building process, and the ultimate result is minimal compared to our knowledge from the millions of structures that have been built using conventional methods. But our knowledge will only increase with more experience.

- Leonard D. Jones, P.E. -

Jones is a Colorado Professional Engineer with over 30 years diverse experience in designing, operating, and trouble-shooting energy systems. A graduate of the Colorado School of Mines with a B.S. in Metallurgical and Materials Engineering, he also holds a M.B.A. from Nova Southeastern University and a M.S. in Information Science from Regis University.

Jones began his career as an officer in the U.S. Army Corps of Engineers, where he received an introduction to the use of modified soils as construction materials as well as building with vernacular (field expedient) materials. His subsequent professional assignments have included engineering and cogeneration operation at a large mine and mill complex, managing energy systems engineering for a large Midwestern natural gas utility, and facilities management at the National Renewable Energy Laboratory.

While currently employed in Information Technology for a large telecommunications company, his primary current interests include earth building and evaluating alternative technologies. He maintains a professional engineering practice supporting non-traditional builders with studies, evaluations, engineering documents, and building permit applications. Jones is currently building a low-energy rammed earth house at Crestone, Colorado, and is interested in discussing possible consulting assignments with potential clients.

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