



Evaluating the Impact of Sustainable Material and Geosynthetic Use on Microplastic Pollution: A Comparative Approach

Emre Akmaz¹ | Şilan Alpaydın¹ | Mohammad Saber Sadid¹

¹ Department of Civil Engineering, Sakarya University, Türkiye

Geocell Reinforcement • Tire-Wear Microplastics • Finite Element Analysis • Sustainable Pavement Design

Motivation & Problem Statement

~80%

of urban respirable PM
from road transport

~1/3

of river/ocean microplastics
from tire abrasion

3–7%

of ambient PM_{2.5}
from tire wear (TWP)

The Challenge

1. Tire-Wear Particles (TWP) are a major, continuous microplastic source — produced not only during vehicle operation but also from construction haulage
2. Road construction consumes large volumes of aggregate, generating heavy-truck trips that further emit TWP and CO₂
3. Conventional pavement design does not integrate environmental co-benefits of geosynthetic reinforcement

Research Objectives

01

FE Structural Comparison

Develop 3D Abaqus FE models for conventional vs. geocell-reinforced pavements under a moving single-wheel load

02

Structural Equivalence

Identify reinforced sections with reduced subbase thickness that match or exceed the reference section's performance

03

Logistics Quantification

Translate thickness savings into aggregate volume reduction, fewer truck trips, and measurable emission decreases

04

Dual-Benefit Framework

Provide an integrated, calculation-based framework linking structural efficiency to TWP and CO₂ reduction

Methodology

1

Pavement Models

- 4 sections:
- A20-SB30-SG45 (reference)
 - +Geocell: SB30, SB25, SB20

2

3D FE Analysis

Abaqus C3D8R elements
Moving wheel load (1900 kg)
Gravity + quasi-static steps

3

Structural Equivalence

3 metrics: deflection, tensile stress (asphalt base), shear stress (subbase)

4

Sustainability Module

$\Delta V \rightarrow$ truck trips $\rightarrow$ TWP & CO₂ emissions
(50 km haul, 13 m³/trip)

Layer

E (MPa)

ν

Finite Element Model – Setup & Sections

Wheel load
1900 kg

Cross-Section Schematic



BCs: fixed base | roller lateral faces | 400×200×95 cm domain | C3D8R elements

Key Material Properties

Layer	E (MPa)	ν
Asphalt	886	0.25
Sub-base	110	0.35
Subgrade	50	0.35

Study Matrix

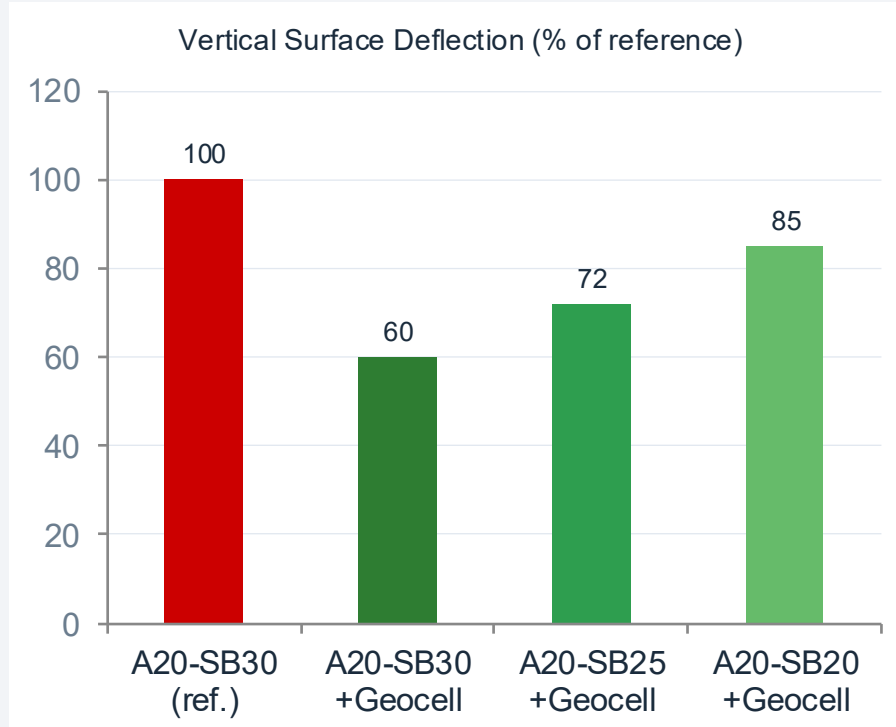
Model	Sub-base	Geocell
A20-SB30-SG45	30 cm	None (ref.)
A20-SB30-G10-SG45	30 cm	10 cm
A20-SB25-G10-SG45	25 cm	10 cm
A20-SB20-G10-SG45	20 cm	10 cm

Analysis Procedure

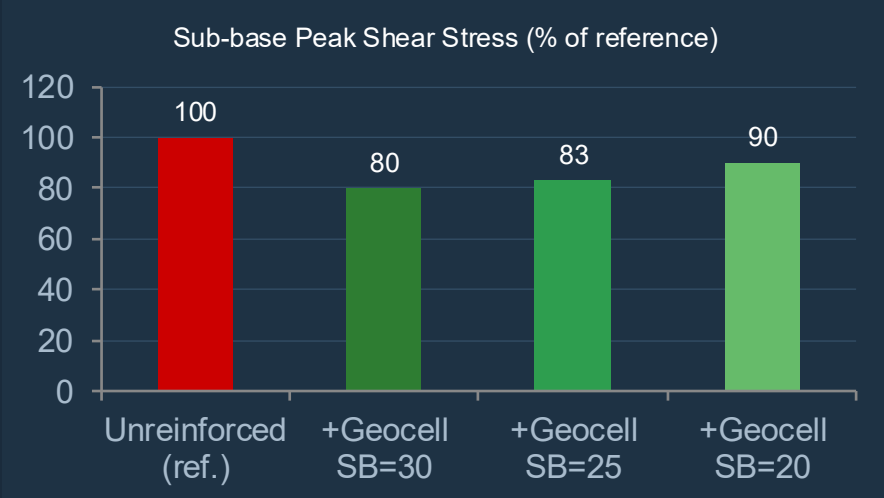
- ▶ Step 1 — Geostatic: establish in-situ stress state
- ▶ Step 2 — Moving load: quasi-static wheel traversal with rotational velocity assigned to tire
- ▶ Geocell modeled as a stiffer zone (confinement & interlock) within the granular sub-base

Results: Vertical Deflection & Tensile Stress

Key Finding: Geocell-reinforced section with 25 cm sub-base outperforms unreinforced 30 cm section on all three structural metrics



Results: Sub-base Shear Stress & Structural Equivalence



Structural Equivalence Summary

Model	vs Reference
SB30 + Geocell	Better on all 3 metrics
SB25 + Geocell	Better / equivalent
SB20 + Geocell	Slightly higher defl.



** SB=20 cm design meets equivalence criteria with marginal trade-off in deflection, within acceptable engineering limits*

Practical Implication

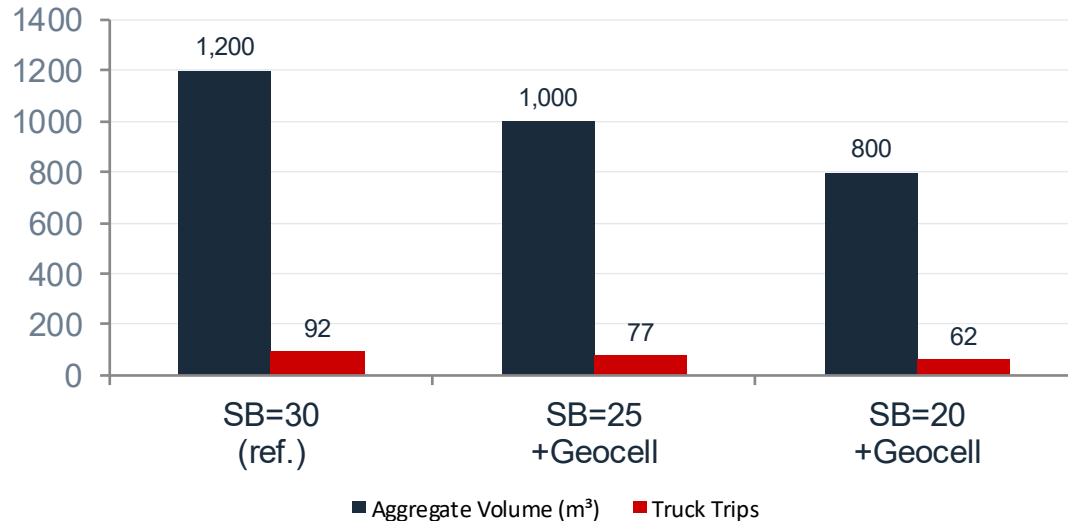
A 5–10 cm reduction in sub-base thickness is achievable with geocell reinforcement while maintaining or improving structural performance. This directly translates to reduced aggregate demand and fewer haulage operations.

Material Savings & Logistics (per km of road)

Assessment Assumptions

- Lane width: 4 m | Assessment length: 1 km
- Truck capacity: 13 m³ (4-axle dump truck, ~22 t)
- One-way haul distance: 50 km from quarry

Aggregate Volume vs. Truck Trips by Design Scenario



SB=25 + Geocell

-200 m³

-15 trips

16% fewer trips

SB=20 + Geocell

-400 m³

-30 trips

33% fewer trips

Environmental Impact: TWP Microplastics & CO₂ Emissions

$TWP = EF_{TWP} \times \text{haul distance} \times N \text{ trips}$ | $EF = 0.11 \text{ g/km/tire}$ | 10 tires/vehicle | $CO_2 \text{ factor: } 2.68 \text{ kg/L diesel}$ | $7.5 \text{ L/trip diesel}$

Design	Aggregate (m³)		Truck Trips		TWP (kg)		CO ₂ (kg)	
A20-SB30 (reference)	1,200		92		5.08		4,082	
A20-SB25 + Geocell	1,000	-17%	77	-16%	4.23	-17%	3,402	-17%
A20-SB20 + Geocell	800	-33%	62	-33%	3.38	-33%	2,722	-33%

Microplastic Reduction Pathway



Conclusions



Structural equivalence achieved

Geocell reinforcement with 25 cm sub-base matches or exceeds the unreinforced 30 cm reference on all three FE metrics (deflection, tensile stress, shear stress)



~40% deflection reduction

Geocell-reinforced section with full sub-base thickness shows nearly 40% lower vertical displacement vs. unreinforced reference



~33% fewer truck trips

SB=20 cm design requires 62 vs. 92 trips per km — a one-third reduction in haulage logistics



Measurable environmental gains

TWP reduced from 5.08 kg to 3.38 kg/km; CO₂ from 4,082 kg to 2,722 kg/km for the optimized design



Dual-benefit framework

First integrated FE + logistics calculation demonstrating geocells as both structural enhancers and environmental impact reducers



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