Usage Guide

Tire-Derived Aggregate (TDA)

CalRecycle

California Department of Resources Recycling and Recovery

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Contractor's Report
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Executive Summary

Currently, California generates more than 40 million waste tires per year. The Department of Resources Recycling and Recovery (CalRecycle) has a goal to increase the diversion of waste tires from landfills. One way that CalRecycle hopes to achieve this goal is by promoting the use of tire-derived aggregate (TDA) in civil engineering applications. TDA is a lightweight and highly permeable aggregate made from used scrap tires.

Since the 1980s, research efforts and extensive material testing have enabled CalRecycle to make significant progress promoting the use of TDA in civil engineering applications. CalRecycle has successfully partnered with both state and local governments to complete projects that have demonstrated its performance and cost-effectiveness. Additionally, CalRecycle continues to develop long-term, sustainable markets for TDA. One of the most notable is the use of TDA in the expansion of the rail systems for both Bay Area Rapid Transit (BART) and the Southern California's Metropolitan Transportation Agency. In addition to diverting about 750,000 tires from our landfills, these two projects saved BART and MTA millions of dollars. Through partnerships with CalRecycle, Caltrans and numerous local agencies experienced firsthand the beneficial engineering properties and the cost savings of using TDA in embankment fills, slope repair, retaining wall backfill, and landfill gas collection system projects. These efforts have saved local agencies substantial funds while building sustainable infrastructure projects and diverting large numbers of waste tires from landfills.

This guide has been designed as a quick reference for engineers and public works directors on the types of projects that can benefit from the use of TDA. This guide also provides state-of-the-design and construction practices for using TDA in civil engineering applications. With this guide, CalRecycle hopes to create advocates who understand the engineering, cost saving, and sustainability benefits of TDA.

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1. Introduction

1.1 What Is TDA?

Tire-derived aggregate, or TDA, is a recycled construction material derived from waste tires. TDA was originally called “tire shreds,” but with the development of gradation standards and specifications that distinguished the material from waste tires and other waste tire derivatives, the name TDA was adopted to differentiate it as a standardized material. TDA has inherent beneficial properties as an engineering material replacement for traditional aggregates like drainage gravel and pumice rock, including, but not limited to, being lighter weight, high permeability levels, and a lower cost material.

1.2 ASTM Definition of TDA

The American Society for Testing and Materials (ASTM) has outlined the Standard Practice for Use of Scrap Tires in Civil Engineering Applications (ASTM D6270-08 2008). TDA is defined in Section 3.1.28 of these guidelines as “pieces of scrap tires that have a basic geometrical shape and are generally between 3 and 12 inches in size and are intended for use in civil engineering applications.” Figure 1-1 shows TDA used as a retaining wall backfill material.

Figure 1-1: Type B TDA Used as Retaining Wall Backfill Material

1.2.1 TDA Production Process

TDA is made by processing waste tires with a tire shredding machine that incorporates rotating cutting shears along with a conveyor and screening system. Sharp shears are necessary to produce clean cuts without leaving significant amounts of exposed wire. A single pass through the machine produces rough shreds. Multiple passes through the shredder and a screening system are used to produce appropriately sized tire shreds. The production process can vary significantly among producers. However, the general principle holds that the smaller the material to be produced, then the more shredder passes are necessary. While there are many TDA vendors and many viable process configurations, ultimately it is the responsibility of the project owner to ensure that the TDA material supplied meets the desired specifications (listed in section 1.4).

Working with vendors to ensure adequate supply and compliance with the specifications is an important part of the project planning process. Vendors typically produce a variety of shredded tire products to meet demand and don’t generally have stockpiles of TDA material. Also, because many scrap tires are commonly processed into tire-derived fuel (TDF) and crumb rubber, vendors may need to adjust their process for TDA applications.

1.3 **Brief History of TDA**

The earliest formal use of waste tires in civil engineering applications occurred in the 1970s. At that time, unshredded waste tires were used for constructing breakwaters and artificial reefs. Use of scrap tires in civil engineering applications was very limited through the 1980s (Humphrey 2003).

Since 1989, CalRecycle has implemented a variety of programs to greatly increase the number of waste tires that are put to beneficial use rather than being sent to a landfill. A number of programs have focused on research and market development for recycling waste tires into TDA for civil engineering applications. In the late 1990s, illegal dumping and environmentally and financially catastrophic tire pile fires led California to accelerate its promotion of the beneficial uses of TDA. The first transportation project using TDA in California was an embankment fill constructed in the year 2000 near Milpitas, Calif., at the Dixon Landing South I-880 onramp. The unique properties of TDA allowed for significant cost and time savings on this project

Using TDA in civil engineering applications has become a major part of CalRecycle's effort to successfully divert waste tires from landfills. As more projects are successfully completed, civil engineering use of TDA is rapidly becoming attractive as a resource reuse and for the cost savings that are realized.

1.4 **How TDA Is Used**

One of TDA's greatest benefits as an engineering application is that it is lightweight. TDA weighs about 45 pounds per cubic foot (pcf) and exerts about half the earth pressure compared to traditional fills. It also has excellent thermal insulation (8 times more insulating than gravel), drainage (permeability greater than 1 cm/sec), and vibration damping properties.

1.4.1 **Appropriate Uses of TDA**

The engineering properties of TDA results in many benefits for civil engineering applications. Its lightweight properties make it suitable to replace conventional fill material by reducing forces in embankments, retaining walls, bridge abutments, and landslide areas. The viscoelastic characteristics of TDA make it a good material for rail vibration damping and potential seismic projects. TDA is also highly permeable, which makes it a good drainage material. It has been commonly used for its drainage properties in landfill gas collection trenches and drainage layers, septic leach fields and, in some cases, French drains.

The ASTM standard separates TDA into two basic types used in engineering applications, Type A and Type B; and two classes of fill associated with them, Class I and Class II. Type A and Type B are size classifications that are used for different applications. Class I and Class II describe lift thicknesses of the fill as defined by ASTM D6270, Section 6.10.1.

Type A material is roughly 3 to 4 inches (75 to 100 mm) in size, and Type B material is roughly 6 to 12 inches (152.4 to 304.8 mm) in size. Class I fills are TDA layers that are less than 3 feet (1 meter) in height, and Class II fills describe TDA layers that are between 3 and 10 feet (1 and 3 meters) high. Typically Type A material is used in Class I fills, and Type B is used in applications requiring a Class II fill. Table 1-1 summarizes Type A and Type B size classifications and Figure 1-2 shows photos of typical samples of the material.

Table 1-1: Fill Classes (ASTM D6270 Section 6.10.1-4)

Characteristics	TDA Type A	TDA Type B
Fill Class	Class I	Class II
Typical Size	3-4 in (75-100 mm)	6-12 in (150-300 mm)
Maximum Layer Depth	Less than 3 ft (1 m)	Less than 10 ft (3 m)

Figure 1-2: Left - Type A TDA, Right - Type B TDA

1.5 Benefits of Using TDA

Besides the environmental benefits of diverting waste tires from landfills, and the engineering properties that make TDA suitable for a number of civil engineering applications, it is also a very durable material: It is not biodegradable and does not lose its engineering properties. TDA can also have significant cost advantages. The benefits of using TDA are discussed in more detail below.

1.5.1 Environment

The United States generates about 300 million waste tires each year; California generates about 40 million waste tires per year. Before the 1990s, many of these tires ended up in stockpiles, both legally and illegally. Stockpiled waste tires pose significant public health and environmental issues. The curved shape of a tire has the ability to retain liquids, such as rainwater, creating an ideal breeding ground for disease-spreading vectors such as insects and rodents.

At very high temperatures, tires are combustible. It is estimated that one passenger tire equivalent (PTE) can release up to 2 gallons of pyrolytic oil during combustion (Zelibor 1991). Although the Environmental Protection Agency (EPA) does not consider scrap tires to be a hazardous waste, tire fires release hazardous compounds that pollute the air, soil, and water.

Public agencies and private companies have spent millions of dollars cleaning up after tire fires across the United States.

1.5.2 Engineering

TDA has beneficial engineering properties that are suitable for a number of applications.

Embankment Fill Material: TDA has been used as an embankment fill material due to its light weight. TDA is one-half to one-third of the weight of a conventional fill material and therefore produces lower pressures on the underlying material. This reduces the amount of settlement that will occur in areas of weak foundation soils and also reduces the chance that an embankment may fail due to the effects of excess vertical pressures. Since TDA is also relatively free-draining, using it as fill will substantially reduce the potential of saturated subgrade conditions.

Retaining Wall Backfill Material: Retaining structures are commonly used in civil engineering applications, including areas adjacent to roads and bridges. Retaining structures typically retain soil backfill and are designed based on the material properties of the backfill. Due to its light weight, using TDA as backfill material could result in a more cost-effective retaining wall design that would use less concrete or steel.

Landslide Repair Material: Road landslides are typically caused when the backfill becomes fully saturated, resulting in excessive hydrostatic pressures and weak soils that cannot support the weight of the backfill. TDA is lighter than soil, so it reduces the loads exerted by the backfill, and since it is also more permeable than soil, it reduces the risk of the backfill becoming fully saturated. These benefits make TDA a good choice for landslide repair.

Vibration Damping Material: TDA has been used in light-rail applications due to its ability to effectively reduce the transmission of ground-borne vibrations to surrounding areas. In this application, TDA is placed in a layer beneath a light rail track and is encased in geotextile. This has proven to be a cost-effective alternative to conventional technologies to mitigate ground vibrations caused by the operation of light-rail trains.

Landfill Applications: TDA has been used in landfill applications to carry out a few main tasks that are important to ensure proper function of a landfill. Due to TDA's high permeability, one of the main uses in landfill applications is its use in both leachate and gas collection. Since it is lighter than rock or gravel, and relatively free-draining, it is also used as underlayment for the winter tipping deck where trash trucks off load their waste.

Septic Leach Field Drainage Material: Septic tank system leach fields require the use of a drainage material to provide an adequate environment for the function of microbial organisms while also maintaining adequate transmission properties to convey septic tank leachate from the system into the surrounding soil. TDA has been used in this application to replace gravel or rock due to its high permeability and provide septic leachate treatment.

1.5.3 Durability

Tires are made of very durable engineered materials in order to provide reliable, safe, and predictable behavior while on the wheels of vehicles. Waste tires are not biodegradable and as a result occupy valuable space if disposed in landfills. Because TDA is derived from tires, it retains the same durable engineering material properties. In addition, in general, once TDA has been placed in a civil engineering project, it is no longer subject to oxidation or UV degradation from the sun.

1.5.4 **Cost**

TDA is a cost-effective alternative to conventional construction materials typically used in civil engineering applications. A cost-benefit assessment performed by a third party for CalRecycle in 2015 evaluated six civil engineering projects that utilized TDA in California. For embankment projects, TDA was evaluated against conventional soil fill as well as other competing lightweight fill options such as pumice rock, expanded polystyrene, expanded shale clay, and wood chips. TDA and crushed gravel costs were analyzed for landfill applications, and TDA and soil were assessed for the landslide repair project. For vibration mitigation, TDA costs were evaluated against floating concrete slabs.

The information in Table 1-2 summarizes the cost for each project if different fill materials were used and provides the percentage of cost savings for four TDA applications: embankment fill projects, landfill applications, landslide repair projects, and light-rail vibration mitigation projects. Based on current market prices, the material and transportation costs of TDA are significantly lower than the competing conventional and lightweight fill options. Additionally, TDA performs equally to floating concrete slabs for vibration mitigation.

Table 1-2: TDA Cost Comparison Summary Table

Application	Material	Total Cost 1	Percent of TDA Costs
Embankment Project – Confusion Hill/Hwy 101 Realignment, Mendocino County, CA			
Traditional Fill Option	Soil	$316,358	169%
Lightweight Fill Option	Pumice Rock	$514,354	274%
	Expanded Polystyrene	$643,539	343%
	Expanded Shale Clay	$632,716	337%
	Wood Chips	$307,138	164%
	Type B TDA	$187,500	100%
Embankment Project – Dixon Landing Road, Milpitas, CA			
Traditional Fill Option	Soil	$562,864	169%
Lightweight Fill Option	Pumice Rock	$632,726	190%
	Expanded Polystyrene	$1,144,984	343%
	Expanded Shale Clay	$489,829	147%
	Wood Chips	$545,226	163%
	Type B TDA	$333,600	100%
Landfill Application – Badlands Landfill, Riverside County, CA			
Traditional Trench Option	Crushed Gravel	$19,102	139%
TDA Material Option	TDA Type A	$13,750	100%
Landfill Application – Kiefer Landfill, Sacramento County, CA			
Traditional Trench Option	Crushed Gravel	$295,343	141%
TDA Material Option	TDA Type A	$209,585	100%
Slide Repair – Marina Drive, Mendocino County, CA			
Traditional Fill Option [2]	Soil	$937,612	492%
TDA Material Option	Type B TDA with Soil Layers	$190,555	100%
Vibration Attenuation – Santa Clara VTA, CA			
-15 dB for 14-17 Hz	Floating Concrete Slabs	$2,115,000	2951%
-10 dB for > 16 Hz	TDA	$71,667	100%

Source: Cost Benefit Assessment: Evaluation of Tire-Derived Aggregate Against Alternate Fill Options for Civil Engineering Applications. Prepared for CalRecycle by GHD, Inc. February 2015.

Notes:

1. Total costs were based on material, transportation, and longevity costs; does not include installation costs or contractor's overhead and profit.
2. Accounted for over excavation needed to stabilize slope for soil.

2. TDA Usage in Civil Engineering Applications

There are many uses for TDA in civil engineering applications. This chapter gives an overview of the types of applications, including TDA design and construction benefits, and example projects.

2.1 Introduction

As discussed in the previous chapter, TDA has many characteristics that make it beneficial for use in civil engineering applications. Since TDA is one-third the weight of soil, it is suitable to replace conventional soil backfill material by reducing forces in when designing embankments, retaining walls, bridge abutments, and landslide repairs. TDA is also more permeable than typical drainage rock and has a higher void ratio. Due to its excellent drainage properties, it has been commonly used in gas collection trenches, drainage layers in landfills, and septic leach fields. The following sections provide an overview of various types of TDA applications in civil engineering.

2.2 Embankment Fill Material

TDA has been used as an alternative embankment fill material due to its light weight. TDA is one-third of the weight of conventional fill material and therefore produces lower pressures on the underlying material. This can be an advantage when designing an embankment fill project in which the weak underlying foundation soil cannot support the weight of a conventional soil backfill.

Additionally, TDA is highly permeable and therefore often does not require the placement of subdrain systems. This provides an additional cost savings. As a lightweight fill material, TDA has proven to be a cost-effective alternative to other materials like pumice or geofoam. Other benefits of TDA in road fill and embankment applications may include increasing the stability of steep slopes along roadways, reinforcing roadway shoulders, and providing an insulating layer against frost penetration due to its thermal resistance properties.

2.2.1 Design

TDA should be considered when a lightweight backfill is needed in the design of an embankment project. This could occur if the embankment is constructed on a soil with low load-bearing capacity, like a soft clay or peat, and if excessive settlement and/or time constrains are an issue. Being less than half the weight of comparably compacted soil, TDA can increase the stability of the embankment by reducing driving forces on the underlying foundation material.

When designing an embankment with TDA, there are several aspects that are important for consideration. These include overlying soil cover thickness, slope stability, geotextile separator, TDA overbuild, and time-dependent settlement. The details of these design aspects can be found in the TDA Technical Handbook (Cheng et al. 2009).

2.2.2 **Construction**

Construction of an embankment that utilizes TDA is similar to typical lightweight fill projects, and other than the 40-foot walking-floor trailers that are typically used to deliver TDA, no special construction equipment is required to spread and compact TDA fill (Figure 2-1).

Figure 2-1: Unloading TDA from Walking Floor Trailer

TDA has a much lower density than traditional fill materials. This means that haul trucks can transport large volumes of TDA at legal weight limits. This reduces the total number of trucks required to complete a fill project, which may be an important issue where traffic control, limited site access, or carbon footprint is a concern.

TDA can be spread with bulldozers and compacted with standard (10-ton) rollers. ASTM D6270 specifies that TDA be placed in 1-foot lifts and compacted by passing over each point in the fill a minimum of six times per lift. Note that traditional methods of determining in-place density such as the sand cone and nuclear gauges do not work with TDA. Estimates of in-place density may be obtained by surveying the volume of the fill and knowing the total weight of TDA placed.

The top layer of a TDA embankment should be at least 3 feet below the base or sub-base layer of the pavement that will be on top of the embankment. Each layer of a TDA embankment must be fully compacted before the next layer is placed. When the top layer of TDA has been fully compacted, the sides and top of the TDA should be fully wrapped with a geotextile fabric. The thickness should be determined by the design of the road, but a minimum of 3 feet of compacted soil should be placed on top of the geotextile and TDA. The TDA backfill will experience minimal settlement during placement and compaction of the soil cover, so overbuilding of the TDA fill volume, calculated based on the final configuration is appropriate.

2.2.3 Example Projects

Dixon Landing Road Project (2000)

TDA was chosen as a lightweight fill for an onramp construction project in Milpitas, Calif., built in 2000 and 2001. The project site is the Dixon Landing I-880 southbound on-ramp. This was the first embankment project that the California Department of Transportation (Caltrans) used TDA. Lightweight fill was necessary because the highway onramp was constructed over bay mud, which has a low load-bearing capacity. Additionally, if a conventional soil had been chosen, the project would have been delayed for an additional year to allow adequate settlement of the soil backfill. This project utilized two layers of TDA, each 10 feet high and wrapped in a geotextile fabric, separated by and covered with conventional soil.

Caltrans considered using both TDA (in place unit weight of 50 lbs/ft^3) and a competitive lightweight pumice rock (in place unit weight of 70 lbs/ft^3). At the design phase of the project, the cost of pumice was compared to the cost of TDA. Caltrans selected TDA for the Dixon Landing Project due to the significantly lower unit weight and unit cost as compared to pumice rock (Humphrey 2003). Figure 2-2 depicts TDA being compacted in place. Figure 2-3 shows the cross section of the Dixon Landing Embankment Project using TDA.

Figure 2-2: TDA Being Compacted at Dixon Landing

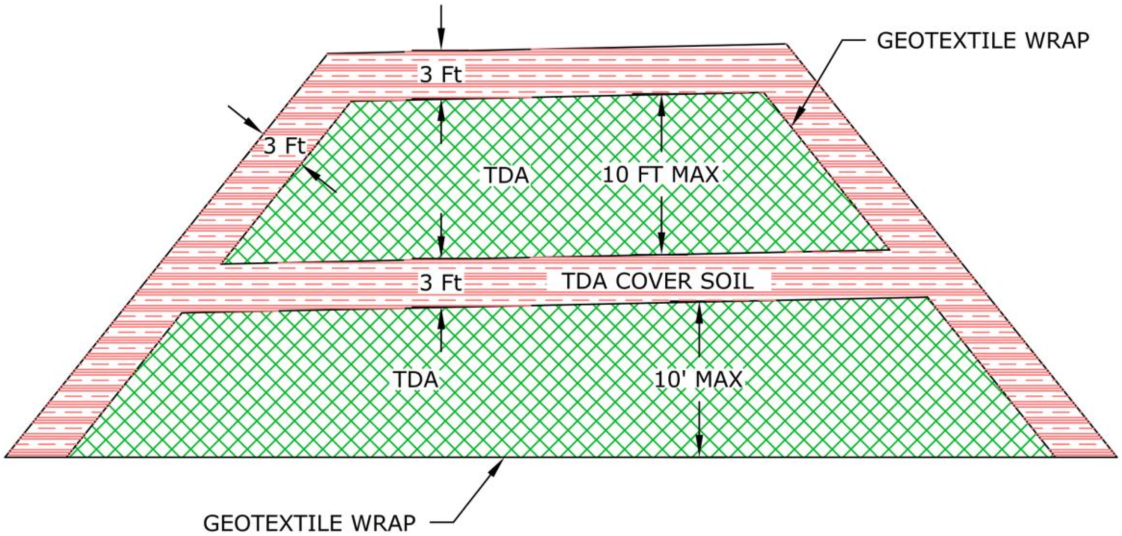

Figure 2-3: Cross Section of Dixon Landing Embankment Project Using TDA

As shown in Figure 2-4, the completed ramp was 26 feet high, 700 feet long and 50 feet wide and contained approximately 6,627 tons or 662,700 passenger tire equivalents (PTE) of TDA (Humphrey 2003). The same volume of other lightweight aggregate or typical soil would have weighed 1.5 to 2.5 times as much as the TDA. There have been no performance issues related to this embankment after 14 years of service life, and the use of TDA as an alternative to pumice rock saved the State of California approximately $230,000.

Figure 2-4: Final Dixon Landing TDA Embankment

Confusion Hill Realignment Project

Completed in 2008 by Caltrans with Federal Highway Administration funding, the Confusion Hill Realignment Project included a highway realignment, construction of two bridges, and repair of a portion of Highway 101 that was damaged by slope failures (see Figure 2-5). Part of the realignment section of the project called for an additional 7 feet of engineered fill over an existing arch culvert. The culvert conveys Red Mountain Creek under the highway to the Eel River. Unfortunately, the arch culvert was not designed to accommodate the weight of the additional engineered fill so the arch would have had to be demolished and reconstructed to allow for the additional weight. This would have provided significant cost to the project.

Caltrans selected lightweight fill as an alternative to constructing a new culvert. Due to its lightweight properties and cost-effectiveness, TDA was selected. This provided a solution that did not increase the overall load on the culvert. Figure 2-6 shows the cross section of Confusion Hill TDA Embankment. Multiple lightweight materials could have been used, but TDA was selected by Caltrans since it was the most cost-effective alternative. Figure 2-7 and Figure 2-8 show the Confusion Hill project overview and the completed project.

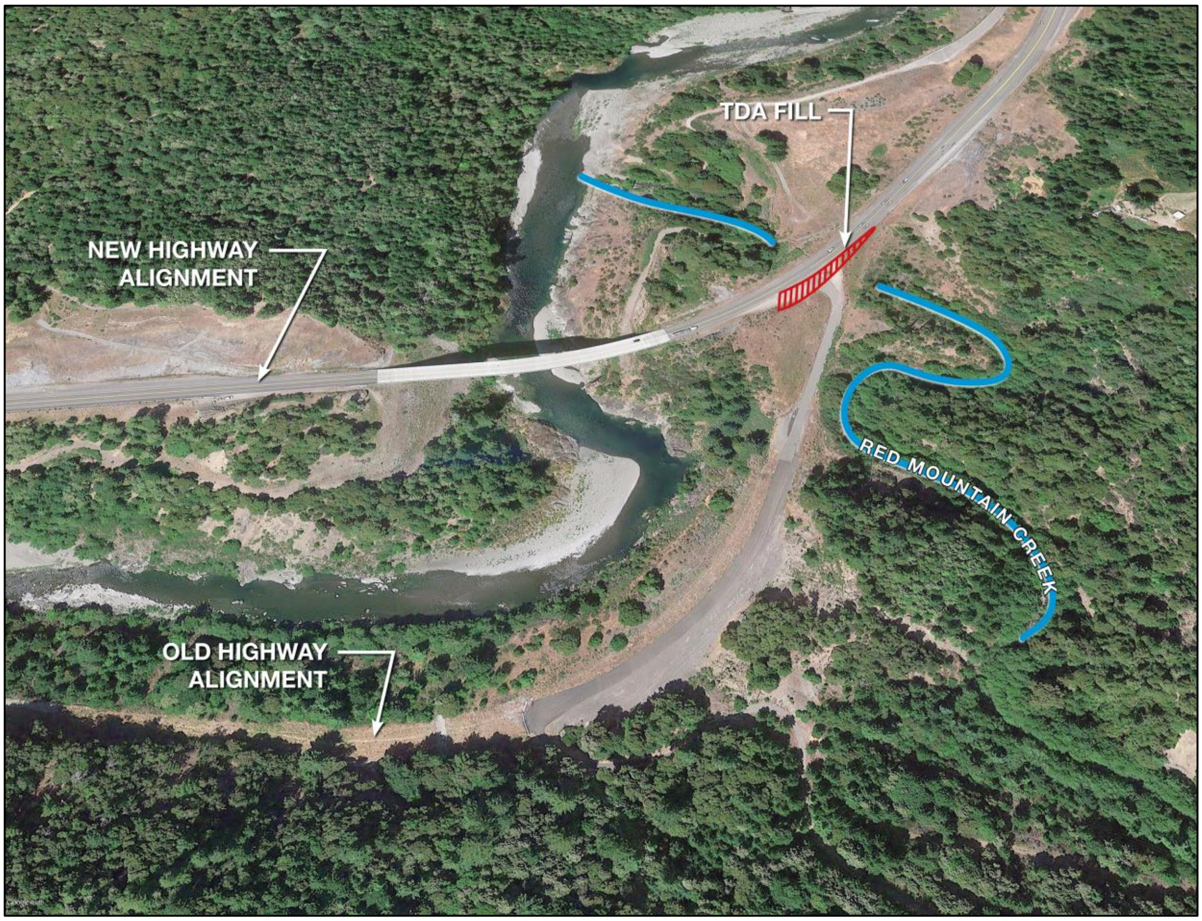

Figure 2-5: Confusion Hill Backfill Project Overview

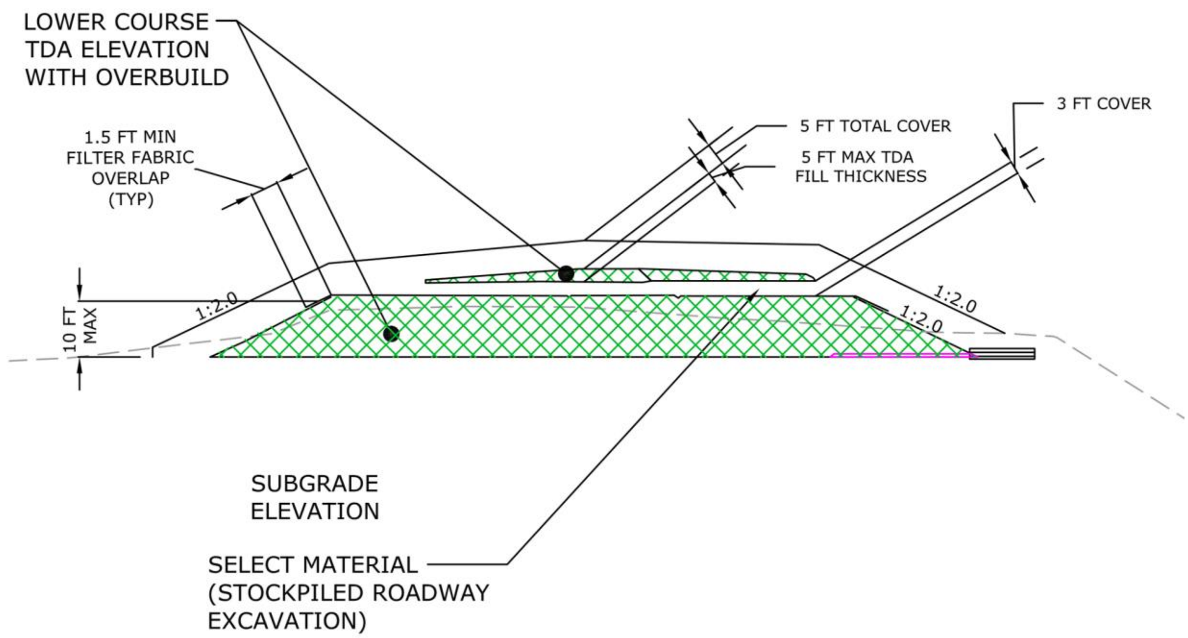

Figure 2-6: Cross Section View of the Confusion Hill TDA Embankment Highway 101–TDA Lightweight Fill

Figure 2-7: TDA Placement at Confusion Hill Site

Figure 2-8: Final Condition, Confusion Hill TDA Fill Volume

Caltrans realized a significant cost savings and reduction in the construction time to complete this project. This is due in large part to Caltrans avoiding the costly demolition of the culvert and using TDA, a more cost-effective lightweight fill material. When compared to the culvert demolition project alternative, the TDA alternative saved Caltrans more than $500,000.

2.3 Retaining Wall Backfill

Retaining walls are commonly used in civil engineering structures adjacent to roads and bridges. Retaining walls typically support soil backfills and are designed based on the material properties of the soil backfill. Properties such as unit weight and cohesion of a soil in addition to the height of the soil backfill are important factors in determining the design characteristics of the retaining wall. Generally, materials having higher unit weight and larger overall height will require more robust structures to retain them due to the increase in the lateral forces applied to the structure by the soil. TDA has advantages as an alternative to conventional soil backfill mainly because it is significantly lighter than soil and is free-draining.

Since the in-place unit weight of TDA typically ranges between 40 and 50 lbs/ft^3 (approximately one-third of the unit weight of most soils), it is very effective in reducing the lateral forces applied to the wall. Using TDA as a retaining wall backfill can result in wall designs that use less steel and/or concrete and require less excavation, which can result in significant cost savings over typical soil backfill retaining walls.

2.4 **Design**

Engineers designing retaining walls with TDA backfills would use the same procedures as retaining walls with a conventional soil backfill. The retaining wall must be designed to take into account bearing capacity as well as resistance to overturning and sliding. Additionally, concrete walls must be designed with adequate reinforcement to oppose the shear forces applied to the wall by the backfill material.

The use of TDA as lightweight backfill not only reduces the forces applied to the retaining wall that contribute to sliding or overturning, but also the resistance to sliding and overturning. This can be validated by comparing the factor of safety calculations for the TDA backfill design to conventional soil backfill design. Therefore, using TDA in a retaining wall design not only reduces the magnitude of forces that the wall experiences due to the backfill, but it also increases the factor of safety. In addition, a retaining wall using TDA as a backfill material will require less reinforcing steel and concrete than a wall with a conventional soil backfill, which can result in significant cost savings.

2.5 **Construction**

Construction of a retaining wall with TDA as backfill is similar to the construction of retaining walls with conventional backfills, except the TDA wall may use less concrete and steel than a conventional retaining wall. Since retaining walls are typically constructed on native or imported compacted soil, the TDA backfill material is wrapped in a geotextile to prevent infiltration of the fines from the base soil or soil cover layers. Whereas most conventional soil backfill material is delivered using an end dump truck, most TDA backfill material is delivered by “walking floor” semi-truck trailers. However, due to the relatively low unit weight of TDA and bulk density, it takes fewer trucks and therefore costs less to transport TDA than conventional soil fill for the same volume.

Figure 2-9: Typical TDA Delivery for Retaining Wall Backfill

2.5.1 **Example Projects**

<u>Caltrans Retaining Wall 207, Riverside, California</u>

There are a number of well-documented case studies regarding TDA as a lightweight backfill behind retaining walls. One project, Wall 207, used TDA as a lightweight fill material behind a retaining wall as part of a freeway widening project in Riverside, Calif. TDA served as both the backfill and the drainage material. A cross section of a TDA retaining wall can be seen below in Figure 2-10.

Retaining Wall 207 was constructed to facilitate the widening of the I-215/Route 60/Route 90 freeway interchange. The construction consisted of a cantilever-type retaining wall backfilled with a combination of geotextile-wrapped Type B TDA and conventional granular backfill. Construction occurred between March 2006 and June 2007. The wall is 460 feet in length and 12.7 to 23.8 feet in height, and it used layers of TDA between 7.3 and 10 feet thick.

In order to determine if the pressures on a retaining wall using a TDA backfill were less than the pressures on a wall using a soil backfill, Wall 207 was instrumented at four different locations: two within the TDA backfill areas and two within the soil backfill. When compared to soil, the pressure data clearly showed that forces exerted on the wall are less in the TDA backfill areas.

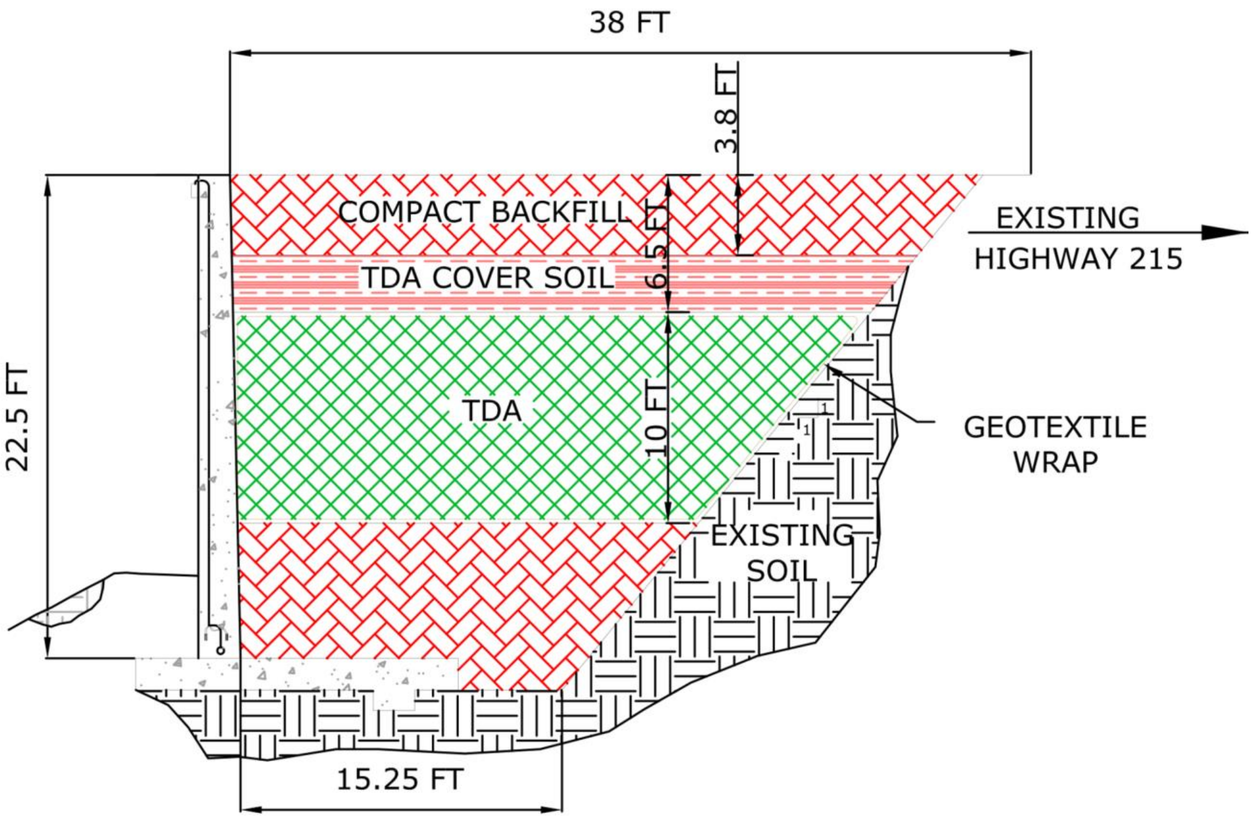

Figure 2-10: TDA Retaining Wall Cross Section

2.6 Road Landslide Repair

2.6.1 Road Landsides

Road landslides are often caused by a combination of excessive hydrostatic pressures and weak backfill material below the road. Landslides typically occur due to the loss of stability in a slope caused by excessive loading from the combination of heavy, saturated soils within the materials that make up the slope. Because TDA is lightweight and permeable, it is effective in reducing excessive loading on an unstable slope. An added benefit to using TDA is that its high permeability permits drainage through the various layers and can dramatically reduce the potential hydrostatic pressures that promote slope stability. These benefits make TDA a good choice for landslide repair and as a result, TDA has been used in numerous landslide repair projects completed to date.

A slope is considered stable when the shear strength of the soil is greater by a factor of safety than the driving force (weight of the backfill) down slope along the projected minimum slip plane. In the case where the driving force exceeds the shear strength of the backfill material, the slope will fail and slide downward. In landslide repair projects that have been completed to date, TDA is typically designed using alternating layers of TDA and soil (see Figure 2-11).

There are several key advantages to designing a slope with a TDA backfill. First, it is less than half the weight of soil, so the driving force causing a potential landslide is significantly reduced. Second, the internal shear strength of TDA is greater than soil, further increasing the resistance to the overlying driving force. Ultimately, using a TDA backfill design will result in a more stable slope as compared to a soil backfill design. In addition, designs using TDA as an alternative backfill can achieve the needed factor of safety values with much less excavation and engineered backfill.

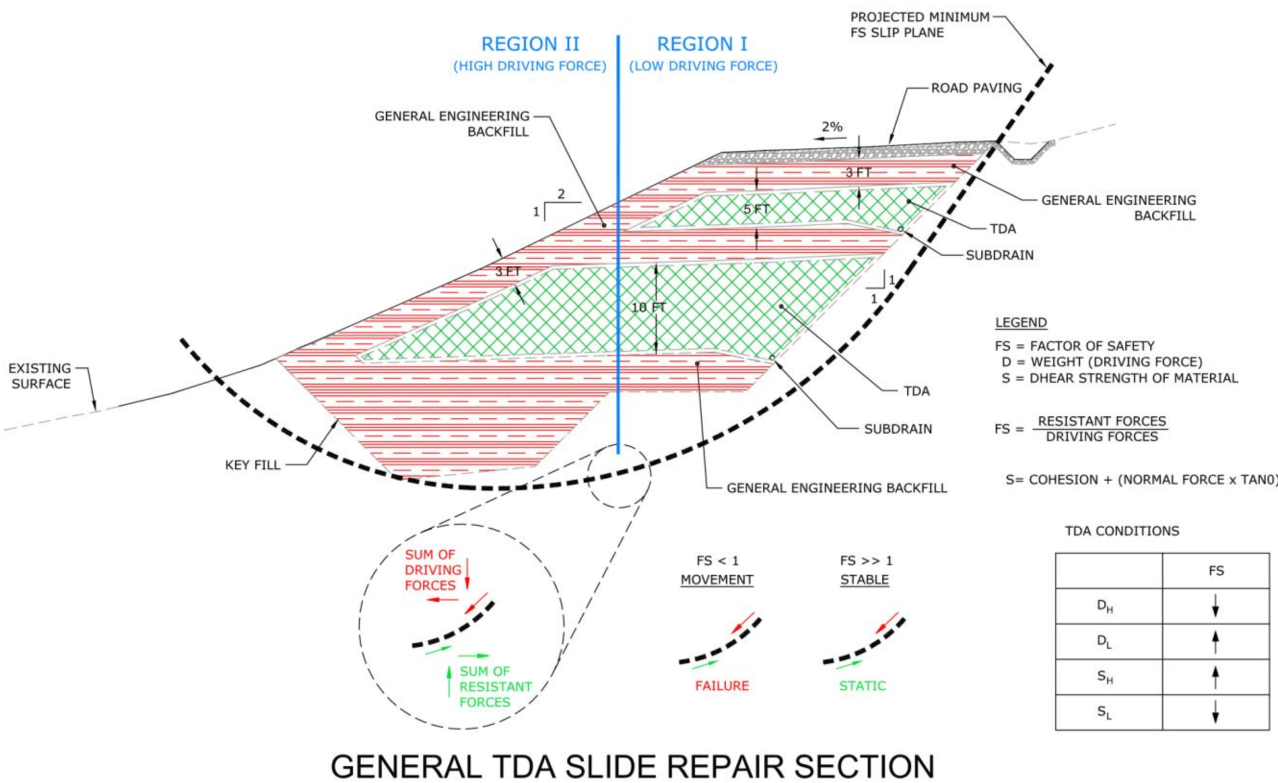

Figure 2-11: Slope Failure Cross Section

2.6.2 **Construction**

Construction of slopes containing TDA is a similar process to slopes constructed using conventional backfills with a few modifications to account for the unique properties of TDA. Engineered slopes are constructed alongside native soil materials whether they use TDA or not. It is important to use a geotextile to surround the TDA layer to prevent the TDA from intermixing with the surrounding soil material, maintaining the void ratio and therefore the lightweight property of the TDA backfill. Once placed, TDA can be spread using a track-mounted dozer or front-end loader. TDA placement is shown in Figure 2-12 and Figure 2-13.

Figure 2-12: Placement of Geotextile During a TDA Slope Repair

Figure 2-13: Walking Floor Semi-Truck Unloading TDA onto Geotextile

2.6.3 Example Projects

Marina Drive Landslide Repair, Mendocino County

A section of Marina Drive in Calpella, Calif., had been gradually failing since the 1960s. It was originally constructed by backfilling an existing ravine to create a base that would allow for the construction of a roadway above. This road is used for access to residential and recreational areas surrounding Lake Mendocino. Over the years, this gradual slope failure had been repaired by re-establishing the road grade using a combination of soil or base rock and asphalt concrete. Even though this method would prove to be ineffective, it did provide a temporary access to the areas surrounding the lake. This repair was repeated numerous times after each subsequent road failure. The repeated repairs to this road eventually led to the accumulation of layers of base rock and asphalt concrete nearly 7 feet thick. The weight of this growing repair section added to the destabilization of the existing slope (Kennec 2011).

CalRecycle coordinated efforts with the Mendocino County Department of Public Works to develop a landslide repair design for this section of road using TDA as a lightweight, permeable fill. The design utilized two layers of Type B TDA wrapped in geotextile (to prevent intermixing of soil with TDA), as depicted in Figure 2-14, and separated and covered by a layer of conventional soil (CalRecycle 2011). Figure 2-15 shows the cross section of the Marina Drive slide repair using TDA.

This landslide repair project used approximately 133,000 passenger tire equivalents (PTEs) and saved Mendocino County an estimated $90,000 over the soil alternatives (CalRecycle 2011). The final conditions can be seen Figure 2-16.

Figure 2-14: TDA Delivered, Spread, and Compacted on Marina Drive

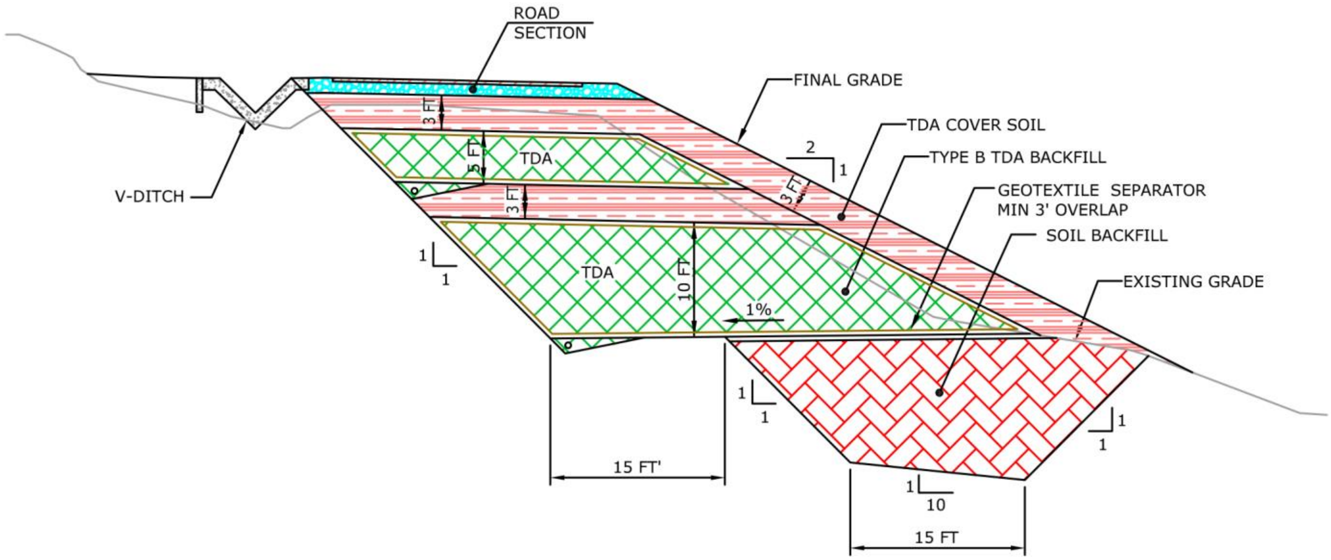

Figure 2-15: Marina Drive–Slide Repair Cross Section

Figure 2-16: Completed Marina Drive Slide Repair TDA Project

Sonoma Mountain Road, Sonoma County

In the 1980s, Sonoma Mountain Road in Sonoma County, Calif., failed due to a landslide. The landslide was caused by the compounded effects of having weak native soil and saturated ground conditions. The slide was originally repaired by means of a corrugated steel retaining wall. This wall was supported by the placement of steel H-piles placed into the slope. During heavy rains in December of 2008, this corrugated steel retaining wall failed, as shown in Figure 2-17. After two or more short-term repairs with H-piles, the county decided to implement a long-term TDA alternative repair.

Figure 2-17: Sonoma Mountain Road Retaining Wall Failure in 2008

This road was closed in January 2009 and rebuilt in the fall of 2009 using TDA as a lightweight fill. The County of Sonoma and CalRecycle, worked together to develop the landslide repair, as seen in Figure 2-18. The finished project resulted in the use of approximately 330,000 passenger tire equivalents (PTEs). The Sonoma Mountain Road design incorporated two layers of TDA separated by a layer of conventional soil. The bottom layer of TDA is 10 feet thick. The top layer is 5 feet thick. The soil separating the layers is 3 feet thick. Figure 2-19 shows the cross section of Sonoma Mountain Road Slope Repair Project using TDA.

Figure 2-18: TDA Placement and Compaction at Sonoma Mountain Road

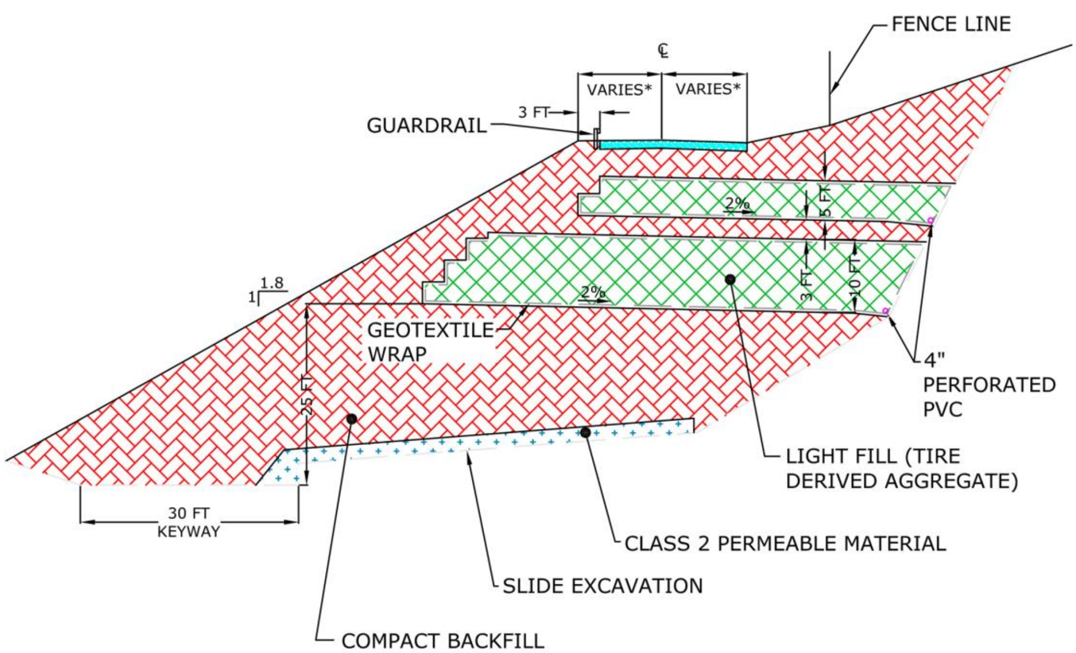

Figure 2-19: Cross Section for Sonoma Mountain Road Slope Repair Project Using TDA

Utilizing the TDA as a lightweight fill material allowed for a smaller excavation and resulted in savings to the county of approximately $300,000 (CalRecycle 2011). The final conditions of the project can be seen in Figure 2-20.

Figure 2-20: Final Sonoma Mountain Road TDA Slope Repair Project

Geysers Road, Sonoma County

During the winter season of 2006, a section of Geysers Road in Sonoma County failed due to a landslide (Figure 2-21). The landslide was likely caused by the saturation of the soil backfill during periods of heavy rain. This saturation was exacerbated by the inadequate function of the existing road subdrain system.

Figure 2-21: Landslide at Geysers Road, Sonoma County

In 2008, CalRecycle worked cooperatively with the County of Sonoma to develop a repair for this landslide using TDA as a lightweight fill (see Figure 2-22). The design included two layers of TDA that were wrapped in geotextile and separated by a layer of low-permeability soil. The top layer of TDA was covered by a layer of low-permeability soil and then a layer of soil backfill to serve as a road subgrade layer.

Figure 2-22: Spreading TDA Above Geotextile in Sonoma County

The final conditions of the project can be seen in Figure 2-23. Approximately 150,000 passenger tire equivalents (PTEs) were used in the repair of the 250-foot-long section of Geysers Road. By using TDA, the county saved approximately $270,000.

Figure 2-23: Completed Geysers Road Slide Repair

2.7 Vibration Damping

Light rail trains often pass through areas where the vibrations disturb the local residents. As the demand for light rail transportation increases, the generation of vibrations and their associated noise can affect public health and safety. By reducing ground-borne vibration through the use of vibration-mitigating materials, this problem can be minimized. TDA is a cost-effective vibration-damping solution.

Historically, vibration damping for light rail tracks has been achieved by either the use of special “elastic” track fasteners or through the construction of a vibration isolation system. This isolation system can be part of the track structure or built beneath the supporting base. These systems can be extremely expensive to install. A more cost-effective solution is the use of a 12-inch layer of TDA beneath the ballast rock, sub-ballast layers, and ties of a light rail track system. This has proven to be effective in the attenuation of ground-borne vibrations.

2.7.1 Design

In general, rubber is a type of viscoelastic damping material that is commonly used in engineering and is widely used for reduction of vibration and noise. The basic principle is that the rubber material (TDA) is effective in transforming the kinetic energy of vibration into heat energy by its viscoelastic properties.

TDA has been shown to be a great sub-base under light rail tracks where vibration mitigation is needed. TDA works well for many damping applications because of its vibration attenuation performance, low cost, and positive environmental impact.

When evaluating vibration mitigation techniques, the frequency levels of the source vibration define the types of mitigation techniques that will work. TDA used as a damping material performs as well as or better than most available alternatives for the most commonly mitigated frequency levels. Figure 2-24 shows a typical TDA cross-section as vibration mitigation for light rail lines.

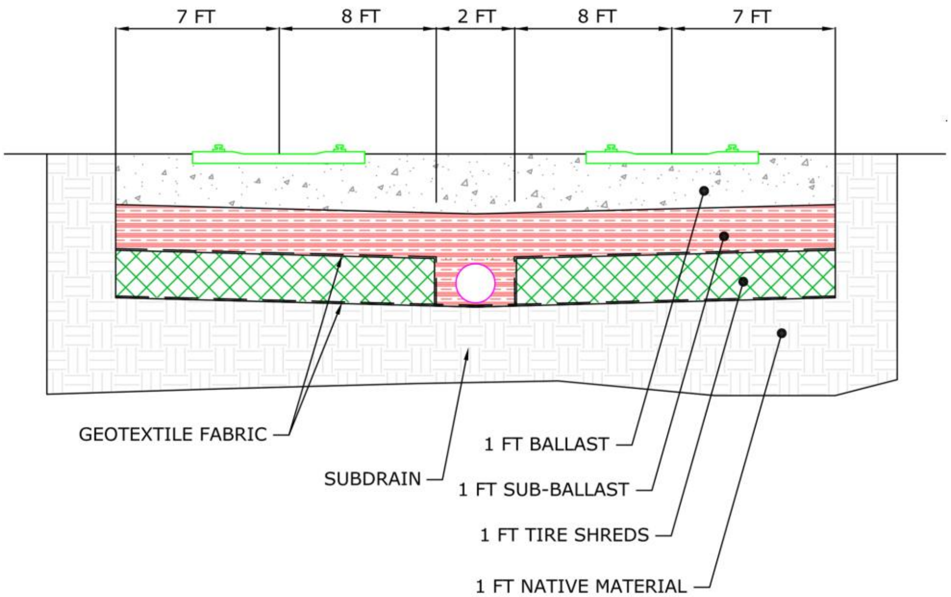

Figure 2-24: TDA as Vibration Mitigation for Light Rail Lines

2.7.2 **Construction**

When rail construction projects call for vibration-damping measures to reduce ground-borne vibrations, there are several options that the designer may consider. TDA is often the least expensive option, and the cost benefit compared to the most common alternatives is substantial.

Type A TDA is placed in a layer 12 inches thick, which is then covered with a 1-foot thick layer of sub-ballast, which is below a 1-foot layer of ballast material. This in turn supports the track structure (Figure 2-25). Tire-derived aggregate is effective in mitigating midrange vibrations (above 16 Hz). TDA performs better than that of a ballast mat technology where reduction of very low frequency vibration is necessary.

Figure 2-25: Spreading Type A TDA During Construction

2.7.3 Example Projects

<u>Bay Area Rapid Transit (BART) Fremont Warm Springs Extension Light-Rail Project</u>

A section of track requiring vibration mitigation was constructed by BART using TDA as a sub-ballast layer for mitigation of ground-borne vibrations (Figure 2-26 and Figure 2-27). This track section was constructed in Fremont, Calif., at the approximate intersection of Osgood and Washington roads. The tracks requiring TDA mitigation are in close proximity to housing developments and cross the Hayward Fault.

TDA was chosen for the BART project because it has proven to be an effective vibration mitigation alternative. In this case, the estimated cost of the track using TDA was determined to be about $121 per foot. This cost is much lower than the cost for sections of track using an alternative method of vibration mitigation, which ranges from $600 to $1,000 per foot.

Figure 2-26: BART TDA Placement

Figure 2-27: BART Sub-Base Over TDA Placement

2.8 Landfill Applications

A modern municipal solid waste (MSW) landfill is a combination of several engineered systems containing composite liners, leachate collection and treatment facilities, gas collection and control facilities, and most commonly after closure, a final impermeable cover. MSW landfills, which are designed to accept highly variable waste streams, use sophisticated environmental technology to control air and groundwater pollution. All MSW landfills in California must comply with stringent regulatory standards and be able to provide sanitary waste disposal mechanisms.

TDA has proven to be a useful part of several of these engineered systems that are essential to proper performance of an MSW landfill. The types of engineered systems utilizing TDA include leachate recirculation systems, gas collection systems, and landfill cover drainage layers.

2.8.1 Design

Designing engineered systems for use in a landfill using TDA is very similar to designing systems using traditional materials like rock or gravel. The only difference would be adjusting the designs to accommodate the difference in the engineering properties of TDA: density, shear strength, compressibility, specification (Type A or Type B), and hydraulic conductivity. TDA is lighter than gravel and rock, and more permeable than rock or gravel, and it has a higher bulk density so less TDA is needed to occupy the same volume of rock or gravel.

2.8.2 Construction

The construction methods for TDA placement are similar to those used for rock or gravel. Although the methods are similar, care should be taken when placing TDA. Steel wire protruding from TDA has punctured rubber tires on loaders and other machinery. When spreading TDA, track-mounted equipment should be used including dozers, loaders, or blade-equipped steel wheel compactors.

2.8.3 Example Project, Kiefer Landfill, Sacramento County, Calif.

Kiefer Landfill is a municipal solid waste landfill that began operation in 1967 and started producing electricity through the use of a gas-to-energy conversion system in 1999. The landfill owners have expanded the gas collection system to the second module of the landfill. A leachate recirculation system has been installed, and TDA is used as a substitute for conventional drain rock or gravel as the permeable fill material (Figure 2-28).

The project consisted of 2,416 feet of total trench length divided among five sections. Approximately 700 tons of TDA was used in the landfill gas/leachate recirculation trenches. The trenches were 5 feet deep and 4 feet wide with 1 foot of TDA placed as initial pipe bedding, as shown in the cross section in Figure 2-29. Once the piping was in place, it was covered with an additional foot of TDA with a geotextile separation layer, and the whole trench was then covered to grade with soil backfill. Piping placement on this project can be seen in Figure 2-30.

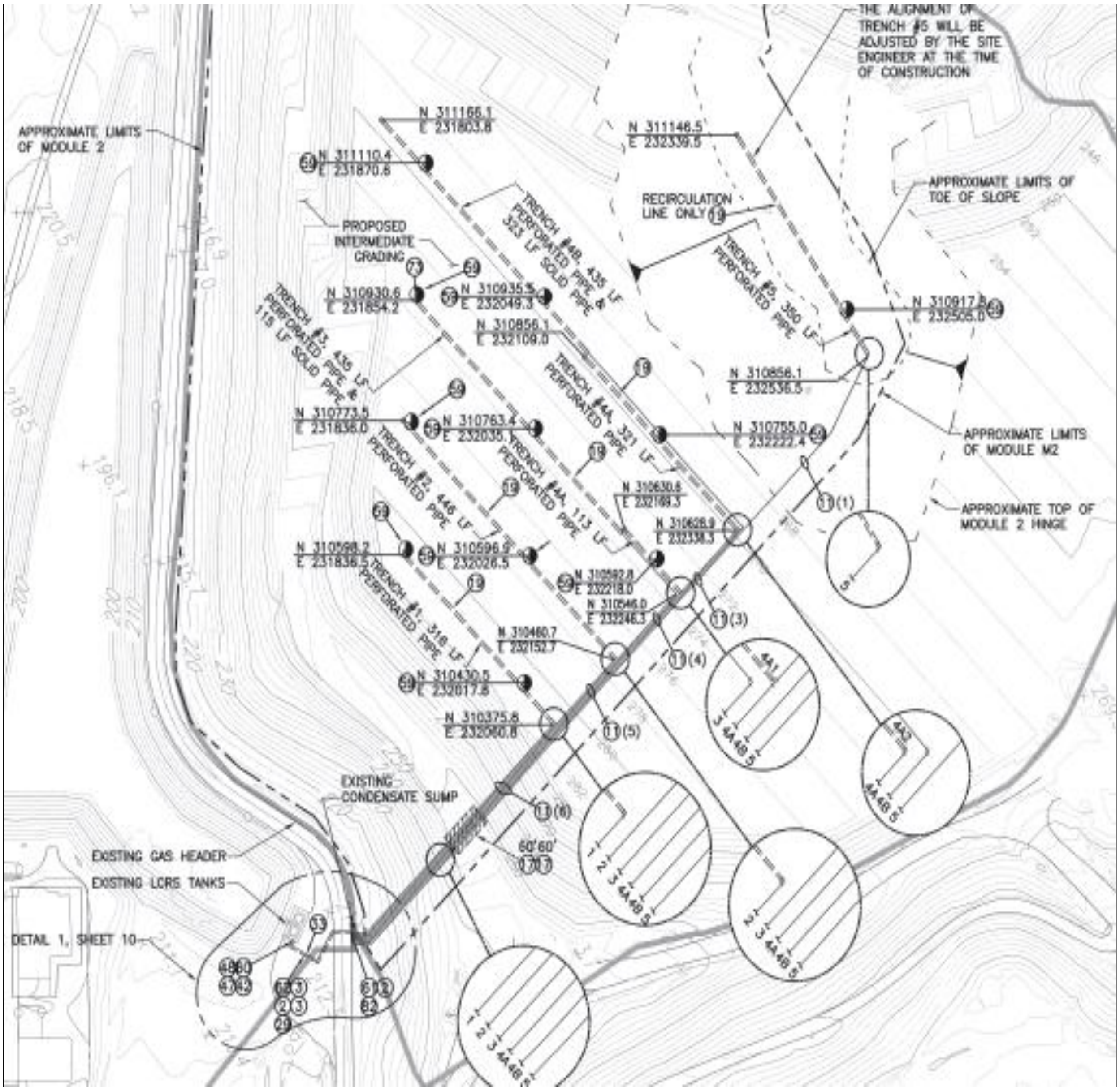

Figure 2-28: LFG and Leachate Recirculation Trench Plan

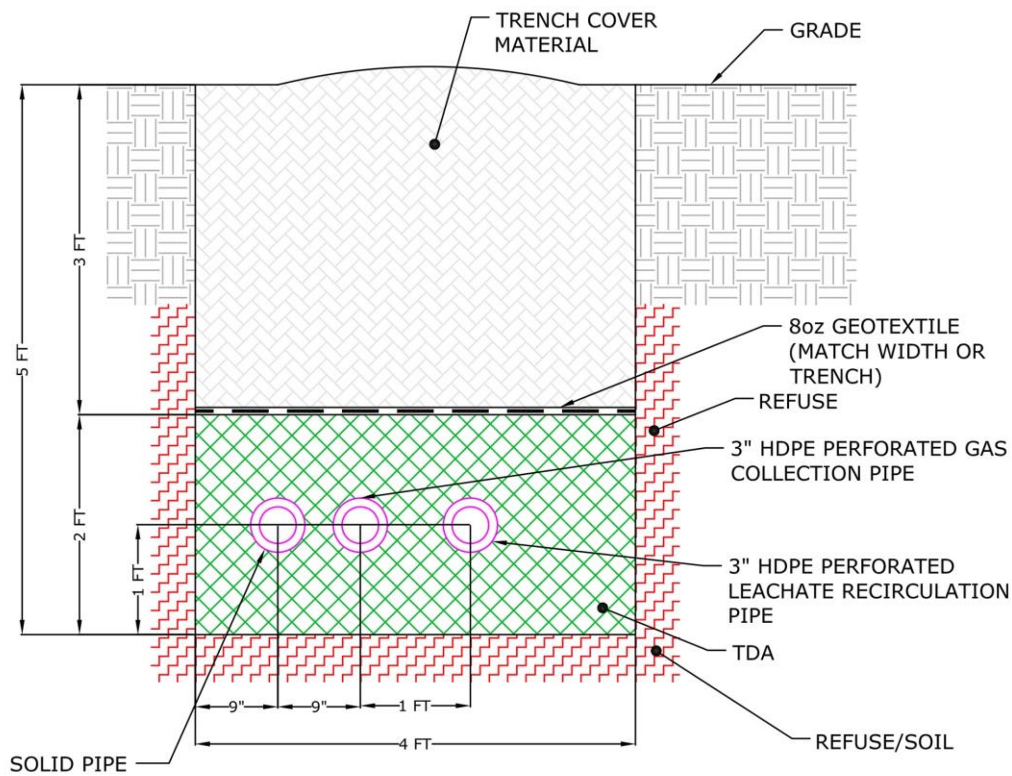

Figure 2-29: LFG and Leachate Recirculation Trench Cross Section

Figure 2-30: Kiefer Landfill TDA and Piping Placement

When the contractor completed the project, he expressed how much easier it was to work with TDA compared to washed gravel. He also said TDA produced very little dust compared to gravel when placing material in the trenches.

2.9 Leach Fields

Rock aggregate (natural or crushed gravel) is the traditional medium used for septic system leach fields. However, the practice of gravel mining from rivers is increasingly limited due to environmental degradation associated with the practice. Environmental controls on rock quarries have increased the operational costs of these facilities, and in some cases they have ceased operation. The net result is that rock aggregate has become expensive and difficult to obtain in many locations.

TDA has numerous benefits that make it an excellent alternative to rock aggregate for drainage applications. TDA has higher permeability than traditional drain rock aggregate and a substantially lower unit weight. TDA has a higher surface area per unit volume, which increases the area for biofilm development and subsequent biological treatment of the drainage water. Rather than causing potential environmental problems by mining or producing rock aggregate, producing TDA reuses a waste product and keeps used tires out of landfills. Because of these benefits, TDA may perform better than rock aggregate and in many locations may be less expensive to use.

TDA has been used successfully as a substitute for rock aggregate in drain fields for the past 20 years in numerous states including Arkansas, California, Colorado, Georgia, Iowa, Kansas, New Mexico, New York, North Carolina, South Carolina, Texas, Vermont, and Virginia (Daniels and Bird 1993; Envirologic 1990; Grimes, et al. 2003; McKenzie 2003; Zicari 2006; GeoSyntec Consultants 2008; Finney, et al. 2013). The driving force for the use of TDA has been largely economic. Depending on the production and transportation expenses, construction cost savings for drain fields can range from 10 percent to 90 percent when TDA is used in place of rock aggregate (McKenzie 2003). Because the density of TDA is about one-third that of gravel, only one-third of the tonnage of TDA is required for the same size drain field, i.e., approximately 15 tons of TDA is required compared to 50 tons of conventional rock aggregate for a single-family dwelling.

Many studies have observed the extensive microbiological and macrobiological activity found in TDA media leach fields. In general, these studies have demonstrated that TDA supports a healthy population of bacteria and other organisms that provide active biofilm treatment of the organic portion of the leachate in systems ranging in age from 3 months to 8 years (Grimes et al., 2003; Amoozegar and Robarge, 2006; Finney et al., 2013).

2.9.1 Design

The design of a leach field project is similar to a project using traditional materials like rock or gravel. The only difference would be adjusting the design to accommodate for the difference in the engineering properties of TDA. Typically leach field projects would require using type A TDA since it has a good range of media sizes—big enough to provide a high value of hydraulic conductivity and not prone to plugging, yet small enough to maintain a high surface area to volume ratio.

2.9.2 Construction

The construction methods for TDA placement is similar to those used for rock or gravel. After excavation of the trenches for the leach field, the TDA would be used as a substitute for rock aggregate backfill. Since the TDA serves as a media for the treatment of wastewater, the material should be free of any contamination or debris that might interfere with treatment or negatively impact the surrounding soil or groundwater.

A separation barrier is generally used in leach field construction between the aggregate media and the soil backfill. The barrier prevents the migration of fines into the aggregate, which could reduce the hydraulic conductivity of the media and result in plugging of the system. Treated paper is often used as the barrier for conventional rock aggregate systems; since the protruding wires in TDA could rip this paper, geotextile fabric is a good alternative.

2.9.3 Example Pilot Project, Septic System Leach Field Study, Finney et. al., 2013

To determine the suitability of TDA for use as septic system leach field media, a leach field was constructed adjacent to the primary oxidation pond at the City of Arcata's wastewater treatment plant (WTP). The leach field consisted of two independent drain lines and their associated trenches. One trench was filled with type A TDA, and the other was filled with rock aggregate. Primary treated wastewater from the influent end of the oxidation pond was loaded into the two drain lines for 17 months to determine the differences in the behavior and performance of the TDA and rock aggregate media. The oxidation pond water had received primary treatment (screening and settling), and served as a substitute for septic tank effluent.

The leach field trench dimension was roughly 40 feet by 2 feet by 2 feet, and was covered with 2 feet of topsoil (Figure 2-32). Two leach lines were built parallel to each other: one using rock aggregate and the other using Type A TDA (maximum 8-in. length).

Primary treated municipal wastewater from the City of Arcata's WTP oxidation pond was discharged to both the rock aggregate and TDA leach fields at the same daily rate for 17 months. The target daily flow rate delivered to each leach field was 349 gallons per day (gpd), which is the average daily household wastewater use in the United States (American Water Works Association, 1999). The actual flow rate for the pilot project was 416 gpd for the rock aggregate and 366 gpd for the TDA leach field.

Based in the results, the TDA performed better and would be a suitable replacement for rock aggregate in a leach field project.

3. Environmental Considerations for Use of TDA

In addition to being a cost-effective alternative in many civil projects, TDA also has been proven to have minimal impact on the environment. This chapter discusses the environmental aspects associated with the use of TDA in a variety of civil engineering applications.

3.1 Introduction

The civil engineering applications of TDA presented in Chapter 2 all involve the beneficial reuse of waste tires. These applications include use as a lightweight fill for embankments, retaining walls, slope repairs, as a subgrade insulation layer, as drainage and cover material at landfills, as a vibration-damping material for rail track applications, and as a gravel replacement in on-site wastewater treatment systems. In each of these applications, the TDA is placed in a location where water may be temporarily present. After coming into contact with the TDA, the water may leave the site and co-mingle with other surface or groundwater sources. When TDA is used as the aggregate, there are compounds present in the tire rubber that may leach out and enter the surrounding water and soil matrix. Fortunately, there is no evidence of significant water or soil contamination that has been found in numerous field trials using TDA as a substitute for rock aggregate. This chapter will explore laboratory and field experiments that have addressed the potential water quality impacts from using TDA in the civil engineering applications presented in Chapter 2.

3.2 TCLP Toxicity Testing

The Toxicity Characteristic Leaching Procedure (TCLP) has been used by many researchers to provide some indication of the relative toxicity of the extracted leachate from TDA (e.g. Downs, et al. 1996; Ealding 1992; and Zelibor 1991). The TCLP uses an acidic extraction solution (pH < 5), which is typically used to simulate the leaching potential for waste in a landfill environment. This would not be representative of the leaching conditions for field settings at most TDA projects. In addition, the regulatory concentration limits for the various constituents are not meant to be public health safety limits. Instead, the limits are used to classify whether there is evidence that potentially toxic compounds are present in the waste, and if the waste is placed in water, these compounds can be mobilized to an extent that the material should be treated as a hazardous waste for disposal purposes. All of the tests that have been performed on TDA have found that regulatory limits were not exceeded for any of the target constituents. On the basis of these tests, TDA would not qualify as a hazardous waste based on the toxicity criteria.

3.3 Aquatic Organism Toxicity Assessment

In order to obtain a general waiver from the Regional Water Quality Control Board (RWQCB), Region 2, Sheehan et al. (2006) performed chronic toxicity testing on fathead minnow larva and water fleas in leachate from two TDA fills constructed in Maine. One of the fills was above the groundwater table, and the other was below. Both TDA fills had been in place approximately 10 years at the time of the testing. The chronic toxicity test showed no adverse effects from the elevated levels of iron and manganese found in the leachate from the TDA fill above the water table. The tests results did indicate a toxicity effect in the leachate from the TDA fill that was below groundwater level, likely due to elevated levels of metals (iron, zinc, and manganese) that had leached from the TDA. However, the metals were found to quickly form immobile, insoluble particles in the subsurface soil, resulting in a rapid reduction in metals concentration a short distance from the fill. With the exception of an acidic and anaerobic soil, dilution, dispersion, and geochemical reactions should result in leachate that is nontoxic to aquatic organisms a short distance away from TDA fills that are placed below the groundwater table. Based on the results of this study, the RWQCB approved the waiver. As of 2015, this waiver is still valid.

3.4 Field Monitoring of Groundwater and Soil at TDA Installation at Arcata, Calif., Finney, et al. (2013)

To determine the suitability of using TDA as a substitute for rock aggregate, leach fields using both TDA and rock were constructed adjacent to an oxidation pond at the City of Arcata's wastewater treatment plant. TDA and rock leach fields were loaded with primary treated wastewater for 17 months to compare the differences in behavior and effluent quality between the two media.

Physical inspections of the media at the midpoint of the rock and TDA leach fields were performed after approximately 4, 7, 10, and 17 months of wastewater loading to observe the presence of any organism growth. During the last inspection, the media was also examined at the end of each trench. Besides a fresh soil type aroma, no odor was detected from either leach field during any of the media examinations. The rock aggregate leach field showed negligible signs of microorganism growth until 17 months from the start of the experiment (Figure 3-1).

Figure 3-1: Microorganism Growth on Rock Aggregate after 7, 10, and 17 Months of Wastewater Loading in Leach Fields (Finney et al. 2013)

Rock aggregate that was above the perforated delivery pipe was relatively clean gravel, but the gravel's grittiness increased with depth. Below the perforated pipe in the TDA leach field, microorganism growth was observed at each inspection, and the TDA media became increasingly more oxidized and covered in organic slime as time progressed (Figure 3-2). Biofilm was much more extensive on the TDA media than on the rock aggregate media.

Figure 3-2: Microorganism Growth on TDA after 7, 10, and 17 Months of Wastewater Loading In Leach Fields (Finney et al. 2013)

3.4.1 Summary

TDA has proven to be a valuable resource in the field of civil engineering. As the use of TDA in engineering applications increase, it becomes important to identify any potential associated environmental impacts and implement design modifications to mitigate potential problems. The laboratory and field testing have shown that TDA is not a hazardous waste based on TCLP toxicity standards. In addition, low levels of metals and various organic compounds were detected in leachate that contacted the TDA, but the levels are below applicable water quality thresholds. Field tests have shown that the metals concentrations within a TDA fill are effectively attenuated within a few feet of soil.

4. Construction Guidelines

The construction methods used for TDA projects are similar to those used in standard soil fill projects. This chapter provides an overview of basic guidelines for the construction of TDA projects.

4.1 Introduction

Through many successfully completed fill projects in California, CalRecycle has developed an understanding of the differences between TDA and conventional soil and how those differences can be managed before, during, and after construction. The following sections provide guidelines for consideration when constructing a project using TDA. These guidelines include pre-construction, construction, and post-construction activities for TDA projects.

4.2 Guidelines for Pre-Construction Activities for TDA Projects

Pre-construction guidelines provide the framework for activities necessary for the production of TDA that will meet all material specifications as well as proper delivery and stockpiling. These tasks are essential to prevent project delays when using TDA as a backfill material.

4.2.1 Communication and Training of Project Stakeholders

Good communication and proper training will assure the smooth and problem-free construction process when using TDA. While communication between all parties is important for the success of any project, it is even more so when introducing an unfamiliar material like TDA to the designers and/or contractors. This is typically accomplished by holding a pre-construction meeting at which TDA can be introduced to all project stakeholders.

The following areas should be addressed by the project manager prior to construction:

- Delivery supplier(s), schedule, rates, and route;
- Stockpiling locations;
- Regulatory requirements for stockpiling and/or delivering of TDA;
- TDA placement and education of the contractors on-site representative; and
- QA/QC of TDA placement, delivery, and material specifications.

Since TDA is much lighter and has a higher bulk density than soil or gravel, contractors should become familiar with the basic properties of TDA before it arrives at the site. The following areas should be addressed by the contractor prior to receiving TDA at the project site:

- Volume of delivery;
- Project stockpile and configuration;
- Placement methodology;
- Proper equipment for placement; and
- QA/QC of material and placement.

4.2.2 **Regulatory Agency Outreach**

The contractor should be aware of the regulatory requirements for TDA projects. The contractor must adhere to state and local regulations for transportation and stockpiling of TDA (described in Section 4.3.1 of this chapter). The contractor may not begin transporting TDA until these requirements are met and regulatory approval has been given.

Material quantities, methods of measurement, delivery methods, and pay rates need to be established with the stakeholders prior to delivery of TDA. Once tires are processed into TDA, sold as a product, and then removed from the tire processor, they are no longer considered a waste tire. Therefore, transportation of TDA does not need to be performed by a registered waste tire hauler, but haulers will still need a letter of exemption issued by CalRecycle to haul TDA.

Because TDA is a compressible material, the density of TDA varies depending on whether it is being stockpiled or installed in the project. The stockpile and shipping densities of Type A and B TDA range from 25 to 35 lb/ft^3, while compacted in place density values for Type A and B TDA ranges from approximately 35 to 50 lbs/ft^3 (See Table 4-1).

Table 4-1: Densities of Type A and Type B TDA

Stages	TDA Type A, lbs/ft^3	TDA Type B, lbs/ft^3
Shipping and Stockpiling	25-35	25-35
Compacted	45-53	45-50

Rate of delivery is an important consideration during the planning stages of a TDA construction project and could have a significant impact on the construction timeline. When processing and delivering TDA, vendors should consider the following:

- Regulatory allowances regarding the amount of TDA that can be stockpiled at the production facility;
- The rate at which vendors can process tires and load or pre-load delivery trucks;
- The distance from the facility to the site (there are only a few TDA vendors in California); and
- The availability of walking floor trailers or similar delivery trailers.

The amount of material that can be stockpiled at the site prior to use may be restricted, or the site may not have a suitable stockpile location. Therefore, it is recommended that the following be considered and addressed in bid documents, specifications, and planning:

- Vendor's maximum rate of production and delivery;
- Distance from the site to the vendor(s);
- Amount of TDA required;
- Securing an appropriate onsite stockpile location;
- Site access and the ability for delivery vehicles to turn around; and

- Personnel required for material quality assurance inspections upon delivery.

Based on experience with existing TDA projects, addressing the issues related to the rate of delivery and construction sequencing can prevent project delays. Contractors have successfully coordinated the TDA delivery rate by having appropriate stockpile location(s), communication with multiple vendor(s), and proper site access.

4.2.3 Material Specifications

TDA specifications for construction are based on ASTM D6270-08. The intent of the ASTM specifications is to define shredded tire material characteristics that are suitable for civil engineering applications. In some cases, a TDA material may meet the intent of the specifications as Type A or Type B, but still satisfy the design requirements for the project. TDA material must be tested intermittently during production to assure that it continues to meet specifications. Appendix A shows an example of the specification.

4.3 Guidelines for Construction Activities

All contractors and subcontractors should be briefed on the use of TDA prior to construction. Information on previously completed projects and how TDA was handled can help the project management team plan and complete the installation with minimal complications and delays. Based on project experience, once they have used TDA, many contractors are typically very comfortable using TDA. The benefits of TDA include the following:

- The material can be transported and placed with conventional construction equipment.
- It is produced from clean waste tires with less fines than rock and gravel.
- The quality of the production is monitored (e.g. size for fill type is specific, quality of shearing, amount of steel belt, etc.).
- No density testing is required to validate maximum in-place densities.
- It is lightweight and free-draining, and it has non-degrading material characteristics.

Since TDA is derived from waste tires, it can attract attention and public interest during construction. An on-site representative should be designated to act as the project public relations (PR) representative. This individual should be appropriately selected so that public or media interests do not disrupt construction progress. The PR person should have on-site duties that would allow interruption without too great an impact on construction-specific tasks.

4.3.1 Transportation, Storage, and Stockpiling

TDA is much lighter than conventional lightweight fill material. Generally, the limiting factor for transporting TDA is not its weight but its volume. To provide the most economical method of trucking, trailers need to be large enough so the weight of the TDA being transported reaches the allowable highway limit (80,000 pounds gross).

The ability to store and stockpile sufficient quantities of TDA onsite prior to utilization may allow for more efficient time and materials management. However, as mentioned above, the stockpiling of TDA may be regulated both at the production facility and at the construction site. When considering a TDA stockpile location, the local fire authority should approve the location and stockpile configuration.

4.3.2 TDA Placement

Projects utilizing TDA do not require any special onsite equipment (Figure 4-1). Standard earth moving, handling, and compaction equipment have been successfully utilized with TDA projects; however, the following special considerations and adjustments from typical earthwork projects should be made:

- Equipment must not have hydraulic or lubrication fluid leaks or excess grease at fittings, as this will contaminate the TDA material. Equipment must be greased outside the TDA area and be inspected frequently.
- It’s strongly recommended that only tracked equipment or equipment with tires filled with self-sealing gels be used to place TDA. This is due to the potential for flats on equipment with rubber tires from the exposed steel belts on the TDA.
- The contractor will need to overbuild TDA material to account for compression and settlement of the TDA in the final configuration. It is important to perform a TDA overbuild calculation based on the density of overlying materials, expected in-place TDA density, and depth of TDA layers. An overbuild example can be found in Appendix D.

For embankment and large retaining wall fills, TDA can be handled and spread with standard tracked construction equipment such as bulldozers, excavators, and end dump trucks, as shown in Figure 4-2. In trenches, TDA can be spread using shovels and hand tools. Equipment operators report that they did not find it difficult to dig, move, or spread material. Excavators with a thumb attachment help maximize the amount that can be picked up with each scoop.

Figure 4-1: Walking Floor Trailer Unloading for Marina Project

Figure 4-2: BART Warm Springs Rail Extension Project

Compaction of TDA fill within embankment and large retaining wall fills can be accomplished with a tracked bulldozer, sheep foot roller, or vibratory smooth drum roller weighing at least 10 tons (Figure 4-3). Most applications require a minimum of six passes made by the compaction equipment to achieve maximum density. Unlike soil, no testing is required to validate maximum in-place densities.

In drainage applications or when pavement will be placed over TDA, tire shreds should be wrapped in geotextile to prevent infiltration of fines and to maintain its hydraulic conductivity. A sufficient amount of soil cover should be placed over the TDA fill to prevent sub-base deflections that could be damaging to overbearing pavement structures. The prescribed thickness can range from 3 to 7 feet depending on the expected traffic loading.

Figure 4-3: Drum Roller at the BART Warm Springs Rail Extension Project

As a general rule of thumb, TDA lift thickness should not exceed 10 feet. Multiple 10-foot-thick layers may be used as long as each layer is wrapped in geotextile and separated by a soil layer with a minimum lift thickness of 3 feet. All TDA placement shall be covered.

4.3.3 Working Outside TDA Fills

Onsite handling of TDA outside the TDA fill areas has been successfully accomplished utilizing tracked or rubber-tired loaders and dump trucks. Material movement from stockpiles to work areas or trenches can be effectively accomplished with this equipment. TDA's angle of repose is relatively high compared to soil, so dump trucks and roll-off box end dumps may have to lift and lower multiple times to get all material out of the bed.

4.3.4 Air Quality and Workers Health

There are no reported issues with air quality when dealing with TDA construction projects. There is a slight odor from the rubber, but there have been no documented worker health or air quality issues.

4.4 **Guidelines for Post-Construction Activities**

After project construction, an “as built” completion report should be produced to provide full documentation of the final project construction. The completion report should include the following:

- Project photos
- Quality assurance logs
- Material delivery and tare tickets
- Documentation of any deviation from the design
- Discussion
- Location of fill

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Appendix A - Sample Specifications

ASTM defines two basic types of TDA used in engineering applications, Type A and Type B; and classes of fill associated with them (Class I and Class II). Type A and Type B are size classifications that are used for different applications. Class I and Class II describe lift thicknesses of the fill as defined by ASTM 6270-08 Section 6.11.1.

Class I fills describe TDA layers that are less than 1 meter in height, and Class II fills describe TDA layers that are between 1 and 3 meters high. Class I fills have a maximum of 50 percent (by weight) passing the 38-mm sieve and a maximum of 5 percent (by weight) passing the 4.75-mm (no. 4) sieve (ASTM 6270-08 Section 7.1.2). Class II fills have a maximum of 25 percent (by weight) passing the 38-mm sieve and a maximum of 1 percent (by weight) passing the 4.74 (no. 4) sieve (ASTM 6270 Section 6.10.4). Typically Type A material is used in Class I fills, and Type B is used in applications requiring a Class II fill designation.

Type A Material

Type A will have a maximum dimension measured in any direction of 200 mm. One hundred percent of Type A TDA will pass through the 100 mm square mesh sieve, and a minimum of 95 percent will pass through the 75 mm square mesh sieve. A maximum of 5 percent (by weight) shall pass through the 4.75 mm (No. 4) sieve.

One ton of Type A is made of approximately 100 passenger tire equivalents (PTE) and has a volume of 1.4 cubic yards. The in-place density is 45 to 50 pounds per cubic foot (pcf), and the permeability is more than 24 in/min (1 cm/sec).

Type B Material

Type B material has a maximum dimension of no more than 450 mm, and 90 percent is smaller than a 300 mm maximum dimension. No more than 25 percent should pass a 37.5 mm square mess sieve, and a maximum of 1 percent will pass a 4.57 mm (no. 4) sieve. At least one sidewall will be removed from the tread of each tire. A minimum of 75 percent (by weight) shall pass the 200 mm square mesh sieve, a maximum of 50 percent (by weight) shall pass the 75 mm square mesh sieve, a maximum of 25 percent shall pass the 38 mm square mesh sieve, and a maximum of 1 percent shall pass the 4.75 mm sieve.

One ton of Type B is made of approximately 100 PTEs and has a volume of 1.5 cubic yards. The in-place density is 30 to 45 pcf, and the permeability is more than 24 in/min (1 cm/sec). Type B is often used as a lightweight backfill for retaining walls and embankment construction on weak soils. TDA is used as a low-cost alternative to geofoam and pumice. Type B TDA is also utilized in landfill leachate and gas collection and removal systems. Type B material is used in Class II fills in which TDA lift thickness is less than 10 feet (3 m).

Appendix B - Glossary of Terms and Acronyms

Glossary of Terms

Embankment: A raised structure (as of earth or gravel) used especially to hold back water to carry a roadway.

Endothermic: Characterized by or formed with the absorption of heat.

Exothermic: Characterized by or formed with evolution of heat.

Inorganic compound: A compound composed of matter other than plant or animal.

In situ: In the natural or original position or place.

Organic compound: A compound that contains carbon compounds.

Rough shred: A piece of shredded tire that is larger than 50 mm by 50 mm by 50 mm but smaller than 762 mm by 50 mm by 100 mm. (ASTM D6270-08)

Rubber fines: Small particles of ground rubber that results as a by-product of producing shredded rubber.

Scrap tire: A tire that can no longer be used for its original purpose due to wear or damage (ASTM D6270-08).

Shred sizing: A term that generally refers to the process of particles passing through a rated screen opening. (ASTM D6270-08)

Shredded tire: A scrap tire that has been reduced in size by a mechanical processing device commonly referred to as a shredder. (ASTM D6270-08)

Shredded rubber: Pieces of scrap tires resulting from mechanical processing. (ASTM D6270-08)

Steel belt: Rubber-coated steel cords that rub diagonally under the tread of steel radial tires and extend across the tire approximately the width of the tread. (ASTM D6270-08)

Tire-derived aggregate (TDA): Pieces of scrap tires that have a basic geometrical shape and are generally between 12 and 305 mm in size and are intended for use in civil engineering applications. Also see the definitions of tire chips and tire shreds. (ASTM D6270-08)

Tire shreds: Pieces of scrap tires that have a basic geometrical shape and are generally between 50 and 305 mm in size. (ASTM D6270-08)

Truck tire: A tire with a rim diameter of 500 mm or larger. (ASTM D6270-08)

Whole tire: A scrap tire that has been removed from a rim but has not been processed. (ASTM D6270-08)

Glossary of Acronyms

ASTM	American Society for Testing and Materials
CalRecycle	California Department of Resources Recycling and Recovery
Caltrans	California Department of Transportation
CIWMB	California Integrated Waste Management Board
CTC	Control Technology Center
EPA	Environmental Protection Agency
GPD	gallons per day
LFG	landfill gas
MCL	maximum contaminant level
MPI	minutes per inch
MSW	municipal solid waste
PAH	polycyclic aromatic hydrocarbons
PE	polyethylene
PTE	passenger tire equivalent
QA	quality assurance
QC	quality control
RAC	rubberized asphalt concrete
RMA	Rubber Manufacturers Association
SVOC	semi-volatile organic compound
TCLP	toxicity characterization leaching procedure
TDA	tire-derived aggregate
TDF	tire-derived fuel
U.S. EPA	United State Environmental Protection Agency

Appendix C - Frequently Asked Questions

- How do you prevent exothermic heating for TDA projects?

  By following the standards described in ASTM D627008, which was developed to provide guidance on how to prevent exothermic heating problems with TDA projects.

- What density values should be used for TDA project?

  TDA is a compressible material. At different stages, the densities of the TDA are different. Table 4-1 of this guide provides some values for the density of TDA.

- How is TDA made? What sizes?

  Waste tires are shredded into pieces. After proper sizing, the TDA is grouped into two types. Type A TDA is generally less than 3 inches, while Type B TDA is less than 12 inches.

- Do I need specialized equipment for a TDA project?

  There is generally no special equipment needed for TDA projects. However, because TDA contains steel wires, it would be good to use tracked bulldozers to handle the material at the site instead of pneumatic tire wheel bulldozers. The walking floor trailer works well for transporting TDA because the material has a low density compared with conventional aggregates.

- How much TDA can I get in one day?

  Depending on the location of the project verses the location of the TDA production facility, TDA may need to be stockpiled near the jobsite. CalRecycle's TDA webpages list TDA product facilities, contract information, and locations.

Appendix D - Calculation of Overbuild

Tire shreds experience immediate compression under an applied load, such as the weight of an overlying soil cover. The top elevation of the tire shred layer(s) should be overbuilt to compensate for this compression. The amount of overbuild is determined using the procedure given below with the aid of a design chart (Figure D-1). Figure D-1 is applicable to Type B tire shreds (12-in. maximum size) that have been placed and compacted in 12-inch layers. To use this procedure with smaller Type A shreds (3-in. maximum size), increase the calculated overbuild by 30 percent.

Single TDA Layer

The amount of overbuild for a single tire shred layer is determined directly from Figure D-1. First, calculate the vertical stress that will be applied to the top of the tire shred layer as the sum of the unit weights times the thicknesses of the overlying layers. Second, enter Figure D-1 with the calculated vertical stress and the final compressed thickness of the tire shred layer to find the amount of overbuild. Consider the following example:

9 in (0.75 ft) pavement at 160 pcf

2 ft aggregate base at 125 pcf

2 ft low permeability soil cover at 120 pcf

10 ft thick tire shred layer

The vertical stress applied to the top of the tire shred layer would be:

(0.75 ft x 160 pcf)+ (2 ft x 125 pcf) + (2 ft x 120 pcf) = 610 psf

Enter Figure D-1 with 610 psf. Using the line for a tire shred layer thickness of 10 feet results in an overbuild of 0.68 feet. Round to the nearest 0.1 feet; thus, use an overbuild of 0.7 feet.

Bottom TDA Layer of Two-Layer Cross Section

The amount of overbuild for the bottom tire-derived aggregate layer of a two-layer cross section is also determined directly from Figure D-1. The procedure is the same as described above for a single tire shred layer. Consider the following example:

9 in (0.75 ft) pavement at 160 pcf

2 ft aggregate base at 125 pcf

2 ft low-permeability soil cover at 120 pcf

10 ft upper tire shred layer at 50 pcf

3 ft soil separation layer at 120 pcf

10 ft thick lower tire shred layer

The vertical stress applied to the top of the lower tire shred layer would be:

(0.75 ft x 160 pcf) + (2 ft x 125 pcf) + (2 ft x 120 pcf) + (10 ft x 50 pcf) + (3 ft x 120 pcf) = 1470 psf

Enter Figure D-1 with 1470 psf and using the line for a tire shred layer thickness of 10 feet results in an overbuild of 1.13 feet. Round to the nearest 0.1 foot; thus, use an overbuild of 1.1 feet for the lower tire shred layer.

Upper TDA Layer of Two-Layer Cross Section

The overbuild of the top elevation for the upper tire shred layer for a two-layer cross section must include both the compression of the upper tire shred layer when the pavement, base, and soil cover is placed, and the compression of the lower tire shred layer that will still occur under the weight of these layers. In other words, the lower tire shred layer has not yet compressed to its final thickness. This will only occur once the embankment reaches final grade. To determine how much compression of the lower tire shred layer will occur due to placing the pavement, base and soil cover, consider the two-layer example used above:

9 in (0.75 ft) pavement at 160 pcf

2 ft aggregate base at 125 pcf

2 ft low permeability soil cover at 120 pcf

10 ft upper tire shred layer at 50 pcf

3 ft soil separation layer @120 pcf

10 ft thick lower tire shred layer

Step 1. The final vertical stress applied to the top of the upper tire shred layer would be: (0.75 ft x 160 pcf) + (2 ft x 125 pcf) + (2 ft x 120 pcf) = 610 psf. Enter Figure D-1 with 610 psf. Using the line for a tire shred layer thickness of 10 feet results in a compression of 0.68 feet.

Step 2. Once the upper tire shred layer is in place, the vertical stress applied to the top of the lower tire shred layer would be: (10 ft x 50 pcf) + (3 x 120 pcf) = 860 psf. To determine the compression of the lower tire shred layer that has occurred up to this point, enter Figure D-1 with 860 psf. Using the line for a tire shred layer thickness of 10 feet results in a compression of 0.84 feet**.**

Step 3. Once the embankment reaches its final grade, the vertical stress applied to the top of the lower tire shred layer would be: (0.75 ft x 160 pet) + (2 ft x 125 pet) + (2 ft x 120 pcf) + (10 ft x 50 pcf) + (3 ft x 120 pcf) = 1470 psf. Enter Figure D-1 with 1470 psf. Using the line for a tire shred layer thickness of 10 feet results in an overbuild of 1.13 feet. (Note: Rounding to 1.1 feet would give the overbuild of the lower tire shred layer).

Step 4. Subtract the result from Step 2 from Step 3 to obtain the compression of the lower tire shred layer that will occur when the pavement, base, and soil cover is placed: 1.13 ft - 0.84 ft = 0.29 ft.

Step 5. Sum the results from Steps 1 and 4 to obtain the amount the top elevation of the upper tire shred layer should be overbuilt: 0.68 ft + 0.29 ft = 0.97 ft. Round to the nearest 0.1 feet. Thus, the elevation of the top of the upper tire shred layer should be overbuilt by 1.0 feet.

Final result: Overbuild the top elevation of the lower tire shred layer by 1.1 feet and the upper tire shred layer by 1.0 feet.

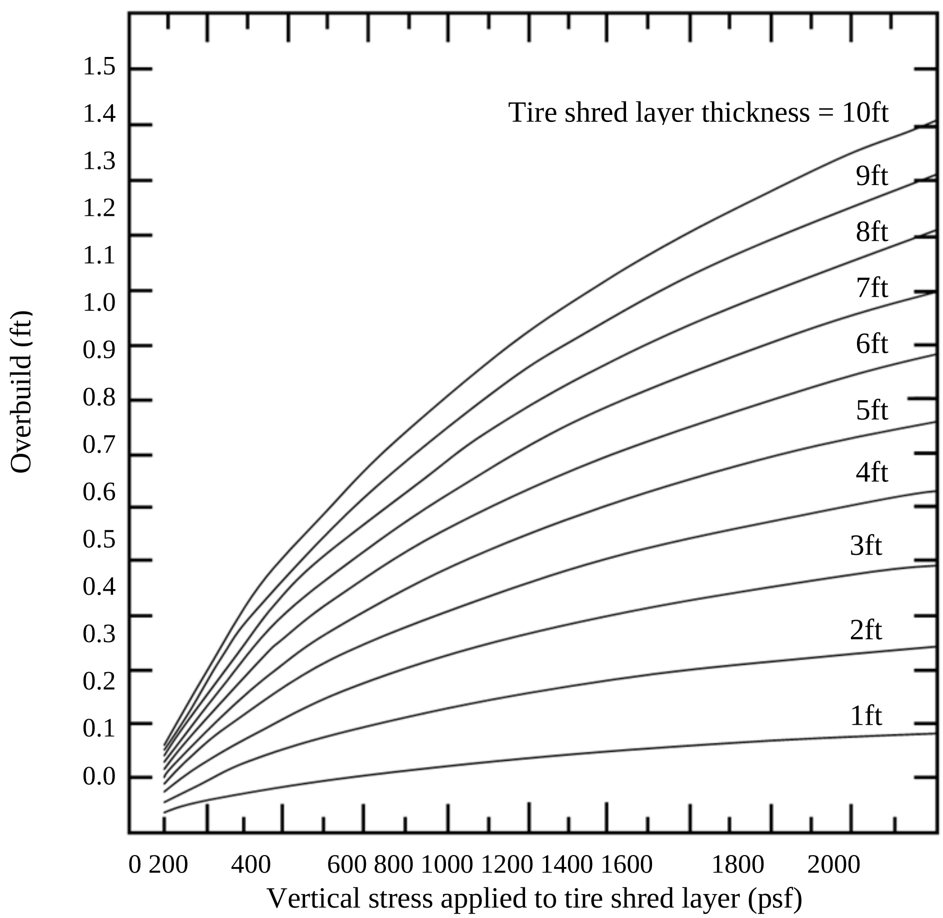

Figure D-1: Overbuild Design Chart for Type B

Appendix E - Summary Table for Applications of Type A and Type B TDA

Table E-1 Summary Table of Type A and Type B TDA

	Type A TDA	Type B TDA
Typical Size:	***3 Inch Minus***	***12 Inch Minus***
General Physical Properties		
	• 1 ton = 1.4 cubic yards (in place)	• 1 ton = 1.5 cubic yards (in place)
	• 1 ton = 100 tires (PTE)	• 1 ton =100 tires (PTE)
	• In-place density = 45-53 lb/ft^3	• In-place density, 45-50 lb/ft^3
	• Stockpile density = 25-35 lb/ft^3	• Stockpile density = 25-35 lb/ft^3
	• Permeability > 1 cm/sec for many application	• Permeability > 1 cm/sec for many applications
Civil Engineering Usage		
	• Drainage material, septic leach fields	• Lightweight fill for embankments fills
	• Vibration-damping layers under rail track	• Lightweight fill behind retaining walls
	• Gas collection media	• Lightweight fill for slope repair
	• Leachate recirculation material	• Lightweight fill over existing structure
		• Thermal barrier for freeze thaw conditions

Notes: PTE - passenger tire equivalent