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Experimental and Numerical Evaluation of Recycled Tire Chips as Backfill Material for Retaining Walls

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1. Abstract

Recycled tire chips are a lightweight, free-draining backfill alternative for retaining walls. The reported evidence indicates that tire chips, used alone or blended with sand, can reduce lateral earth pressures and wall displacements substantially relative to conventional soil backfill, particularly under seismic loading.

Under static loading, reductions in lateral earth pressure and wall displacement are reported at approximately 50–60 percent. Under dynamic loading, reported reductions reach approximately 50–65 percent for wall displacement and 70–80 percent for dynamic earth pressure. These results are associated with physical model tests, numerical simulations, and full-scale shake table experiments conducted across more than two decades.

The main engineering advantage is the material's low compacted density, reported as 0.618–0.642 Mg/m³, combined with high permeability. These properties reduce the vertical weight and lateral stress imposed on a retaining wall while promoting drainage. The principal design concern is initial compressibility, which can produce settlement or deformation if the material is not properly contained, compacted, and integrated with the wall and foundation system.

Keywords- Recycled tire chips; Retaining walls; Lightweight backfill; Lateral earth pressure; Wall displacement; Seismic loading; Dynamic loading; Static loading; Compacted density; Permeability; Compressibility; Sustainable construction; Tire-derived aggregate; Geotechnical engineering; Earthquake-resistant design

2. Introduction

Retaining wall performance depends strongly on the properties of the backfill. Conventional soil can impose substantial lateral pressure, and the problem becomes more demanding when the wall is exposed to seismic excitation. A lightweight backfill can address both issues by reducing the mass behind the wall and limiting the stresses transferred to the wall structure.

Recycled tire chips provide this lightweight alternative by reusing a waste material in a geotechnical application. Their coarse particle structure, low density, high permeability, and frictional resistance make them suitable for consideration as retaining wall backfill, either as a standalone material or in combination with sand.

This report synthesizes the engineering information provided on recycled tire chips as retaining wall backfill. It focuses on the reported effects on earth pressure and wall displacement, key material properties, behavior under loading cycles, and the design implications of using tire-derived aggregate in retaining systems.

3. Evidence Base and Reported Performance

The available evidence spans several types of investigation rather than relying on a single experimental method. Physical model tests provide direct observations of wall response, numerical simulations extend the analysis to different configurations and loading conditions, and full-scale shake table experiments examine behavior under controlled dynamic excitation.

This combination is important because retaining wall response is affected by scale, boundary conditions, wall stiffness, backfill geometry, interface friction, and loading history. Agreement across physical, numerical, and full-scale approaches provides a stronger basis for identifying tire chips as a potentially effective lightweight backfill than reliance on one test type alone.

The reported static-loading reductions are substantial. Tire chips mixed with sand or used alone are associated with approximately 50–60 percent lower lateral earth pressures and wall displacements than conventional soil backfill. These values indicate that the benefit is not limited to reducing the wall's structural demand: the backfill system may also reduce the movement required to mobilize the resulting stresses.

Dynamic performance is reported to be even more favorable in terms of earth pressure. Reductions in wall displacement reach approximately 50–65 percent, while dynamic earth pressure reductions reach approximately 70–80 percent. The difference between displacement reduction and pressure reduction suggests that the material's response under seismic loading cannot be represented simply by applying a static density correction.

4. . Key Engineering Properties

The most consequential property of tire-chip backfill is its low compacted density. Reported compacted densities range from 0.618 to 0.642 Mg/m³, approximately one-third the density of conventional compacted soils. Reducing the mass of the backfill directly lowers the overburden contribution to lateral earth pressure and decreases the inertial force associated with seismic excitation.

Tire chips are also coarse-grained and free-draining. Reported permeability values range from 1.5 to 15 cm/s, indicating a highly permeable material. This drainage capacity is significant because water accumulation behind a retaining wall can add hydrostatic pressure to the soil pressure and can increase the risk of deformation or instability.

The reported friction angles range from 19° to 25°, while cohesion intercepts measured in large-scale direct shear apparatus range from 8 to 11 kPa. These parameters indicate that tire chips can develop shear resistance through both frictional interaction and an apparent cohesion intercept under the reported test conditions.

For design, these values should not be treated as universal constants. Tire-chip behavior may vary with particle size, tire composition, steel or glass belt exposure, degree of compaction, confinement, moisture condition, and the proportion of sand in a blend. Site-specific testing or conservative parameter selection is therefore important when the backfill response materially affects wall stability or deformation.

5. Lateral Earth Pressure and Wall Displacement

The reported reductions in earth pressure and displacement arise from the interaction of low density, particle deformability, and stress redistribution. Compared with conventional soil, a tire-chip backfill places less self-weight on the wall. The material can also deform internally, allowing part of the imposed movement to be absorbed within the backfill rather than transferred directly to the wall.

Illustrative Calculation Using Hypothetical Data

Assume a conventional soil backfill produces a lateral earth pressure of 100 kPa and a wall displacement of 20 mm under static loading. After replacing the conventional backfill with recycled tire chips, suppose the measured values are 45 kPa and 9 mm, respectively.

The percentage reduction is calculated as:

$$\text{Reduction (\%)} = \frac{Conventional\ value - Tirechip\ value}{Conventional\ value} \times 100$$

For lateral earth pressure:

$$Reduction = \frac{100-45}{100} \times 100 = 55\%$$

For wall displacement:

$$Reduction = \frac{20-9}{20} \times 100 = 55\%$$

Thus, the hypothetical results demonstrate a **55% reduction** in both lateral earth pressure and wall displacement, which falls within the reported 50–60% range.

Test condition	Backfill material	Lateral earth pressure (kPa)	Wall displacement (mm)	Reduction in pressure (%)	Reduction in displacement(%)
Static	Conventional soil	100	20	_	_
Static	Tire chips	50	10	50	50
Static	Tire chips	45	9	55	55
Static	Tire chips	40	8	60	60
Static	Tire chips	48	9.8	52	52

Example for a 60% Reduction

If the conventional backfill produces 100 kPa, a 60% reduction would give:

$P_{TC} = 100(1-0.60) = 40\ kPa$

Similarly, if conventional soil causes 20 mm displacement:

$\delta_{TC} = 20(1-0.60) = 8\ mm$

Therefore:

Under static loading, the 50–60 percent reduction reported for both lateral pressure and wall displacement indicates a combined structural and geotechnical benefit. Lower pressure can reduce demands on the wall stem, facing, reinforcement, and foundation system. Lower displacement can improve serviceability and reduce the likelihood of distress to structures, pavements, utilities, or other features located near the retained ground.

The use of sand in a mixture may alter the balance between compressibility, stiffness, drainage, and shear resistance. Tire chips alone maximize the lightweight character of the backfill, while a sand blend may provide a different contact structure and may help control deformation. The appropriate mixture therefore depends on whether the governing design objective is minimum lateral pressure, displacement control, constructability, or a combination of these requirements.

5. Behavior Under Dynamic Loading

Dynamic loading is a particularly relevant application for tire-chip backfill because the material combines low mass with the ability to deform under cyclic stress. The reported results show displacement reductions of approximately 50–65 percent and dynamic earth pressure reductions of approximately 70–80 percent compared with conventional soil backfill.

The lower dynamic earth pressure is consistent with the reduced mass of the tire-chip zone. During seismic excitation, a lighter backfill generates lower inertial demand than a denser soil mass, which can reduce the dynamic force transmitted to the wall. The coarse, resilient particle structure may also contribute to energy dissipation and stress redistribution during repeated loading.

Dynamic displacement remains an essential design consideration even when pressure is reduced. A backfill may impose lower force on the wall while still undergoing internal compression or rearrangement. The reported range of displacement reduction is therefore important because it suggests that tire chips can reduce both demand and movement, rather than trading one response for the other.

A small-scale laboratory experiment was conducted to compare the deformation behavior of conventional soil and recycled tire-chip backfill under repeated surcharge loading. A model retaining wall was constructed inside a transparent container, and a rigid loading plate was placed over the backfill. Known masses of dumbbell plates were used to apply controlled loads. The same wall geometry, backfill height, loading plate, and loading procedure were maintained for both materials.

Wall displacement and backfill settlement were measured after each loading stage. The applied load was calculated using

$P = mg$,

where m is the applied mass and $g = 9.81\ m/s^2$.

The percentage reduction in wall displacement was calculated using:

$$R = \frac{\delta s - \delta t}{\delta s} \times 100$$

where δs and δt represent soil and tire-chip wall displacement, respectively

Applied load (kg)	Applied load (N)	Soil displacement (mm)	Tire-chip displacement (mm)	Reduction (%)
5	49.5	2	1.2	40
10	98.1	3.5	1.9	45.7
15	147.15	5	2.6	48
20	196.20	6.5	3.2	50.8

The illustrative results indicate that tire-chip backfill could produce lower wall displacement than conventional soil under the same surcharge loading. The calculated reduction increases from approximately 40% to 51% as the applied load increases. This behavior can be attributed to the low density and deformability of tire chips, which allow part of the imposed deformation to be accommodated within the backfill.

These values are hypothetical and provided only to demonstrate the presentation and calculation method. Actual experimental measurements should replace them before the results are submitted for publication.

6. Compressibility and Loading History

Tire chips are highly compressible during initial loading, but their compressibility decreases substantially during subsequent unloading and reloading cycles. This loading-history effect is central to design because the largest deformation may occur during placement and the first major loading event rather than during later service cycles.

Initial compressibility can be beneficial when the design objective is to reduce pressure through controlled deformation, but uncontrolled compression can produce differential settlement or changes in backfill geometry. The consequences depend on the wall type, the presence of facing elements, the stiffness of any overlying pavement or structure, and the tolerance for post-construction movement.

Construction sequencing should therefore be treated as part of the geotechnical design. The backfill may need to be placed in controlled lifts, compacted using equipment appropriate for the material, and monitored for deformation. Where the retained surface supports a roadway, slab, building, or utility, the design should address the transition between compressible tire chips and adjacent conventional soil or structural fill.

The reduction in compressibility after unloading and reloading suggests that preloading or controlled conditioning could improve predictability in some applications. Such measures should not be assumed without supporting project-specific data, but the observed behavior indicates that the initial loading path has a lasting influence on subsequent performance.

6. Coefficient of Lateral Earth Pressure at Rest

Numerical Calculation of At-Rest Earth Pressure

The horizontal stress under at-rest conditions can be calculated as:

$\sigma h = K_0 \sigma_v$

Assume a tire-chip backfill has a vertical overburden stress of 50 kPa at a particular depth. For tire chips with exposed steel belts:

$\sigma_h = 0.26(50) = 13.0$ kPa

For glass-belted tires:

$\sigma_h = 0.47(50) = 23.5$ kPa

Thus, for the same vertical stress, the glass-belted tire material produces a higher horizontal stress.

Tire-chip type	K_0	Vertical stress, σv (kPa)	Horizontal stress, σh (kPa)
Exposed steel belts	0.26	50	13.0
Glass-belted tires	0.47	50	23.5
Difference	0.21	_	10.5

Thus, for the same vertical stress, the glass-belted tire material produces a higher horizontal stress.

The reported coefficient of lateral earth pressure at rest, K_0, ranges from 0.26 for chips with exposed steel belts to 0.47 for glass-belted tires only. This range demonstrates that tire construction and particle surface characteristics can influence the stress state developed behind a wall.

A lower K_0 value corresponds to a lower horizontal stress ratio under at-rest conditions, while a higher value indicates greater lateral stress relative to vertical stress. The reported range should therefore be incorporated into sensitivity checks rather than replaced by one unqualified value for all recycled tire materials.

The difference between exposed steel belts and glass-belted tires also highlights the need to characterize the actual recycled tire product. Surface roughness, belt exposure, particle interlocking, and contact behavior can affect shear resistance and lateral stress development. Material specifications should identify the relevant tire-chip characteristics instead of describing the backfill only as recycled tires.

For walls that can move sufficiently to mobilize active earth pressure, the relationship between K_0, wall movement, and interface friction requires separate evaluation. The at-rest coefficient is not automatically interchangeable with active or seismic earth pressure coefficients. Design calculations should use the coefficient that corresponds to the wall's deformation condition and the governing loading case.

8. Drainage and Construction Considerations

High permeability is one of the strongest practical advantages of tire-chip backfill. Reported permeability values of 1.5–15 cm/s indicate that water can pass rapidly through the material, reducing the potential for water pressure to accumulate behind the retaining wall.

High permeability does not eliminate the need for a complete drainage system. The wall should still include appropriate drainage outlets, filters, separators, and surface-water controls. Fine soil migration into the voids between tire chips could reduce drainage performance over time, so filter compatibility and separation from adjacent soils are important design considerations.

Placement quality is equally important. The material should be delivered, spread, and compacted in a manner that achieves a reasonably uniform zone without damaging drainage components or creating large voids at the wall interface. Because tire chips are compressible and irregularly shaped, construction verification should

focus on achieved thickness, elevation, density or placement condition, and observed deformation rather than relying only on conventional soil compaction criteria.

Blending with sand may change the drainage and compressibility characteristics of the system. A sand-rich mixture can reduce the void structure associated with tire chips, while a tire-chip-rich mixture preserves more of the lightweight and free-draining behavior. The selected blend should be evaluated as an engineered material with its own density, shear strength, permeability, and compressibility parameters.

9. Design Implications and Limitations

The reported evidence supports considering recycled tire chips where reduction of wall pressure, seismic demand, or backfill weight is a primary design objective. The material is particularly attractive when conventional soil would impose high lateral loads or when drainage behind the wall is difficult to maintain with a less permeable fill.

Designers should evaluate the retaining wall as an interacting system rather than treating tire chips as a simple substitute for soil. The assessment should include wall stability, foundation bearing and sliding, global stability, wall deformation, settlement of retained surfaces, seismic response, drainage, and compatibility with adjacent materials.

The principal limitation identified in the provided evidence is initial compressibility. A design that benefits from low lateral pressure must still control the resulting deformation. The selected backfill thickness, wall flexibility, construction sequence, surcharge condition, and connection between the tire-chip zone and surrounding ground should be checked against the project's serviceability requirements.

The reported performance ranges also contain material and test variability. Density, friction angle, cohesion intercept, permeability, and K_0 vary across the cited studies and tire types. These variations do not invalidate the material concept, but they do mean that performance should be represented through appropriate parameter ranges, sensitivity analyses, and project-specific verification where consequences are significant.

10. Recommended Evaluation Framework

A practical evaluation should begin by defining the governing performance objective. If the principal concern is static wall pressure, density and at-rest or active stress parameters may control. If seismic response governs, dynamic pressure, wall displacement, cyclic compression, and post-event settlement require greater attention.

- **Material characterization:** Confirm tire-chip size, belt type, steel exposure, density, friction angle, cohesion intercept, permeability, and compressibility.
- **System analysis:** Evaluate wall pressure, sliding, overturning, bearing, global stability, deformation, and interaction with the foundation and retained ground.
- **Drainage design:** Provide filters, separators, outlets, and surface-water controls that preserve the high-permeability pathway.
- **Construction control:** Specify placement procedures, lift thickness, compaction or conditioning requirements, survey checks, and deformation monitoring.
- **Performance verification:** Compare predicted behavior with field observations and use physical or numerical testing when the project lies outside the conditions represented by existing evidence.

This framework keeps the material's advantages and limitations in the same design process. Low density and high permeability can reduce wall demand, but initial compression and material variability must be managed explicitly.

11. Conclusions

Recycled tire chips have the properties needed to function as a lightweight retaining wall backfill: low compacted density, high permeability, measurable shear resistance, and the capacity to reduce lateral stress through mass reduction and internal deformation.

The reported studies associate tire chips, alone or mixed with sand, with static reductions of approximately 50–60 percent in lateral earth pressure and wall displacement. Under dynamic loading, reported displacement reductions reach approximately 50–65 percent and dynamic earth pressure reductions reach approximately 70–80 percent.

The material's engineering behavior is not uniform. Friction angles of 19°–25°, cohesion intercepts of 8–11 kPa, permeability of 1.5–15 cm/s, and K_0 values of 0.26–0.47 describe ranges rather than fixed design constants. Initial compressibility is the key behavior requiring control, while reduced compressibility during subsequent unloading and reloading cycles may improve performance after the first loading stage.

Recycled tire chips are therefore best treated as an engineered backfill whose performance depends on material type, placement, confinement, drainage, wall movement, and loading history. With these factors incorporated into design and construction verification, tire-chip backfill can provide a technically credible approach for reducing retaining wall pressure and seismic response while diverting used tires into beneficial geotechnical use.

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