



USE OF SHREDDED TIRES AS LIGHTWEIGHT BACKFILL MATERIAL FOR RETAINING STRUCTURES

Vanessa Cecich, Linda Gonzales, Ase Hoisaeter, Joanne Williams and Krishna Reddy

*Department of Civil and Materials Engineering, University of Illinois at Chicago,
2095 Engineering Research Facility, 842 West Taylor Street, Chicago,
Illinois 60607, U.S.A.*

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Each year in the United States, approximately 242 million automobile, truck and specialty tires are discarded. Almost 78% of these scrap tires wind up in overcrowded landfills, and thousands more are strewn across the country's empty lots, highways and illegal tire dumps. Used tires pose both a serious public health and an environmental threat. Therefore, economically feasible alternatives for scrap tire disposal must be found. Some of the current uses of scrap tires are tire-derived fuel, barrier reefs, and crumb rubber as an asphalt additive. However, all of the recycling, re-use and recovery practices combined only consume about 22% of the discarded tires. Thus, a need still exists for the development of additional uses for scrap tires. This paper addresses one potential use of scrap tires within the civil engineering field. Specifically, the feasibility of using shredded tires as a lightweight backfill material for retaining walls has been investigated.

In this study, laboratory tests were first performed to determine the engineering properties of shredded tires. Based on sieve analyses, the shredded tires used for this study can be classified as uniformly graded material. The unit weight of shredded tires was found to range from 35 to 38 lbs ft⁻³ (pcf), and the hydraulic conductivity was determined to be 0.03 cm s⁻¹. The values of shear strength parameters, cohesion and angle of internal friction, were determined to be 147 lbs ft⁻² (psf) and 27 degrees, respectively. Using these properties, retaining walls of various heights were then designed using shredded tires as the backfill material. Retaining walls were also designed using conventional sand as the backfill material for comparison purposes. When comparing the overall cost for the retaining wall using shredded tires with the retaining wall using sand, a substantial cost saving was realised by the use of shredded tires. An increase in the factor of safety was also a result of using shredded tires instead of sand as backfill. The results of this study indicate that shredded tires have a definite potential to be used as a backfill material for retaining structures.

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Key Words—Shredded tires, backfill, retaining walls, recycling, civil engineering, solid waste, waste management.

1. Introduction

The development of environmentally acceptable methods of used tire disposal is one of the greatest challenges that waste management experts face today. Approximately 242 million automobile, truck and specialty tires are scrapped each year in the United States (Lund 1993). The state of Illinois alone contributes about 12 million waste tires to these evergrowing scrap tire stockpiles. Almost 78% of these scrap tires wind up in already overcrowded landfills, and thousands more are strewn across empty lots, highways and illegal tire dumps (Lund 1993). Since rubber tires do not decompose

easily, this unchecked accumulation can create a solid waste concern of staggering proportions in American landfills.

When scrap tires are not disposed of properly, the health of the individual and the community is put at risk. Stockpiled tires provide an ideal breeding ground for mosquitoes and other disease-carrying vermin. Also, vast tire mountains can trap a sufficient amount of oxygen to start a fire. A tire fire poses a unique environmental threat since fuel oil is a byproduct of the chemically decomposing tires (Zarpas 1990). According to the United States Environmental Protection Agency studies, one melted automobile tire will yield approximately two-thirds of a gallon of oil which is contaminated with various tire chemicals. These toxic substances can seep into the surrounding soil and groundwater, thus creating a serious environmental hazard to the neighboring community.

In July 1994, a ban went into effect prohibiting all whole used tire disposal in Illinois landfills [Illinois Department of Energy and Natural Resources (IDENR) 1990]. As a result, marketable uses for these waste tires must be found. Some of the current uses for recycled tires include fuel chips used for energy generation, highway crash barriers, tire retreading applications and asphalt-binding material for road surfaces (Lund 1993). However, the quantity of tires used for these applications represents 22% of the actual tires that are discarded every year. Many more alternative uses for scrap tires must be found.

This paper describes a potential civil engineering application for scrap tires. Specifically, the purpose of this study is to determine the feasibility of using shredded scrap tires as an alternative backfill material for retaining structures. Retaining walls utilising shredded tires for backfill are designed and compared to conventional retaining walls using a granular backfill. This paper first presents brief background information on scrap tires and then describes: (1) laboratory tests which were performed to determine the engineering properties of shredded tires; (2) the design of various height retaining walls using sand as the backfill material vs. shredded tires as the backfill material; and (3) an economic analysis performed to determine the cost savings realised by using shredded tire backfill. Finally, the paper provides a summary of the results from this study and makes recommendations on additional shredded tire research which should be conducted prior to actual field applications.

U.S. and Imperial measurements have been used in this paper. The following conversion factors are provided to convert to SI units:

1 lb (U.S.)	= 0.4535 kg	1 ft	= 30.48 cm
1 mch	= 2.54 cm	1 BTU lb ⁻¹	= 2324 J kg ⁻¹
1 ton (U.S.)	= 0.907 t	1 mile	= 1.609 km
1 lb ft ⁻³ (pcf)	= 16.02 kg m ⁻³	1 lb m ⁻² (psi)	= 6.895 × 10 ³ Pa
1 yd ³ (cy)	= 0.764 m ³	1 lb ft ⁻² (psf)	= 4.88 kg m ⁻²

2. Background

2.1 Problem overview

Each year, used tires represent approximately 1.2% of all solid waste generated in the United States (Lund 1993). Despite these small numbers, used tires pose a serious public health and environmental threat for three main reasons:

(1) Tires take up a significant amount of space in already overcrowded landfills and, many times, used tires will “float” to the surface of the landfill, breaking the compacted clay or the membrane covers. When these covers are broken, surface water can enter the landfill and produce harmful leachate (IDENR 1990).

(2) Several scrap tire storage centres have caught fire. In February 1990, for example, the Tire King scrap tire yard of Toronto, Ontario, caught fire and forced hundreds of residents from their homes. Canadian experts declared the fire a “major environmental disaster” and described it as “one of the worst disasters in Ontario history”. The fumes that these tire fires emit contain chemicals such as benzene, which is known to cause leukemia in laboratory animals, and toluene which can cause kidney and liver damage (Jenish 1990). Additionally, these fires can smolder beneath the surface of a tire dump for months, producing a most serious environmental threat; an oil spill. In that case, millions of dollars must be spent to prevent groundwater contamination and to restore the site.

(3) A scrap tire dump provides an ideal breeding ground for mosquitoes, rats and other disease-carrying vermin. In the late 1980s, Illinois scrap tire sites were found to house significant quantities of the Asian Tiger Mosquito, which is known to carry the encephalitis virus (IDENR 1990).

The scrap tire disposal problem has reached overwhelming proportions. Legislation promoting the safe disposal and recycling of scrap tires is increasing. Economically feasible alternatives for scrap tire disposal must be found.

2.2 Tire composition and characteristics

The average scrap automobile tire weighs approximately 20 pounds. Heavy truck and industrial tires can weigh from 35 pounds to several hundred pounds. Since 1983, all new car and light truck tires are steel-belted radials. Eighty-five percent of all scrap tires are passenger car or light truck tires, 14% are heavy truck tires, and the remaining 1% are specialty tires, ranging from aircraft tires to construction equipment tires (Lund 1993). A typical tire casing is composed of 83% carbon, 7% hydrogen, 1.2% sulfur and 6% ash. Primary constituents of tires include polymers, carbon black and softeners. The softeners are mostly composed of hydrocarbon oils which in combination with the polymers give the tire a very high heating value (Lund 1993).

2.3 Disposal practices

Currently, three main options exist for the disposal of scrap tires: (1) landfilling; (2) recycling and re-use; and (3) incineration. The most common method used in the United States is landfilling. This disposal method accounts for nearly 70% of all scrap tires. In Illinois, the current cost to landfill tires ranges from \$1 to \$8 for automobile tires and this amount increases substantially for heavy truck tires. In Illinois, almost eight million scrap tires are currently stockpiled in various locations (IDENR 1990).

The first step in processing a recycled tire is to reduce its size by either chopping, shredding or grinding. This size reduction greatly increases the possible recycling options. After shredding, a whole tire is reduced into strips. These strips range in size from 2 in × 8 in down to 2 in × 2 in, and the tire volume is reduced by up to 75% in this process (Lund 1993).

2.4 Alternative uses for scrap tires

The alternative uses for scrap tires can be divided into two general categories; whole or processed. Uses for whole tires include artificial reefs, fuel and retreading, while uses for processed tires include rubber products, fuel chips and civil engineering applications. Some of these common uses are outlined below.

2.4.1 Artificial reefs and breakwaters

Artificial reefs are built by bundling scrap tires together and then anchoring them in coastal waters. These tires soon become a permanent habitat for fish and other marine life. Breakwaters can be constructed from the scrap tires to help protect harbors from the harmful effects of a tidal wave.

2.4.2 Fuel

Scrap tires provide an excellent source of energy. Combustion facilities can be constructed or modified to burn whole tires as the only fuel source or to burn tires along with other fuel sources. In Modesto, California, for example, a giant tire pile fuels a nearby power plant, which burns one tire per household per day in order to supply energy to 15,000 households (Pennisi 1992).

2.4.3 Retreading

The process of retreading is used to replace the worn tread portion of a tire with new tread.

2.4.4 Recycled rubber products

Tires are ground into fine particles by either mechanical or cryogenic grinding methods. The ground that is produced is called crumb rubber. Crumb rubber can be used for various applications such as athletic fields, carpet underlay, parking curbs, railroad crossing beds, and as an asphalt additive. The Rubber Pavements Association stated that adding rubber to asphalt will increase the engineering properties of the pavement, including traction, wear and resistance to cracking (Phillips 1994).

2.4.5 Fuel chips

As with whole tires, shredded tire chips can be used as a source of fuel. Since tires consist of 83% carbon, they possess a comparatively high heating value of approximately 15,000 British Thermal Units per pound (BTUs lb⁻¹). These tires can be burned in the following facilities: a dedicated scrap tire incineration facility; a cement kiln; a pulp and paper mill; or a utility boiler (Lund 1993).

2.4.6 Civil engineering applications

Scrap tires are currently being used for landfill applications either as a daily cover or as part of the leachate collection system in four different states: Florida; West Virginia; Ohio; and Pennsylvania. In Minnesota and Oregon, scrap tires have been used as a fill in roadway embankments (Minnesota Pollution Control Agency 1990; Upton & Machan 1993). In Maine, significant efforts are underway to use tire chips as subgrade road fill, retaining wall backfill, and as a road subgrade insulation layer (Humphrey *et al.*, 1993;

Humphrey & Eaton, 1993). Other states have also initiated studies on the use of discarded tires in civil engineering construction.

2.4.7 Summary

Currently, all of the recycling, re-use and recovery practices combined only consume about 22% of discarded tires in the United States. The major problem for virtually all of the scrap tire recycling businesses is the development of a high-volume, consistent market for their products. One potential market that could utilise significant quantities of these tires is the construction industry. The possibility of using shredded tires as a lightweight backfill material for retaining wall applications has been investigated in this study.

2.5 Scrap tire legislation

In December 1991, the United States Congress signed into law the Federal Intermodal Surface Transportation Efficiency Act, which requires that 5% of all federally funded roads laid in 1994 must contain scrap rubber from tires. This means that more than 3000 miles of rubberised roadway will be laid in the United States in 1994 (Pennisi 1992).

In Illinois, provisions of Public Act 86-452, enacted on 31 August 1989, include the following (IDENR 1990):

(1) As of 1 July 1994, whole scrap tires may not be mixed with municipal waste, and separated tires may only be accepted by a sanitary landfill if the landfill has provisions for shredding, chopping or slitting the tires, and has implemented a programme to actively seek alternative uses for the tires.

(2) A scrap tire storage site, defined as any site storing more than 50 tires, must notify the Illinois Environmental Protection Agency (IEPA) after opening. Provisions were also set which limits tire pile height and size, and assumes that tires are stored or processed in a manner that prevents water from accumulating in the tire.

(3) A Used Tire Management Fund was established on 1 January 1990 which allows the IEPA to manage, inspect and administer waste tire sites. For each vehicle title issued in the state, \$0.05 of the revenue received will be deposited in this fund; approximately \$1.7 million is expected to be generated annually.

3. Engineering properties of shredded tires

In order to analyse the feasibility of shredded tires as a potential backfill material, the engineering properties of the shredded tires must first be established. The following experiments were performed to determine essential engineering properties which are required for the design of a retaining wall using shredded tires as backfill material: (1) sieve analysis to determine gradation; (2) compaction test using the Modified Proctor method to determine maximum unit weight; (3) constant head permeability test to determine hydraulic conductivity; and (4) direct shear test to determine shear strength. The results from these tests are presented in the following sections.

3.1 Sieve analysis

Sieve analysis was performed in accordance with ASTM Testing Standard D422 (ASTM 1994) to determine the particle size distribution (gradation) of the shredded tires. The

TABLE 1
Sieve analysis before compaction

Sieve no.	Sieve opening (mm)	Weight retained (g)	Percent of weight retained	Cumulative percent retained	Percent finer
1/2	12.5	2	0.4	0.4	99.6
3/8	9.5	131	26.2	26.6	73.4
4	4.75	287	57.4	84.0	16
6	3.35	33	6.6	90.6	9.4
10	2	16	3.2	93.8	6.2
20	0.85	15	3.0	96.8	3.2
Pan	–	16	3.2	100.0	0

TABLE 2
Sieve analysis after compaction

Sieve no.	Sieve opening (mm)	Weight retained (g)	Percent of weight retained	Cumulative percent retained	Percent finer
1/2	12.5	1	0.2	0.2	99.8
3/8	9.5	123	24.6	24.8	75.2
4	4.75	306	61.2	86	14
6	3.35	28	5.6	91.6	8.4
10	2	12	2.4	94	6
20	0.85	14	2.8	96.8	3.2
Pan	–	17	3.4	100.2	0

sieve analysis was performed twice, using two samples of shredded tires; one before compaction and the other after compacting in a modified Proctor mould. Two tests were performed in order to verify the effects of compaction on the gradation of shredded tires.

The sieve analysis results are summarized in Tables 1 and 2. Figure 1 shows the gradation of the shredded tires. It is evident that the gradation of tire chips is not affected significantly by compaction. The uniformity coefficient, C_u , was determined to be 2.14 and the coefficient of curvature, C_c , was determined to be 1.26. These values indicate that the shredded tires can be classified as uniform, meaning the particles are nearly the same size. The gradation of shredded tires is comparable to the gradation of sandy or gravelly soils commonly used as backfill materials. From the perspective of gradation, the shredded tires are considered acceptable backfill material for retaining walls.

3.2 Unit weight testing

The Modified Proctor Compaction Test, performed in accordance with ASTM Test Designation D1557 (ASTM 1994), was used to determine the maximum dry unit weight of the shredded tires. Unit weight is defined as the weight per unit volume. Dry unit weight was needed for the calculation of pressures in retaining wall designs. In this

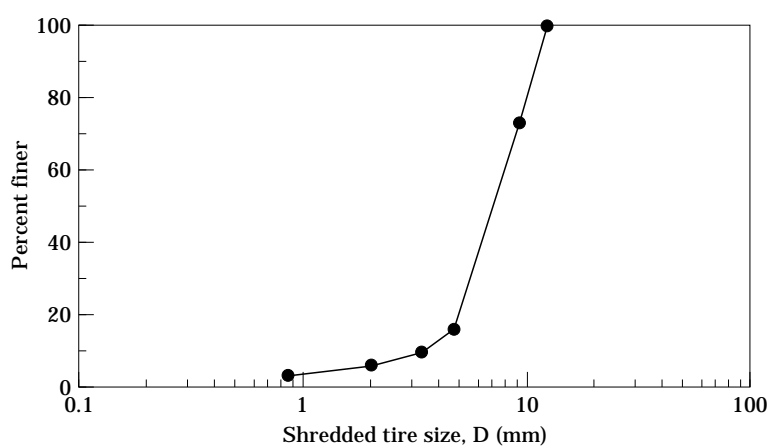


Fig. 1. Gradation of shredded tires used for this study.

test, a 10 lb hammer was dropped through a vertical distance of 18 in producing a compaction energy equal to $56,250 \text{ ft lb ft}^{-3}$. It is noted that this test is commonly used for clayey soils in order to determine moisture–density relationships. Because shredded tires are comparable to sands and gravels, moisture effects are considered negligible. Therefore, the testing was performed using a dry shredded tire sample.

The unit weight of the shredded tires ranged from 35.1 to 37.3 pcf (lb ft^{-3}). This unit weight may be used to specify the amount of compaction necessary when constructing the shredded tire backfill. It is expected that field compaction can be performed using conventional equipment. The unit weight of typical soils ranges from 120 to 140 pcf (Sowers 1979). Thus, the unit weight of shredded tires is less than one-third of the unit weight of soils. Therefore, the shredded tires are considered lightweight backfill material for retaining walls.

3.3 Constant head permeability testing

The constant head permeability test was performed in accordance with ASTM D2434 (ASTM 1994) to determine the hydraulic conductivity of shredded tires. It should be mentioned that ideal backfill material should possess high hydraulic conductivity. High hydraulic conductivity allows free drainage and prevents build-up of hydrostatic pressures. This test was used to determine the drainage characteristics of shredded tires.

The dry unit weights of the samples used for testing ranged from 35 pcf to 37 pcf. These values are comparable to the values determined from the unit weight test. The calculated hydraulic conductivity values from these tests ranged from 0.033 to 0.034 cm s^{-1} , which are comparable to sandy or gravelly soils. This high value of hydraulic conductivity indicates that shredded tires will allow free drainage of water which makes shredded tires a desirable backfill material for retaining structures.

3.4 Direct shear testing

To determine the shear strength of shredded tires, direct shear tests were conducted according to ASTM D3080 (ASTM 1994). A total of three direct shear tests were performed. The tests were performed using three different normal stresses. During each test, shear force, horizontal deformation and vertical deformation of the shredded tire sample were measured. By plotting the shear stress vs. the horizontal deformation, the maximum shear stress that can be sustained by the shredded tires was obtained. By plotting the maximum shear stresses vs. the corresponding normal stresses, the shear strength parameters (friction angle and cohesion) were calculated. These parameters were used in calculating the pressures for the retaining walls with shredded tires as backfill.

The vertical deformation versus the horizontal deformation is plotted and shown in Fig. 2(a)–(c) for the three different normal stresses. The shear stress vs. the horizontal deformation for all three normal stresses is shown in Fig. 3. Since no peak shear stress is observed (Fig. 3), failure was defined to be horizontal deformation equal to 15% of the sample diameter. These shear stresses at failure were plotted vs. corresponding normal stresses as shown in Fig. 4. Linear regression was performed to obtain the best-fitting straight line through the data points. The cohesion is the y -intercept, which is 147 psf, and the friction angle is the slope of the line, which is 27 degrees. The average dry unit density of the three shredded tire specimens was determined to be 38 pcf. These results were used in the design of the retaining walls using shredded tires as backfill.

4. Design of retaining walls

4.1 Problem statement

A retaining wall system was designed for use in the Chicagoland area to provide an adequate level surface for a proposed roadway. The soil at the project site is predominantly silty clay. Because of low hydraulic conductivity, silty clay is not considered to be an ideal backfill material. The silty clay possesses very poor drainage characteristics which results in build-up of hydrostatic pressure behind the wall. The retaining wall must be designed to withstand this hydrostatic pressure which means building a larger retaining wall and incurring increased costs as a result. An alternative to using the existing soil is to excavate this soil and replace it with a suitable backfill material which can produce a more economic and structurally sound design.

There are several viable materials that can be used as backfill and the purpose of this project is to test the potential of using shredded tires as backfill. This was done by comparing a retaining wall design using a conventional backfill, sand, with the design obtained for the same situation using shredded tires as the backfill. To make a thorough comparison, the retaining walls were designed for three different heights 10, 20 and 30 feet, first using sand and then shredded tires as backfill. A cost estimate was done for each retaining wall and backfill material. A cost comparison of retaining walls utilising sand as backfill vs. shredded tires as backfill was used to determine the economic feasibility of shredded tires as backfill material.

4.2 Design criteria

A cantilever wall was selected for the site. The design of this wall consists of two parts:

- (1) the geotechnical design which involves designing the retaining wall dimensions

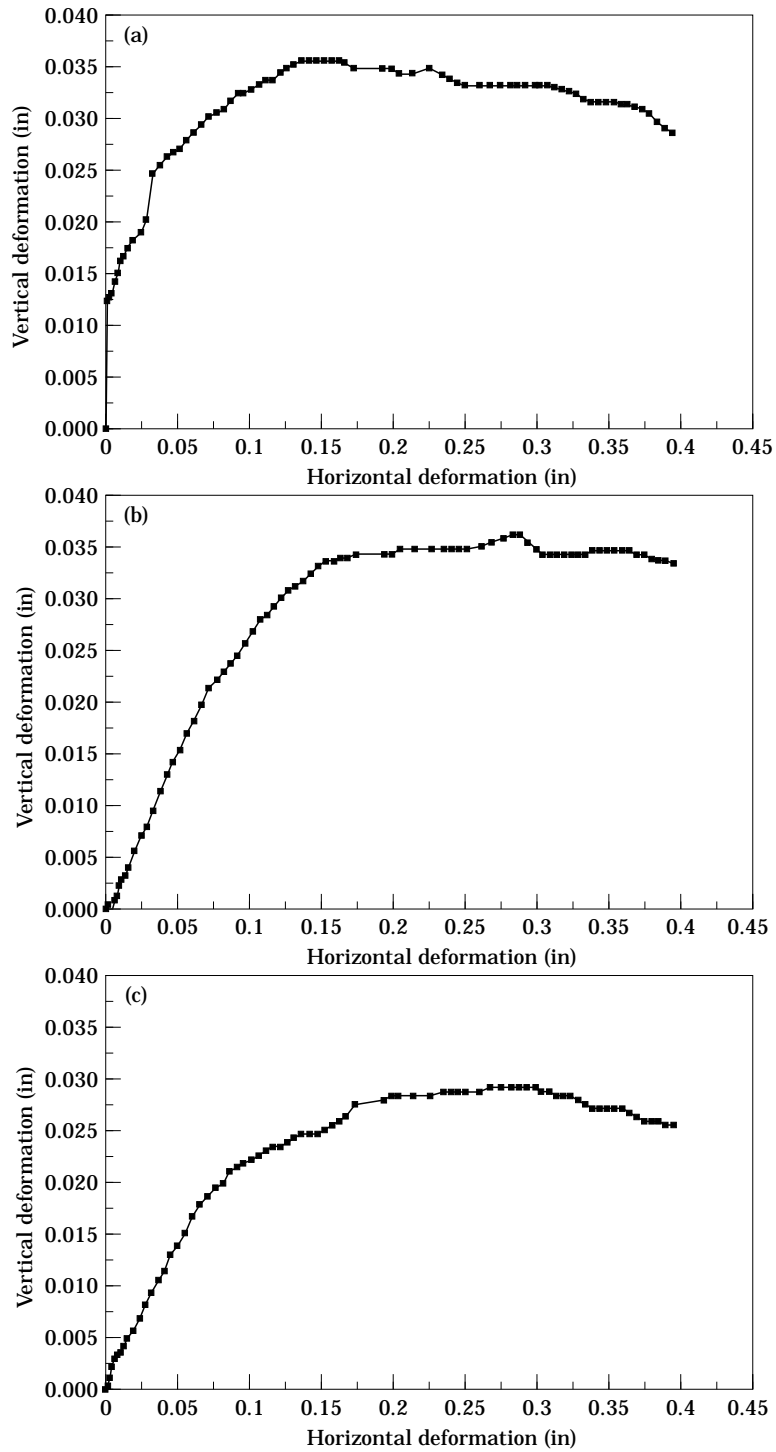


Fig. 2. Horizontal deformation vs. vertical deformation for normal stress (a) 0.5 psi, (b) 2.0 psi and (c) 4.0 psi.

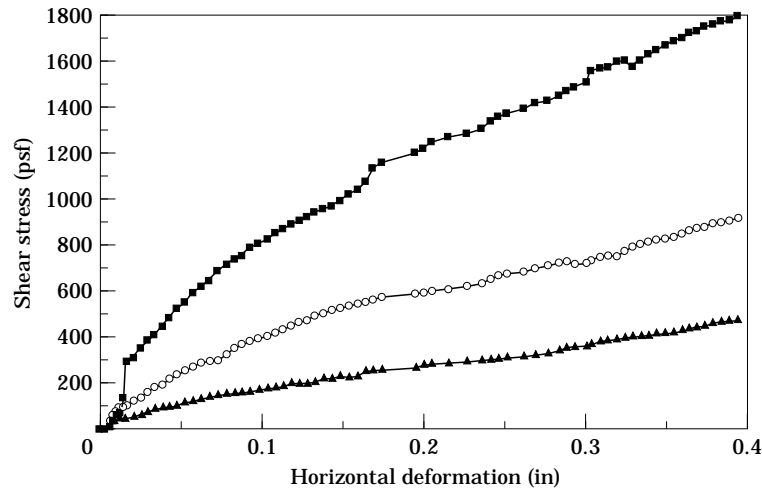


Fig. 3. Horizontal deformation vs. shear stress. ■, 4 psi; ○, 2 psi; ▲, 0.5 psi.

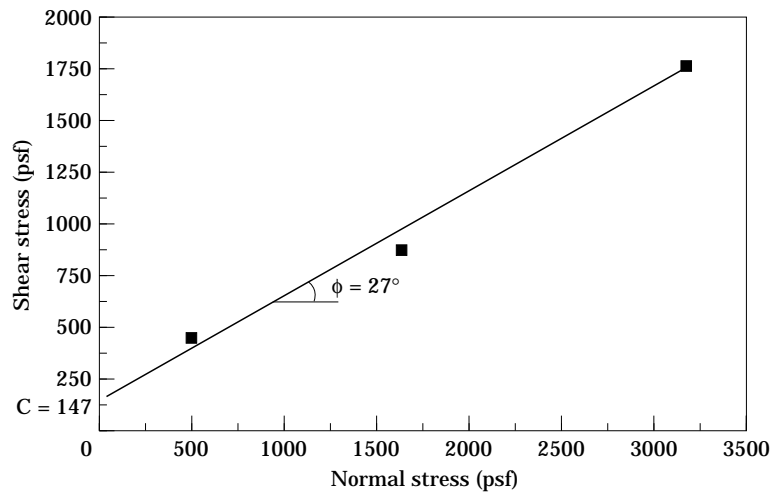


Fig. 4. Normal stress vs. shear stress.

such that the wall satisfies the external stability requirements (overturning, sliding and bearing capacity); and

(2) the structural design which involves determining the amount and type of concrete and reinforcement needed.

The following data was used for all retaining wall design:

- (1) No surcharge loading exists behind the wall.
- (2) Existing soil behind and below the retaining wall is silty clay. Based on tri-axial tests on this soil, the following properties were obtained: cohesion = 1224 psf, friction

angle = 17 degrees, and unit weight = 130 pcf. The footing friction is assumed to be 18 degrees. All of the clay behind the wall must be excavated.

(3) The backfill slope is 14 degrees based on site conditions.

Fine to medium sand was considered as a typical conventional backfill for the purpose of this study. The properties of sand used in design of retaining walls were obtained based on published literature and were as follows: cohesion = 0, friction angle = 38 degrees, unit weight = 125 pcf, and wall friction = 20 degrees. The properties for shredded tires are based on the results from the laboratory testing and are as follows: cohesion = 120 psf, friction angle = 22 degrees, unit weight = 38 pcf, and wall friction = 15 degrees (two-thirds of friction angle).

4.3 Geotechnical design

The initial trial retaining wall dimensions were assumed. The analysis for the sliding stability was done by determining the active earth pressures on the wall using Coulomb's method. The passive earth pressure was calculated using the Rankine method. The sliding friction was determined by calculating the weight on the footing and the friction force at the bottom of the footing. The sliding factor of safety is the horizontal resisting forces divided by the horizontal driving forces. If the factor of safety is not satisfied, the dimensions of the wall must be changed until a satisfactory result is achieved. When the trial design satisfies the sliding stability, the overturning factor of safety must be evaluated.

The overturning factor of safety is the ratio of the sum of the resisting moments to the sum of the driving moments. A trial and error procedure must be done until the factor of safety is adequate. The next criteria that must be satisfied is that the normal force must act in the middle third of the footing. In this instance, the objective is to locate the resultant force and then check if this force is located within the middle third of the footing. Once the resultant force is located within the middle third of the footing, the bearing capacity must be analysed. This analysis is done by calculating the equivalent bearing capacity and comparing it to the calculated allowable bearing capacity. The equivalent bearing capacity must always be less than the allowable bearing capacity. The heel and toe bearing capacity are also calculated. The final dimensions of the retaining wall are obtained once these criteria have been satisfied.

The final dimensions for a 10-ft high wall using sand vs. shredded tires as backfill are shown in Fig. 5. The dimensions for 20-ft and 30-ft high walls are given in Cecich *et al.* (1994). Once the dimensions of the retaining wall were satisfactory with respect to geotechnical stability, the structural design was performed.

4.4 Structural design

The purpose of this design is to ensure that the retaining wall will remain structurally sound. The objectives for adequate design include: (1) selecting the efficient strengths of materials for the concrete and reinforcing steel; (2) verifying the minimum thickness of reinforced concrete in the stem and footing due to lateral and shear earth pressures; and (3) determining the quantities of reinforcing required, including size, length and spacing.

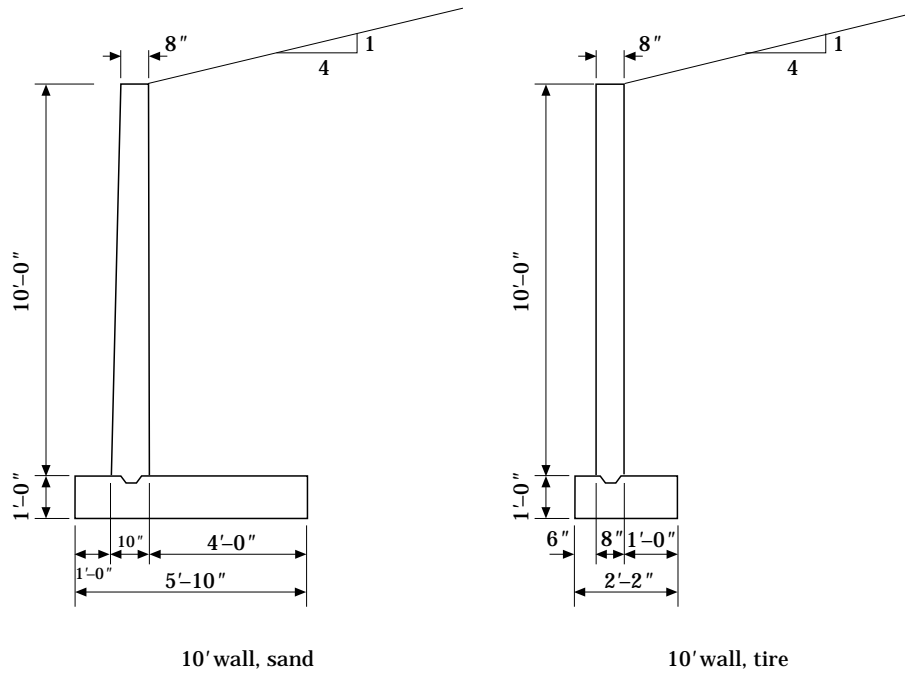


Fig. 5. Geotechnical design of 10-ft high retaining wall with sand and shredded tires as backfill materials.

The structural design was performed to meet the ACI Code requirements. First, in order to determine the design of the retaining wall, the ultimate loads acting on it must be known. Active earth pressures acting on the stem were calculated using Coulomb's method, while passive earth pressures acting on the footing were calculated using Rankine's method. These forces were then factored and applied to preliminary stability design parameters, as per the previous analysis described.

In this analysis, the strengths of both concrete and steel were changed to determine the most efficient and economical design. The stem and heel of the retaining wall were designed by the Cantilever method, where a flexural analysis was conducted on the dimensions of concrete and rebar specified. Because concrete does not resist tension, steel reinforcing is placed in all areas where tension occurs. Flexural analysis requires the determination of ultimate, or factored, shear and moment acting on the wall. The ultimate shear and moment is determined once the applied load is multiplied by the ACI specified factors, 1.4 for dead loads and 1.7 for earth loads. The ultimate shear and moment calculated specifies the required strength the wall must have in order to remain structurally sound. Once the moment was determined, the type, spacing, lengths and quantity of reinforcing required could be found as well as the minimum thickness of concrete required for the stem and heel.

The toe reinforcing was designed after designing the reinforcement for the heel. The moment acting on the toe was determined from taking the moment about a point of the resulting moments that act on the heel and stem. This point was located at the face of the wall and top of the footing. Once the moment was found, the area, spacing, lengths and quantity of reinforcing could be determined. The minimum required steel ratio for each segment of the retaining wall are specified as follows (Coduto 1994):

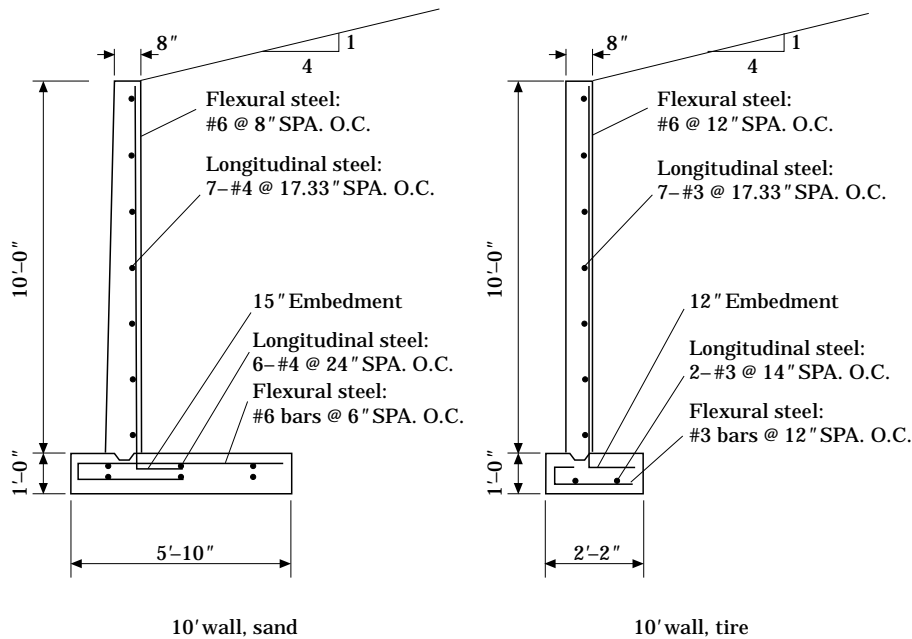


Fig. 6. Structural design of 10-ft high retaining wall with sand and shredded tires as backfill materials.

Component		Steel ratio
Stem:	Flexural steel (base of the stem)	0.0200
	Longitudinal steel	0.0020
Heel and Toe:	Flexural steel	0.0015–0.0020
	Longitudinal steel	0.0020

The development length of each type of rebar, in each type of concrete, also needed to be determined. The development length is the theoretical length of rebar required before the bond between the rebar and the concrete is considered to be 100%. The length is added to the length required by flexural analysis to create a member which will resist the stresses determined in design. The development lengths depend on the size of the rebar, the strength of the concrete and the strength of the steel.

The structural design of the 10-ft high retaining wall with sand vs. shredded tires as the backfill material is shown in Fig. 6. The structural design of 20- and 30-ft high retaining walls is presented in Cecich *et al.* (1994). It should be noted that this analysis did not include hydrostatic pressures. It is assumed that a drainage system consisting of weepholes and/or drain pipes will be incorporated in the wall design in order to prevent the build-up of hydrostatic pressures.

5. Economic analysis

Cost estimates were made for the 10-, 20- and 30-ft high retaining walls with sand vs. shredded tires as backfill materials to determine the economic advantages of using shredded tires as the backfill material. In each case, the length of the wall was 100 ft.

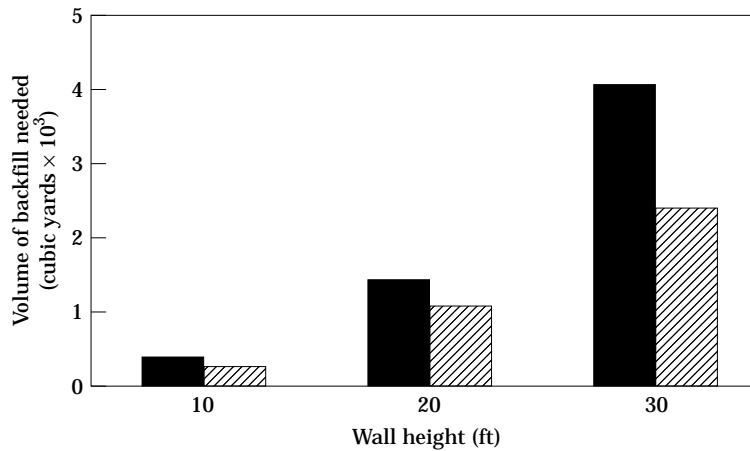


Fig. 7. Comparison of backfill volumes for retaining walls with sand (solid bars) and shredded tires (hatched bars) as backfill material.

The cost estimates were based on prevailing labour costs and included all other major costs such as clearing and grubbing, excavation and material costs. The construction site was assumed to be located relatively close to the material suppliers. Based on the information collected from local vendors, the average cost of sand was \$20 per cubic yard (cy) or \$12 per ton. The cost of shredded tires depends on the processing costs to shred the tires to the required tire chip sizes and the transportation costs which depend on the distance of the project site from the shredding facility. Based on the information obtained from the local tire shredding companies, the cost of shredded tires ranges from \$1.5 to \$5 per cubic yard or \$3 to \$10 per ton. For the purpose of this study, the maximum cost of \$5 per cubic yard or \$10 per ton was used for shredded tires.

The largest expense in the cost analysis was the quantity of backfill material used for the retaining wall. Therefore, the volume of excavation is an important parameter in determining the overall costs. For cost estimate purposes, the volume of excavation is assumed equal to the theoretical volume of Rankine's wedge, and the volume of backfill required is taken equal to the volume of excavation. Based on this, the required volume of sand for the 10-, 20- and 30-ft sand retaining walls was 396 cy, 1466 cy and 4070 cy, respectively. The required volume of shredded tires for the 10-, 20- and 30-ft shredded tire wall was 247 cy, 1099 cy and 2422 cy, respectively. These volumes are graphically compared in Fig. 7.

A comparison of estimated material costs for both shredded tires and sand is shown in Table 3 and Fig. 8. It can be seen that material costs can be reduced by 81% to 85% by using shredded tires instead of sand as the backfill material. The savings in material costs will increase as the retaining wall height increases, as shown in Fig. 9.

The total costs for the shredded tires vs. sand as backfill materials for the retaining walls are compared in Table 3 and Fig. 10. The cost savings realised by using shredded tires as the backfill material can range from 52 to 67%. Summarising the overall cost savings in Fig. 11, it is seen that the total savings will increase as the wall height increases.

In addition to the cost savings, the stability of retaining walls is enhanced by the use of shredded tires as the backfill material. A comparison of factors of safety against

TABLE 3
Comparison of costs for retaining walls with sand vs. shredded tires as backfill materials
(100-ft long walls)

Height of wall (ft)	Estimated material cost (U.S. \$)			Estimated total cost (U.S. \$)		
	Sand backfill	Shredded tire backfill	Savings from shredded tires (%)	Sand backfill	Shredded tire backfill	Savings from shredded tires (%)
10	8000	1300	84	17,900	8600	52
20	29,700	5600	81	53,900	19,700	63
30	82,500	12,400	85	145,800	48,300	67

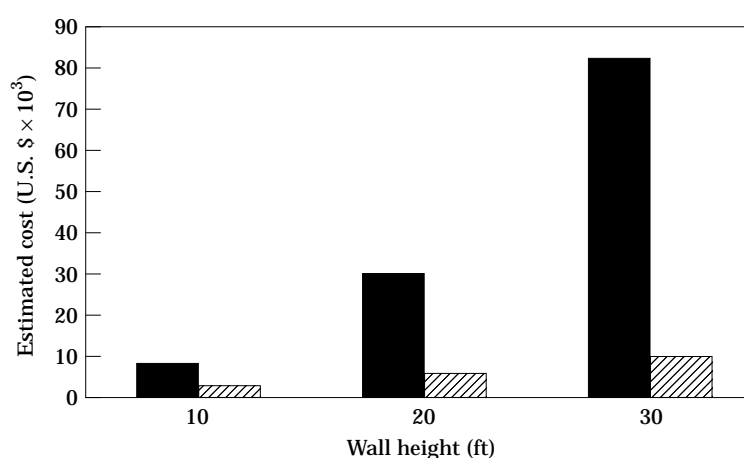


Fig. 8. Comparison of material cost for retaining walls with sand (solid bars) and shredded tires (hatched bars) backfills.

sliding and overturning for the walls with sand vs. shredded tire backfills is shown in Table 4 and Figs 12 and 13. The sliding and overturning factors of safety for the retaining walls with shredded tire as backfill were significantly greater than that for the retaining walls with sand as the backfill material. Therefore, the retaining walls with shredded tires as backfill material are considered more stable than the retaining walls with sand as backfill material.

6. Summary and conclusions

The scrap tire disposal problem has reached overwhelming proportions in the U.S.A. Each year in the United States, approximately 242 million automobile, truck and specialty tires are discarded. Almost 78% of these scrap tires wind up in overcrowded landfills and thousands more are strewn across the country's empty lots, highways and illegal tire dumps (Lund 1993). Used tires pose a serious public health and environmental threat for three major reasons: (1) a scrap tire dump provides an ideal breeding ground for mosquitoes, rats and other disease-carrying vermin; (2) scrap tire disposal centres

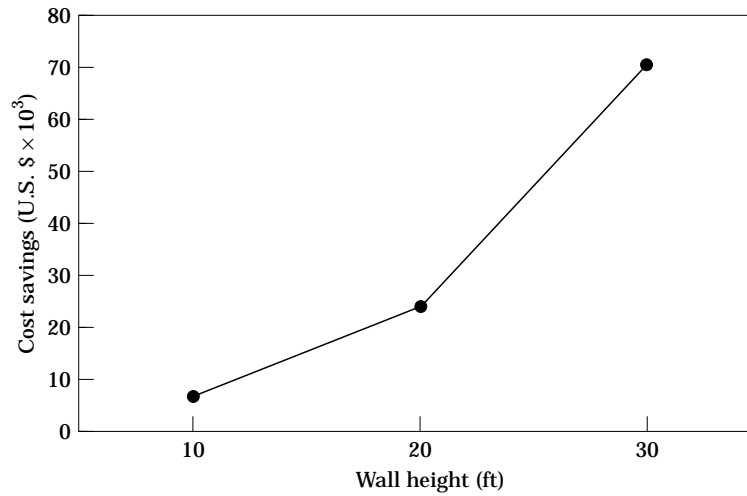


Fig. 9. Estimated material cost savings using shredded tires as backfill material.

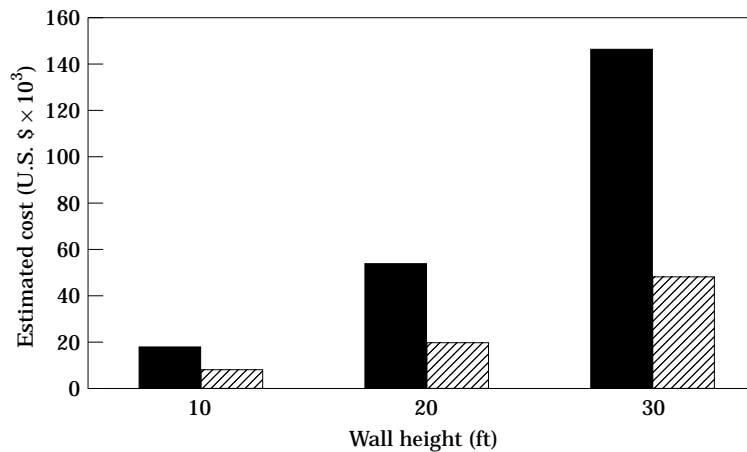


Fig. 10. Comparison of total cost for retaining walls with sand (solid bars) and shredded tires (hatched bars) as backfill material.

can easily catch fire which can produce toxic air emissions; and (3) tires tend to “float” to the surface of a landfill, breaking the landfill cover and causing increased leachate production which could contaminate groundwater.

Economically feasible alternatives for scrap tire disposal must be found. Some of the current uses of scrap tires are tire-derived fuel, barrier reefs and crumb rubber under asphalt surfaces. However, all of the recycling, re-use and recovery practices combined only consume about 22% of the nation’s discarded tires. Therefore, a demand still exists for development of additional uses for scrap tires. This project addresses one potential use of scrap tires within the civil engineering field. Specifically, the feasibility of using shredded tires as a lightweight backfill material for retaining walls has been investigated.

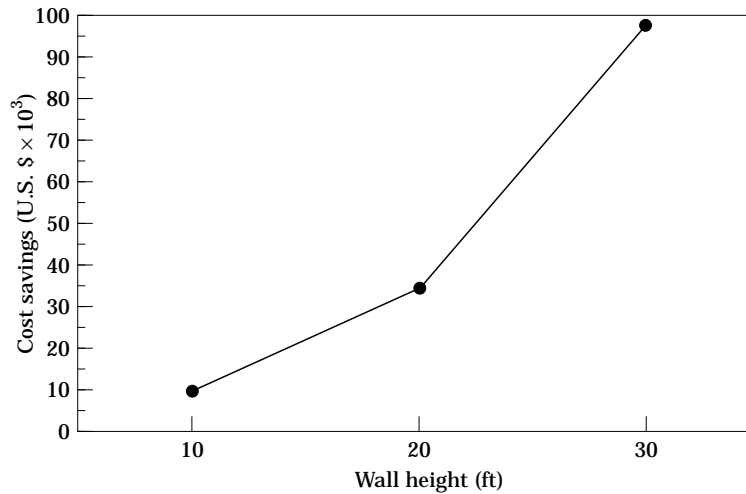


Fig. 11. Estimated total cost savings using shredded tires as backfill.

TABLE 4

Comparison of factors of safety for retaining walls with sand vs. shredded tires as backfill materials (100-ft long walls)

Height of wall (ft)	Sliding factor of safety		Overturning factor of safety	
	Sand backfill	Shredded tire backfill	Sand backfill	Shredded tire backfill
10	4.15	>20*	2.10	>20*
20	1.68	10.37	1.84	2.12
30	1.54	3.35	1.65	2.14

* Design incorporates minimum dimensions for the wall, yet the calculated factors of safety were significantly greater.

Laboratory tests were performed in order to obtain the engineering properties of shredded tires. First, sieve analyses were performed using the shredded tire sample both prior to and after compaction in order to determine gradation characteristics. Based on these analyses, the shredded tire sample used for this study can be classified as uniform in size, and compaction did not alter the gradation significantly. The unit weight of shredded tires was determined using the Modified Proctor Test Set-up and the maximum value of the unit weight was found to be 38 pcf. The permeability of the shredded tires was determined using the constant head permeameter and the value of hydraulic conductivity was found to be 0.03 cm^{-1} . The shear strength of shredded tires was determined based on the direct shear tests. The shear strength parameters determined based on these tests were equal to: cohesion = 147 psf, and angle of internal friction = 27 degrees. All of these engineering properties were used for the design of the retaining walls.

A detailed geotechnical and structural design of retaining walls was performed for

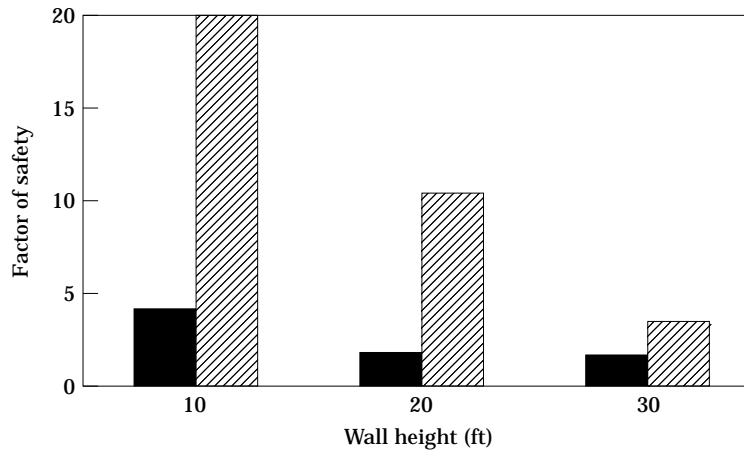


Fig. 12. Comparison of sliding factors of safety for retaining walls with sand (solid bars) and shredded tires (hatched bars) as backfill materials.

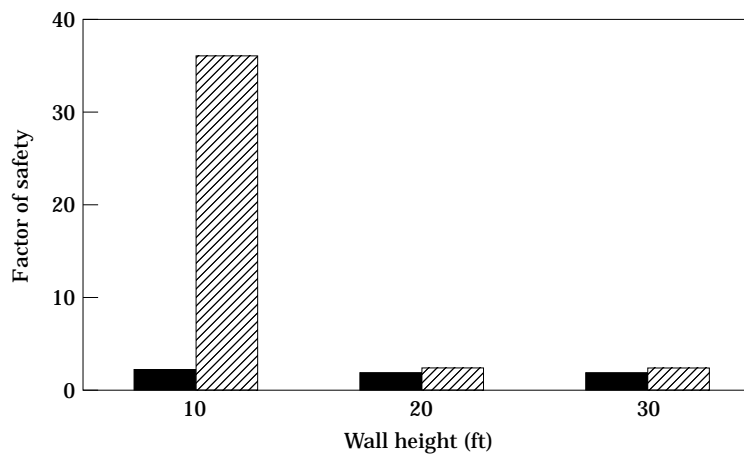


Fig. 13. Comparison of overturning factors of safety for retaining walls with sand (solid bars) and shredded tires (hatched bars) as backfill materials.

both shredded tires and sand as backfill materials for comparison purposes. To make a thorough comparison, retaining walls were designed for three different heights; 10, 20 and 30 ft. A cost estimate was done for each retaining wall and backfill and for a 100-ft wall length. From these estimates, it was determined that using a shredded tire wall instead of a sand wall will generate an average saving of 60%. For example, for the 30-ft high and 100-foot long wall, the total construction cost savings generated by using shredded tires was \$97,500 or 67% of the total cost. Therefore, a substantial savings was realised for walls utilising a shredded tire backfill.

Based on the results of testing, design and cost analysis, it can be concluded that using shredded tires as an alternative backfill material is not only economically feasible, but it is also quite economically advantageous. Also, the use of scrap tires as a backfill

material helps to reduce the enormous amount of tires currently stockpiling in landfills.

It is recommended, however, that further studies be conducted in order to determine actual field feasibility. The major concerns which need to be addressed when using shredded tires as backfill material are: (1) inadequate load bearing capacity to resist heavy surcharge loads; (2) high compressibility; and (3) adverse leaching effects. These concerns must be examined adequately before this new backfill material can gain acceptability.

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