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TIRE SHREDS AS LIGHTWEIGHT FILL FOR RETAINING WALLS – RESULTS OF FULL SCALE FIELD TRIALS

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ABSTRACT : Tire shreds offer several advantages when used as backfill for retaining walls. Most importantly, they have an in-place density of 0.80 to 0.93 Mg/m³, which is less than half the density of conventional soil fill. This results in significantly lower earth pressures. In addition, they have a hydraulic conductivity that is greater than 1 cm/sec which promotes rapid drainage of water from the backfill and a thermal conductivity that is 80% lower than soil, which helps to reduce problems with buildup of ice lenses in the backfill in cold climates. Tire shreds used for these applications generally have a maximum size between 50 and 300 mm. Case histories of instrumented projects that use tire shreds as retaining wall backfill are presented. The first is a 4.9-m high retaining wall test facility constructed on the University of Maine campus. Horizontal stresses were measured with pressure cells and load cells. Surcharges up to 35.9 kPa were applied. The at-rest horizontal stress with tire shreds was approximately 45% less than expected for conventional gravel backfill. After taking these measurements, the wall was rotated outward to achieve active earth pressure conditions. For this case, the horizontal stress with tire shreds was 35% less than expected for gravel. In the second project, a 4.3-m thick tire shred layer was used as backfill behind a bridge abutment. The abutment was instrumented with pressure cells. Measured horizontal stresses were similar to those described above for the wall on the University of Maine campus. The results from these full-scale trials demonstrate the viability of using tire shreds as retaining wall backfill.

KEYWORDS: walls, retaining walls, earth pressure, at rest earth pressure, earth pressure coefficient, lightweight fill, tire shreds

1. INTRODUCTION

In recent years using tire shreds, which are pieces of whole tires cut into 25-mm to 305-mm pieces, in highway applications has increased. These uses include: lightweight fill [1,2,3,4,5], insulation beneath roads [6], and lightweight backfill for retaining walls [3,7,8,9,10]. The effects on water quality are negligible [11,12]. Although, three thick tire shred fills have experienced a serious self-heating reaction [13], design guidelines are now available to prevent this from occurring [14].

Using tire shreds as retaining wall backfill has several potential benefits. In areas where the underlying soil is weak or compressible, the low unit weight of tire shreds would apply a smaller vertical stress than conventional backfill, leading to lower settlement and increased global stability. The horizontal stress on a retaining wall would be lower than with conventional backfill, resulting in a less expensive retaining wall design. The insulation qualities of tire shreds would reduce frost penetration. Moreover, their high permeability would provide good drainage. This paper presents the measured horizontal pressure from full scale projects that used tire shreds as backfill. The first is a

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series of tests conducted in a retaining wall test facility on the University of Maine campus [9,10]. The results are compared to a bridge abutment with tire shreds as backfill constructed as part of the Route 196 Bypass project in Topsham, Maine [8].

2. FULL SCALE TEST WALL

2.1 Facility Design

The test facility is 4.88 m high and 4.47 m by 4.57 m in plan. It consists of four walls and a reinforced concrete foundation. The two sidewalls are reinforced concrete. The back wall is removable, which allowed the backfill to be removed after completion of a test. The front wall consists of three panels. Measurements of forces and pressures were taken on the center panel to lessen the influence of friction between the backfill and the sidewalls. The center panel was mounted on six load cells: two oriented vertically at the base of the panel to measure the shear force; and four oriented horizontally, two at the bottom of the panel and two at the top, to measure the horizontal force. The center panel also contained four pressure cells cast into its concrete face. Outward rotation of the three panels about their base was controlled using screw jacks. Concrete blocks were used to apply surcharges up to 35.9 kPa. The facility design is shown in Figures 1 and 2.

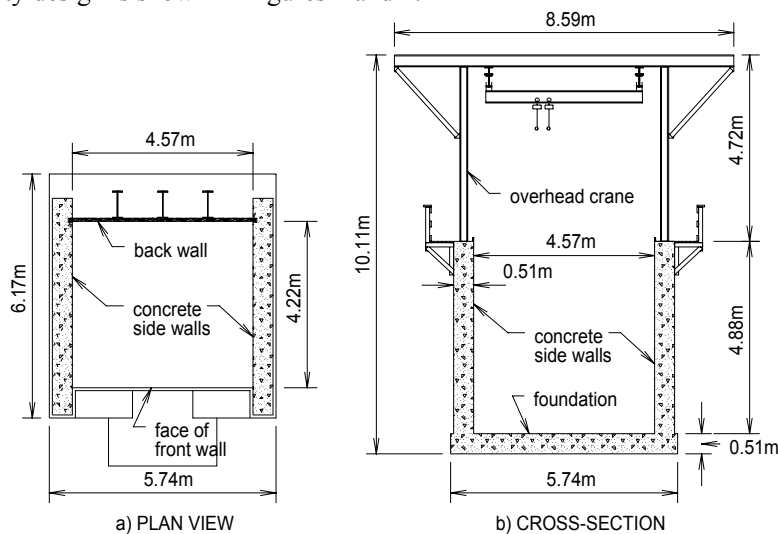


Figure 1. Plan and cross-section of full-scale retaining wall test facility.

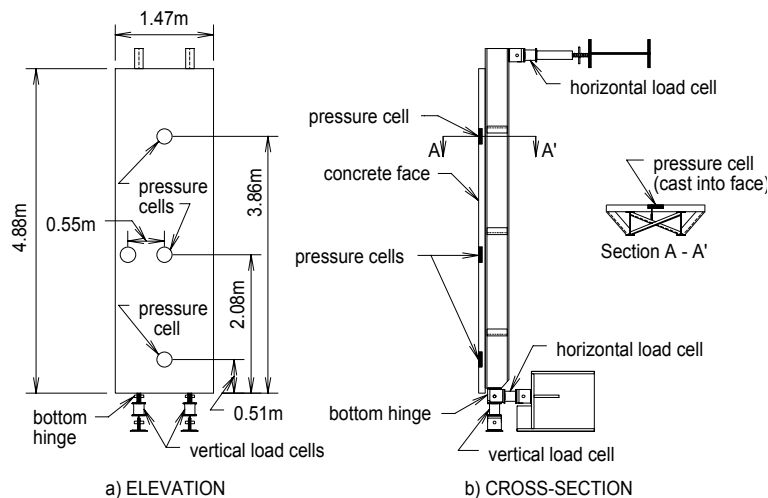


Figure 2. Elevation and cross-section for front wall center panel.

2.2 Tire Shred Properties

Tire shreds from three suppliers were tested. The tire shreds from Pine State and Palmer were long and flat with many exposed steel belts, while those from F&B were equidimensional with few exposed steel belts. The tire shreds were uniformly graded and composed primarily of gravel size particles. Gradation of the tire shreds [15], showed that F&B shreds were the smallest with a 38-mm maximum size, while Pine State and Palmer shreds both had a 76-mm maximum size. The tire shreds were placed in 200-mm lifts and compacted with four passes of a walk-behind vibratory tamping foot roller with a static weight of 1180 kg. The field density was determined by compacting a lift of tire shreds in a 3.05-m long by 1.02-m wide box. The average field density based on five tests was 0.71 Mg/m³ for F&B, 0.69 Mg/m³ for Palmer, and 0.71 Mg/m³ for Pine State.

2.3 At-Rest Horizontal Pressure

The horizontal stress distribution was determined using the load cell measurements by summing the moments about the base of the panel and assuming the distribution to be trapezoidal. The horizontal stress distributions for each of the suppliers were very similar. A typical plot with Palmer shreds is shown on Figure 3. This shows that the horizontal stress increases with increasing surcharge. At the lower surcharges, the horizontal stress increases with depth; but at the higher surcharges, the horizontal stresses becomes almost constant with depth.

The horizontal stress distributions of tire shreds and granular fill under the 35.9 kPa surcharge were compared. As part of the study, a granular fill was tested in the facility. However, the granular fill was a well graded gravelly sand. It was placed near optimum water content and therefore exhibited considerable apparent cohesion. This was evidenced by the granular fill standing on a 4.57 m high vertical face when the back wall was removed. The apparent cohesion lead to unrealistic values of horizontal stress [15]. Therefore, the horizontal stress distributions at the 35.9 kPa surcharge for each of the tire shred suppliers were compared to the expected horizontal stress distribution for a typical granular fill with a compacted density of 2.02 Mg/m³ and coefficient of lateral earth pressure at rest (K_0) of 0.38 as shown in Figure 4. The resultant of the horizontal stress from the tire shreds is approximately 45% less than for granular fill. This is due, at least in part, to the density of tire shreds being 1/3 to 1/2 that of conventional granular backfill.

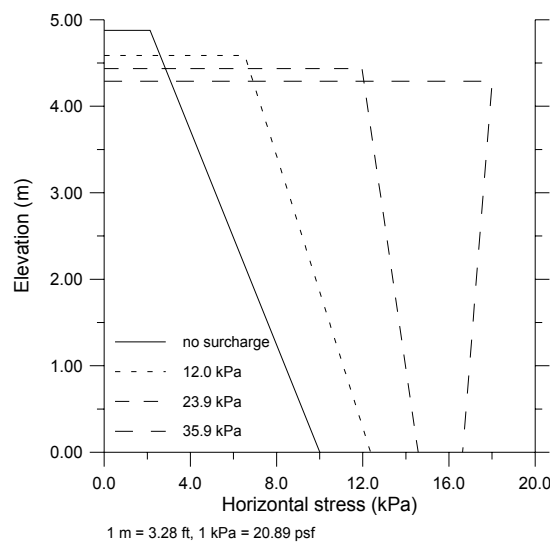


Figure 3. At-rest stress distribution for Palmer shreds at four surcharges.

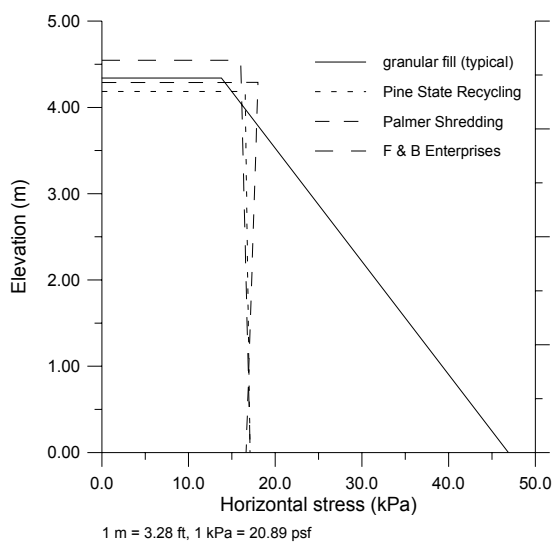


Figure 4. At-rest stress distribution at a 35.9 kPa surcharge compared to granular fill.

The coefficient of lateral earth pressure at rest for tire shreds was determined. For no surcharge, K_o was calculated just below the fill surface because the vertical stress is zero at the fill surface, so K_o is undefined. The values for K_o are summarized in Table 1, which shows that the coefficient of lateral earth pressure at rest decreases with depth for all four loading conditions. The values for K_o also decrease from no surcharge to 23.9 kPa. K_o then remains approximately constant from 23.9 kPa to 35.9 kPa. The differences between K_o for each supplier at a given surcharge and depth are small. Comparison of K_o for tire shreds shown on Table 1 with typical K_o of normally consolidated granular soils of 0.35 to 0.50 [16], shows K_o for tire shreds is lower at the 2.0-m and 4.0-m depths. This suggests that the lower at-rest pressures produced by tire shreds are due to both their lower K_o and lower density.

TABLE 1 Coefficient of Lateral Earth Pressure At Rest, K_o

Supplier	Depth (m)	Surcharge			
		0	12.0 kPa	23.9 kPa	35.9 kPa
F&B Enterprises	0	0.99 ^a	0.51	0.44	0.45
	2	0.39	0.33	0.32	0.32
	4	0.31	0.28	0.26	0.25
Palmer Shredding	0	0.94 ^a	0.58	0.51	0.51
	2	0.37	0.33	0.27	0.33
	4	0.29	0.27	0.17	0.24
Pine State Recycling	0	0.93 ^a	0.55	0.46	0.47
	2	0.37	0.32	0.32	0.32
	4	0.28	0.26	0.26	0.25
Average	0	0.95 ^a	0.55	0.47 ^b	0.47 ^b
	2	0.38	0.33	0.31 ^b	0.31 ^b
	4	0.29	0.27	0.24 ^b	0.24 ^b

^a Value found at a depth of 0.5 m

^b Average from 23.9 kPa and 35.9 kPa surcharges

2.5 Active Earth Pressure

After measurements for the at-rest condition were completed, the wall was rotated outward to achieve active earth pressures. The horizontal stress distributions for all of the suppliers at the same wall rotation were very similar. The horizontal stress distributions immediately after each wall rotation for Palmer shreds under an applied surcharge of 35.9 kPa are shown in Figure 5. Before rotation the horizontal stress decreases slightly with depth; then, as the wall is rotated from at-rest conditions to 0.01H, the horizontal stress decreases significantly at the top. At a rotation of 0.01H the magnitude of the resultant horizontal force was 50% less than before rotation. Similar decreases in horizontal stress were measured for F&B and Pine State. The horizontal stress for tire shreds at a rotation of 0.01H were compared to a typical granular fill with a compacted density (ρ) of 2.02 Mg/m³ and coefficient of lateral earth pressure at rest (K_a) of 0.24 as shown in Figure 6. The resultant horizontal force from the tire shreds was approximately 35% less than that of the granular fill.

The earth pressure coefficient, K , was determined for each tire shred supplier at the 0.01H rotation and the larger rotations for Palmer and Pine State, at the depths of 0 m, 2.0 m, and 4.0 m. The results are shown in Table 2. It is seen that for a rotation of 0.01H, K is very similar for the three suppliers at each depth with values ranging from 0.22 to 0.25. At larger rotations, K ranges from 0.16 to 0.18 at a rotation of 0.03H for Palmer and from 0.08 to 0.12 at a rotation of 0.04H for Pine State. This suggests that K decreases with outward movement. Figure 7 shows that the effect of wall rotation on K is

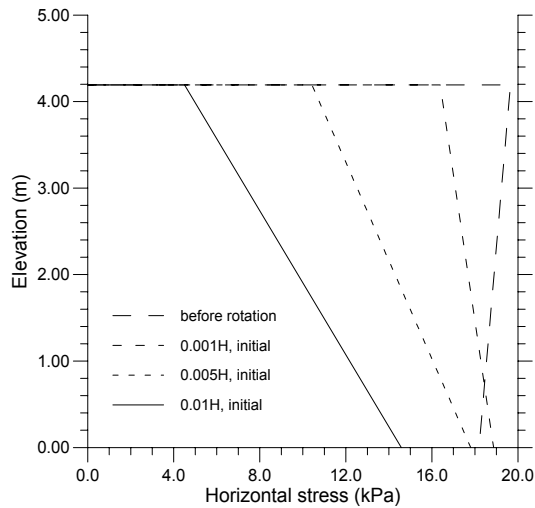


Figure 5. Stress distribution for Palmer shreds for wall rotations of zero to 0.01H

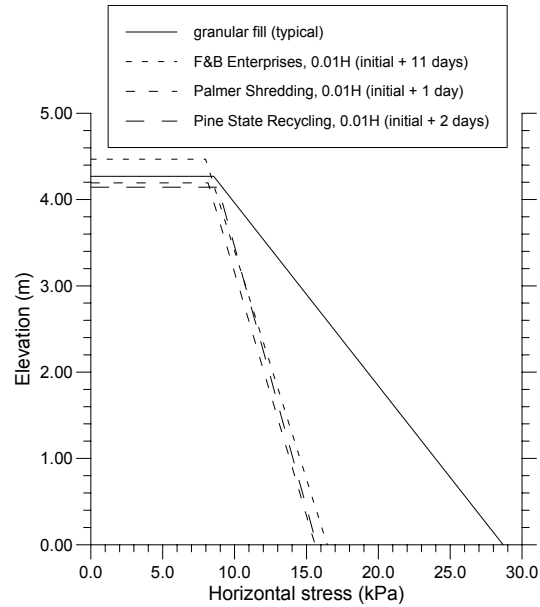


Figure 6. Stress at 35.9 kPa surcharge and 0.01H rotation compared to granular

TABLE 2. Earth Pressure Coefficient, K for rotated case

Supplier	Depth (m)	Rotation		
		0.01H	0.03H	0.04H
F&B Enterprises	0	0.23	--	--
	2	0.23	--	--
	4	0.23	--	--
Palmer Shredding	0	0.23	0.18	--
	2	0.22	0.17	--
	4	0.22	0.16	--
Pine State Recycling	0	0.25	--	0.08
	2	0.23	--	0.11
	4	0.22	--	0.12

greater at the shallower depths. Moreover, reduction in K is small for rotations greater than 0.01H, suggesting that the reported K's were approaching the minimum values that meet the definition of active conditions. A reasonable approach for design would be to use the K for a rotation of 0.01H. Thus, for conditions similar to this trial, a design K of 0.25 would be reasonable and slightly conservative compared the values in Table 2.

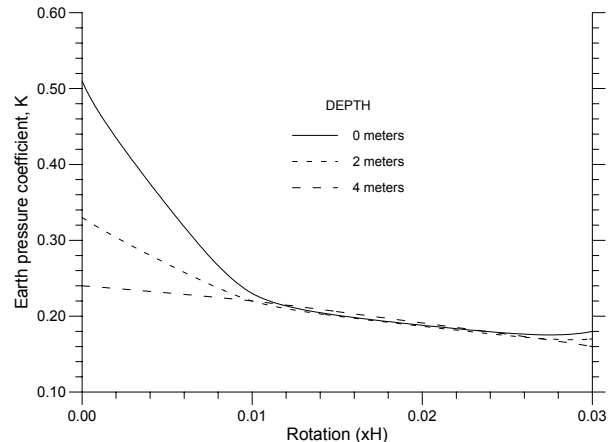


Figure 7. Effect of rotation on earth pressure coefficient at 35.9 kPa surcharge.

A simplified design approach was developed based on equivalent fluid pressure. The semiempirical design parameters were developed following the methods presented in Terzaghi et al. [17] for soils. The key parameter is a semiempirical value, k_h , with units of weight per unit volume. The method can be thought of as replacing the backfill with a fluid of density k_h . The value k_h can then be used to determine the horizontal stress using

$$\sigma_h = gk_h d \quad (1)$$

where g is gravity, 9.81 m/s^2 , and d is the depth of the fill, as shown on Figure 8a. In cases where a surcharge is applied and the surface of the backfill is horizontal, the horizontal stress at any depth is increased by the amount

$$p_q = Cq \quad (2)$$

where C is a coefficient dependent on the backfill type, and q is the surcharge in units of load per unit area. The combination of the stress due to the backfill and the surcharge results in a trapezoidal distribution, as shown on Fig. 8b. k_h and C were found by dividing the trapezoid distributions determined from the load cells into two parts, as shown on Fig. 8c. The contribution to the horizontal stress from the tire shreds was taken to be the triangular portion of the distribution, shown as $\sigma_{\text{tire shreds}}$. The remainder of the horizontal stress was assigned to the $\sigma_{\text{surcharge}}$. The results for a rotation of 0.01H are shown in Table 3. It would be reasonable to use a $k_h = 0.18 \text{ Mg/m}^3$ and $C = 0.23$ for design for conditions similar to this study. For comparison the k_h for granular backfill is about 0.5 Mg/m^3 [17].

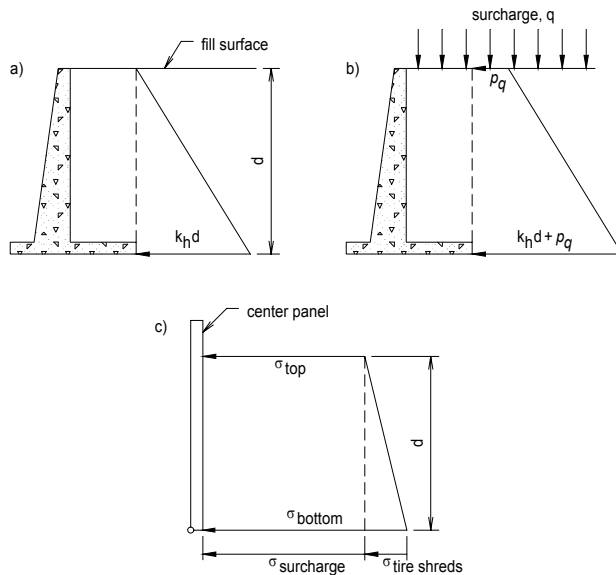


TABLE 3. Semiempirical Design Parameters for rotation of 0.01H.

Supplier	k_h (Mg/m^3)	C
F&B Enterprises	0.19	0.22
Palmer Shredding	0.18	0.23
Pine State Recycling	0.17	0.25

Figure 8. Semiempirical design procedure. a) no surcharge, b) with surcharge, c) separation of effect of surcharge and tire shreds.

3. NORTH ABUTMENT OF MERRYMEETING BRIDGE

Tire shreds were used as backfill for the North Abutment of the Merrymeeting Bridge to improve the factor of safety for a rotational slope stability failure seated in a weak marine clay layer. A cross section through the project is shown in Figure 9. The project is described more fully in [8]. Horizontal stress was measured with six pressure cells cast into the back face of the concrete abutment. Results are summarized in Table 4. The pressures are similar to those measured in the UMaine test facility for the at-rest case. The surcharge on the tire shred zone for the North Abutment was 38.4 kPa which is 7% greater than the maximum used in the UMaine test facility. If the stresses measured in this facility at a surcharge of 35.9 kPa are increased by 7%, they would range from 17.8 to 19.3 kPa. This compares favorably to the pressures measured at the North Abutment on August 6, 1997 of 16.3 to 22.3 kPa for all cells except PC2-2 which measured a higher pressure of 30.8 kPa.

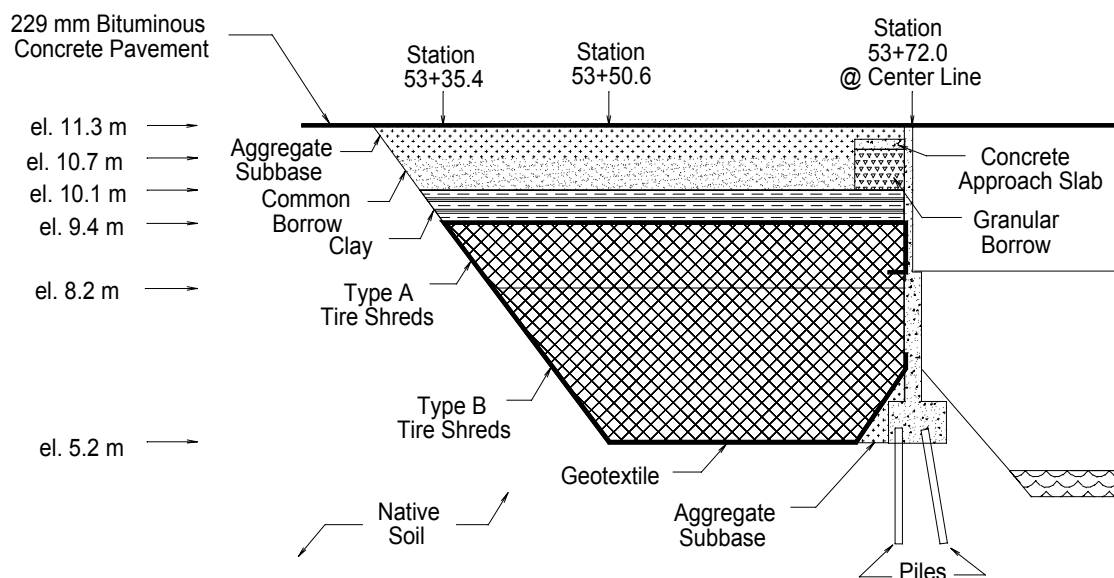


Figure 9. Cross section through north abutment of Merrymeeting Bridge in Topsham, Maine.

Table 4. Summary of lateral pressures on abutment wall.

	PC1-1	PC2-1	PC1-2	PC2-2	PC1-3	PC2-3
Date	Cell el.=6.70m		Cell el.=7.77m		Cell el.=8.84m	
10/3/96 ²	7.84 ¹	7.41	6.04	7.27	2.62	1.41
10/9/96 ³	17.04	20.04	19.61	30.22	17.05	10.91
10/31/96	18.27	21.05	20.98	32.84	20.24	12.31

¹Horizontal pressure in kPa.

²Date tire shred placement completed.

³Date soil cover and surcharge placement completed.

4. CONCLUSIONS

A full scale retaining wall test facility was constructed to test tire shreds from three suppliers as retaining wall backfill. Horizontal earth pressures were measured under surcharges up to 35.9 kPa and varying magnitudes of outward wall rotation. The horizontal stress and movement within the backfill was measured. The results from the test facility were verified with a field project. Several conclusions can be made relative to the use of tire shreds as retaining wall backfill.

1. For at rest conditions with surcharges less than 12.0 kPa, the horizontal stress increases with depth. As the surcharge increases the horizontal stress becomes nearly constant with depth.
2. The coefficient of lateral earth pressure at rest, K_0 , decreases with depth at each surcharge. K_0 decreases as the surcharge increases until 23.9 kPa and remains constant from 23.9 to 35.9 kPa.
3. The at-rest horizontal stress measured for tire shreds is 45% less than that of typical granular fill.
4. The horizontal stress for the tire shreds decreases as outward rotation of the wall increases.
5. At a rotation of 0.01H and a surcharge of 35.9 kPa, the horizontal stress for tire shreds is 35% less than that expected for active conditions with conventional granular fill.
6. There is little difference in the horizontal pressure for tire shreds from three suppliers, suggesting that for maximum tire shred sizes ranging from 38 to 76 mm, K is not dependent on the tire shred size and amount of exposed steel belts.

5. ACKNOWLEDGMENTS

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