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Effect of Using Geocell in paved, unpaved roads on sustainability, technology for digitizing roads, and infrastructure

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26-28 January 2025
The Ritz-Carlton Jeddah, Kingdom of Saudi Arabia

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Effect of Using Geocell in paved, unpaved roads on sustainability, technology for digitizing roads, and infrastructure

Abstract

Road construction is evolving, yet traditional pavement technologies remain common, primarily flexible and rigid pavements. Flexible pavements are cost-effective but can suffer from rutting, while rigid pavements offer durability but face issues like cracking.

Innovations like geocell, which are expanded on-site and filled with soil, enhance load-bearing capacity by confining infill material. Studies show geocell layers can increase bearing capacity up to three times compared to unreinforced soil.

Building Information Modeling (BIM) has improved design and construction efficiency but lacks integration with pavement maintenance. We propose to integrate BIM with geocell by adding sensors to monitor pavement deformation, enabling real-time data transmission. This proactive approach aims to detect potential issues early, improving pavement durability and maintenance efficiency.

Overview and Requirements of Road Pavement Structures

A road pavement consists of multiple layers of processed materials placed over the natural soil sub-grade, designed to distribute vehicle loads effectively. It must provide a smooth riding surface, adequate skid resistance, favourable light reflection, and minimize noise pollution. The aim is to ensure that wheel loads do not exceed the sub-grade's bearing capacity.

Pavements are categorized into two types: flexible and rigid. This chapter reviews these types, detailing their layers, functions, and common failures. Poor pavement design can lead to premature failure, negatively impacting ride quality.

Pavement Requirements

An ideal pavement should meet the following criteria:

1. Adequate Soil Thickness: A sufficient layer of soil on the sub-grade is required to accommodate stresses from wheel loads.

2. Structural Integrity: The pavement must withstand all imposed stresses while maintaining strong structural integrity.

3. Friction: Adequate friction is necessary to prevent vehicle skidding.

4. Comfort: The surface should provide comfort to road users even at high speeds.

5. Noise Reduction: The pavement should minimize noise generated by vehicles.

6. Dust Control: To ensure traffic safety, the road surface should be dust-proof.

7. Protection of Sub-grade: An impervious surface is required to effectively protect the sub-grade soil.

8. Longevity and Maintenance: The pavement should be low-maintenance and have a long service life.

Types of Roads

Classification of Roads Based on Accessibility and Speed

1.Freeways or Controlled Access Highways

Freeways, also known as motorways or controlled-access highways, are designed specifically for high-speed vehicle traffic. These routes are free from obstructions such as signals, parking spaces, intersections, footpaths, and railways, allowing for uninterrupted traffic flow.

2 .Highways

Highways are crucial roads with a high traffic density, accommodating both heavy and fast-moving vehicles, including cars, buses, and trucks. They connect villages, cities, and states, and usually have multiple entry and exit points. Unlike freeways, highways include essential services like petrol stations, food plazas, and toll points.

3. Arterials

Arterial roads, often referred to as urban roads, are major roads within cities designed to handle significant traffic volumes. These roads are equipped with signals, footpaths, and pedestrian crossings (zebra crossings), catering to all types of land vehicles. Arterials facilitate efficient movement within urban areas, serving as key routes for daily traffic.

4. Local Streets

Local streets are smaller roads with lower traffic density, primarily accommodating slower-moving vehicles and pedestrians. They lack specific crossing points, allowing pedestrians to cross at any location. Streets are typically marked with white break lines to indicate lanes and boundaries.

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5. Collector Roads

Collector roads function to gather and distribute traffic between local streets and arterial roads. They provide access to and from arterial roads and usually have lower speed limits compared to arterials. Collector roads play a vital role in managing traffic flow within a road network.

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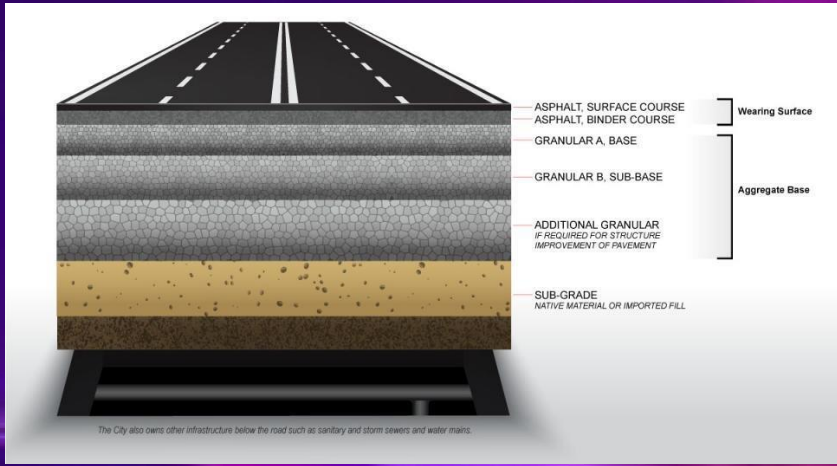
Types of Roads

Classification Of Road Based on Construction Materials Used:

1. Earthen Roads
2. Gravel Roads
3. Murram Roads
4. Kankar Roads
5. Water Bound Macadam (WBM) Roads
6. Bituminous Roads
7. Concrete Roads
8. Local Material (Infill Geocell)



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Types of Roads

I- Classification of Roads Based on Traffic Volume

1. **Light Traffic Roads**
2. **Medium Traffic Roads**
3. **Heavy Traffic Roads**

II- Classification of Road Based on Structural Performance

1. **Flexible pavement**
2. **Rigid pavements**
3. **Composite Pavements**

III- Different Types of Road Surface Materials

1. **Asphalt**
2. **Concrete**
3. **Bituminous Seals and Slurries**
4. **Geosynthetics**

Geosynthetics

Geotextiles are defined by ASTM (1994) as permeable textile fabrics used in civil engineering projects, structures, or devices that interact with rock, soil, earth, or other geotechnical materials. In contrast, geomembranes are inherently impermeable and are commonly used as cut-offs and liners in the construction industry, including in landfill applications.

Permeable geotextiles can penetrate soil, rock, and other geotechnical materials in various civil engineering projects. Geogrids are polymeric structures with a network of interconnected pieces, used in geotechnical, environmental, hydraulic, and transportation engineering applications. Geonets are polymeric sheet structures with apertures generally larger than the material itself. Recomposite materials, consisting of engineering polymers in the form of sheets or bars, are utilized in geotechnical, environmental, and transportation engineering.

1-Geomembrane

2 -Geotextiles

3- Geogrids

4- Geocell

5- Drainage board

Basic Construction Considerations and an Overview of Geocell Technology

Introduction to Geocells

Geocells are created by expanding a network of linked strips into an open-cell structure. Manufacturer-approved connection devices, which must be strong enough to prevent panel separation during installation and throughout the design life, can join individual geocell sections. The basic physical and material properties of geocells, such as cell diameter, density (cells per unit area), height, and surface characteristics (e.g., roughness or perforations), can vary. Since their introduction in the 1980s, geocells have been effectively used in various applications. Selecting the appropriate geocell requires evaluating the specific needs and conditions of the project.

Infill Material Options

Various materials can be used as infill for geocells, including sand, granular fillers, concrete, and recycled materials. Free-draining granular fill is commonly used for pavements and retaining walls, while graded fill is required for reinforced slopes. Topsoil can be utilized for planted fascias, and concrete is effective for channel protection.

Geocells are particularly beneficial with lower-quality infill, providing significant performance improvements. High-quality granular-layered geocells enhance surface support, reduce deflections, extend service life, and can lead to lower project costs and faster construction timelines.

LOCAL Material

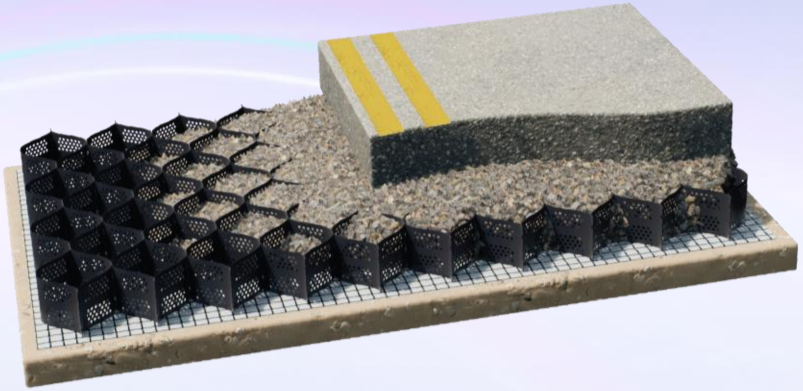
Recycling Building Waste

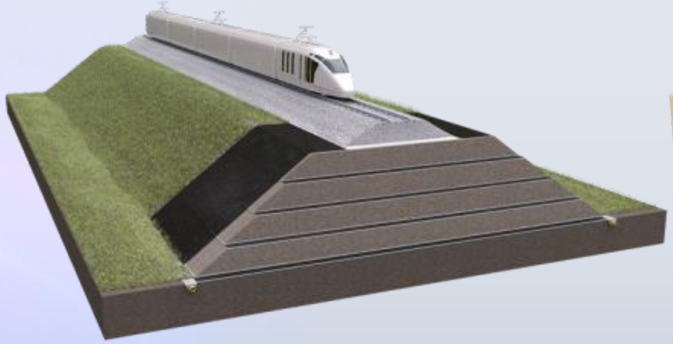
Crashed Stone

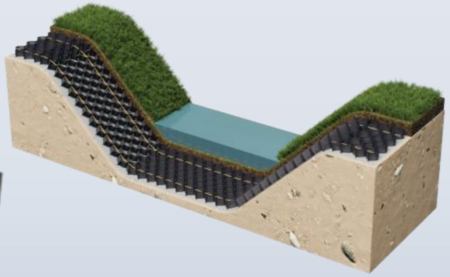
Applications and Benefits

Geocells have a wide range of applications, including erosion control, retaining walls, steep slopes, channel protection, and roadway load support. Typically, geocell walls are perforated to improve drainage, which enhances soil carrying capacity and laterally distributes vertical loads.

In pavement construction, geocells effectively distribute loads from upper layers, reducing embankment deformation and enhancing bearing capacity. Compared to unreinforced pavements, geocell-reinforced flexible pavements can extend pavement life by about 2 to 4 times. They maintain a level surface under heavy loads, evenly distribute vertical stresses, minimize lateral soil movement, and create a stiffened mattress effect.







The History of Geocell

1- Invention and Early Use

The US Army developed cellular confinement technology in the 1970s, commonly known as geocells. This technology was initially employed to construct quick, stabilized sand paths for military vehicles.

2- Early Materials and Development

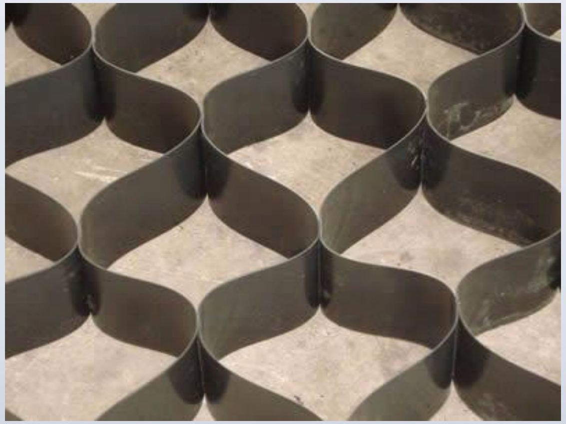
Early experiments with geocells utilized various materials, including plastic pipes, recycled substances, untreated polyethylene without UV protection, and aluminum. The U.S. Army Corps of Engineers sought the help of a plastics manufacturer to create a more robust grid confinement system that could maintain strength under heavy loads. They developed a method for attaching polyethylene strips, with high-density virgin polyethylene proving to be the most effective for weld quality and structural strength. Over time, geocells have been further refined for a range of soil stabilization applications.

Different Types of Geocell

Geocells are available in various types and specifications to address different issues in diverse soil conditions. They are primarily categorized into two types:

1. **Perforated Geocell**
   Perforated geocells feature uniform holes in the cell walls, which enhance stress distribution and reduce deformation. This design involves numerous edges forming cells. The overall strength of the geocell relies on the robustness of the perforated strip and its welds. The tensile strength and seam weld strength of the geocell are assessed using a tensile testing machine. The weld strength of the strip should be equal to or exceed the tensile strength of the strip itself.

2. **Non-Perforated Geocell**
   Non-perforated geocells have thick, smooth walls and typically consist of a polymer sheet with a three-dimensional mesh structure. These geocells are linked either by rivets or ultrasonic welding.



The Role of Geocells in Infrastructure Development

1- The Role of Geocells in Stabilizing Unpaved Roads

Typically, unpaved roads are built on unstable soils such as expansive clay, peat bogs, or sand. Without suitable technology, these materials can deteriorate, threatening road stability. Geocells provide the essential stiffness and creep resistance needed to stabilize soft soils. They prevent the shrinking and cracking of clay, aid in the lateral dispersion and filtration of sandy soils, and reinforce the subsoil across various types of soft soils.

2- Maintenance Benefits of Geocells

Using cellular restraint systems like geocells helps maintain roads in optimal condition. Roads may encounter maintenance issues due to unsuitable underground conditions, leading to damage, cracking, erosion, and settlement of unpaved surfaces. Geocells facilitate the construction of both permanent and temporary roads, improving ground stability and enhancing the load-bearing capacity of granular pavements and porous surfaces used by heavy machinery, while also reducing costs.

3- Water Management and Installation Advantages

Geocells assist in managing surface water and contribute to groundwater replenishment. Traffic or parking areas covered with vegetation or small plants offer a space-saving and environmentally friendly solution. Installation is simplified as no special equipment is required to expand the geocell sections. The cells can be placed on soft substrates without needing low-pressure equipment for filling, allowing fully loaded dump trucks to efficiently unload and spread granular material inside and on top of the geocells.

4- Versatility and Effectiveness in Infrastructure

Geocells have become crucial in modern infrastructure projects due to their versatility and effectiveness. Their applications range from road construction and erosion control to slope protection and load support. By providing three-dimensional confinement to infill materials, geocells enhance the mechanical and physical properties of the soil, thereby improving the performance and longevity of the structures built upon them.

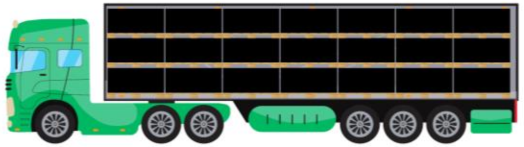
5- Promoting Sustainable Construction Techniques

Traditional road construction often involves significant extraction and transportation of natural resources, which can negatively impact the environment. In contrast, geocells help reduce the carbon footprint associated with construction. They promote vegetative growth and decrease soil erosion, leading to improved water quality and enhanced biodiversity. These environmental benefits make geocell technology a sustainable choice for road construction.

6- Alignment with Sustainable Development Principles

Sustainability has become a central focus in modern construction, and geocells play a key role in minimizing the environmental impact of infrastructure projects. They align with sustainable development principles by conserving natural resources, reducing soil erosion, and improving water quality. Geocells are particularly eco-friendly, designed to complement rather than disrupt natural processes. By minimizing waste, absorbing rainwater, reducing erosion, and stabilizing soil, geocells integrate seamlessly into the ecosystem.

Sustainable and Zero carbon footprint

Geocell 20cm With Local Materiel = 40cm Crushed Rock		
TRUCK / TRELLA	Storage Capacity Par / M^2	The NO. Of Trucks used of $18,060m^2$
 Truck With 42Plat Without Cover	Geocell 20CM = $18,060m^2$	1 TRUCK
 Container 40Fit With 28Plat	Geocell 20CM = $12,040m^2$	1.5 TRUCK
	Crushed rock $30m^3$ = $75m^2$	241 TRUCK
	Crushed rock $54m^3$ = $135m^2$	134 TRUCK

1 Truck Geocell = 134 Truck Crushed Rock

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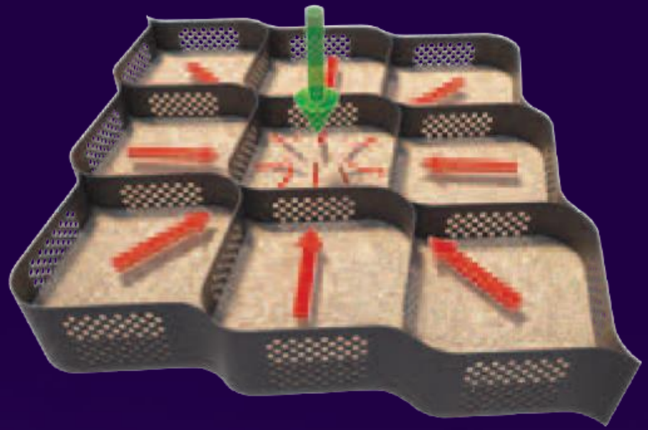
Advantage of using geocell



1-Improved Load Distribution and Erosion Control

2-Sustainability and Cost-Effectiveness

3-Durability and Structural Enhancement

4-Protection and Stabilization of Steep Slopes

5-Groundwater Recharge and Dust Control

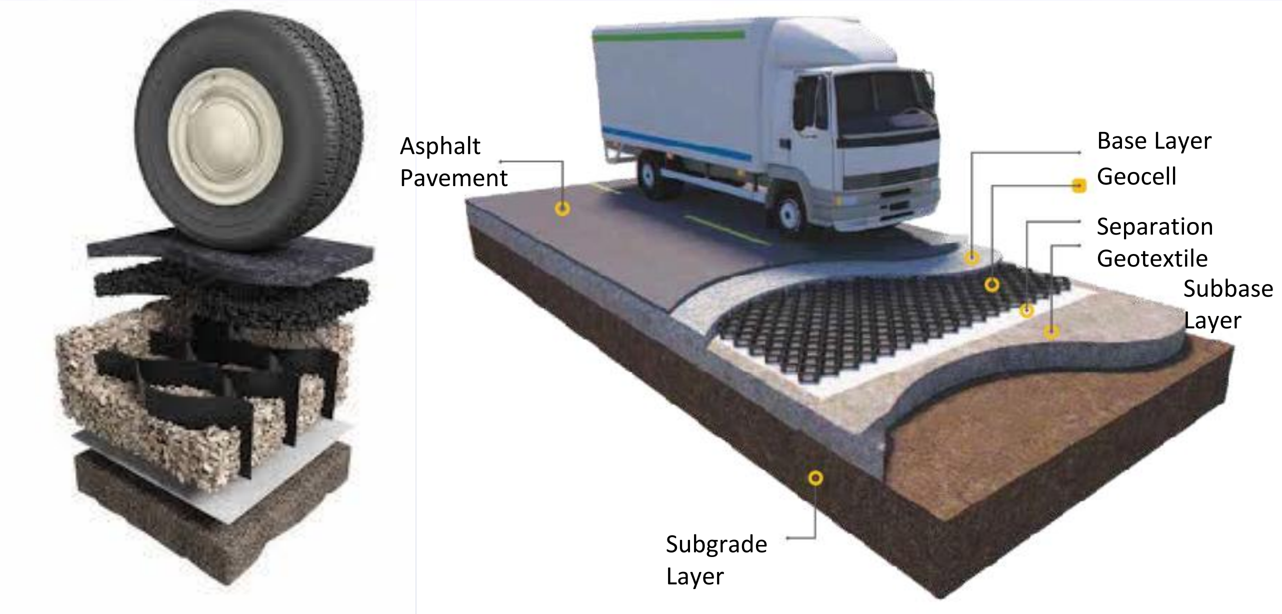
6-Reduced Excavation Needs and Environmental Impact

7-Longevity and Sustainability

8- Zero carbon footprint

Geocells in Roads Construction

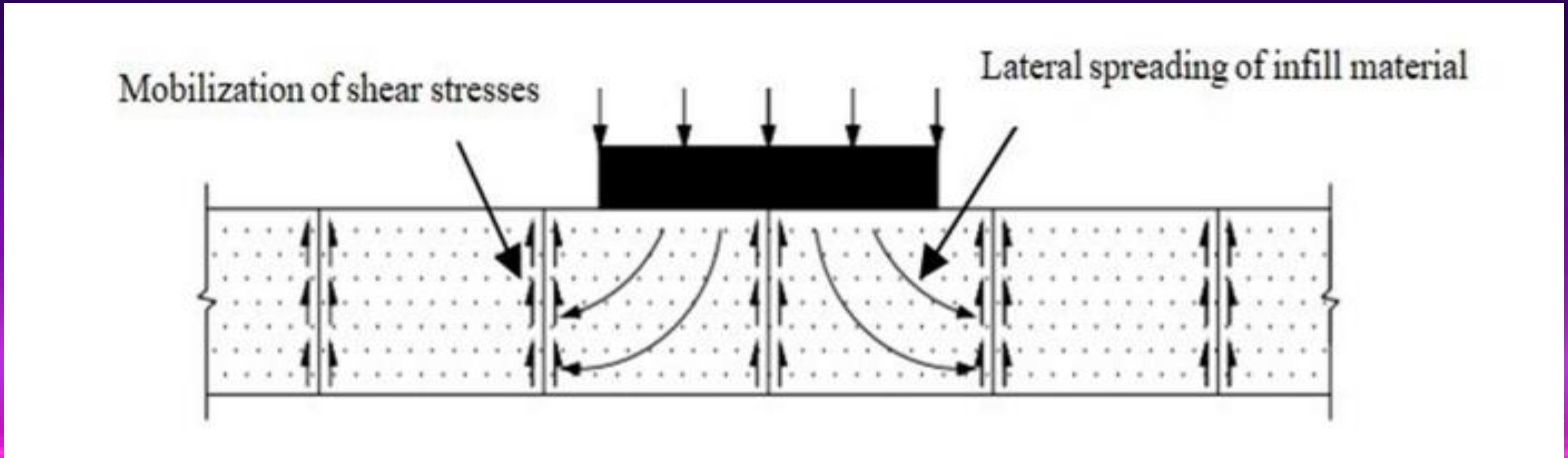
1- Revolutionizing Road Construction with Geocell Technology
2- Enhancing Pavement Durability
3- Preventing Permafrost Issues
4- Addressing Soil Challenges with Geocells
5- Geocell Road Construction
6- Geocell Installation Technique on Site
7- Reinforcement Mechanism of Geocell



Reinforcement mechanism of Geocell

1- Lateral Restraint or Confinement Effect

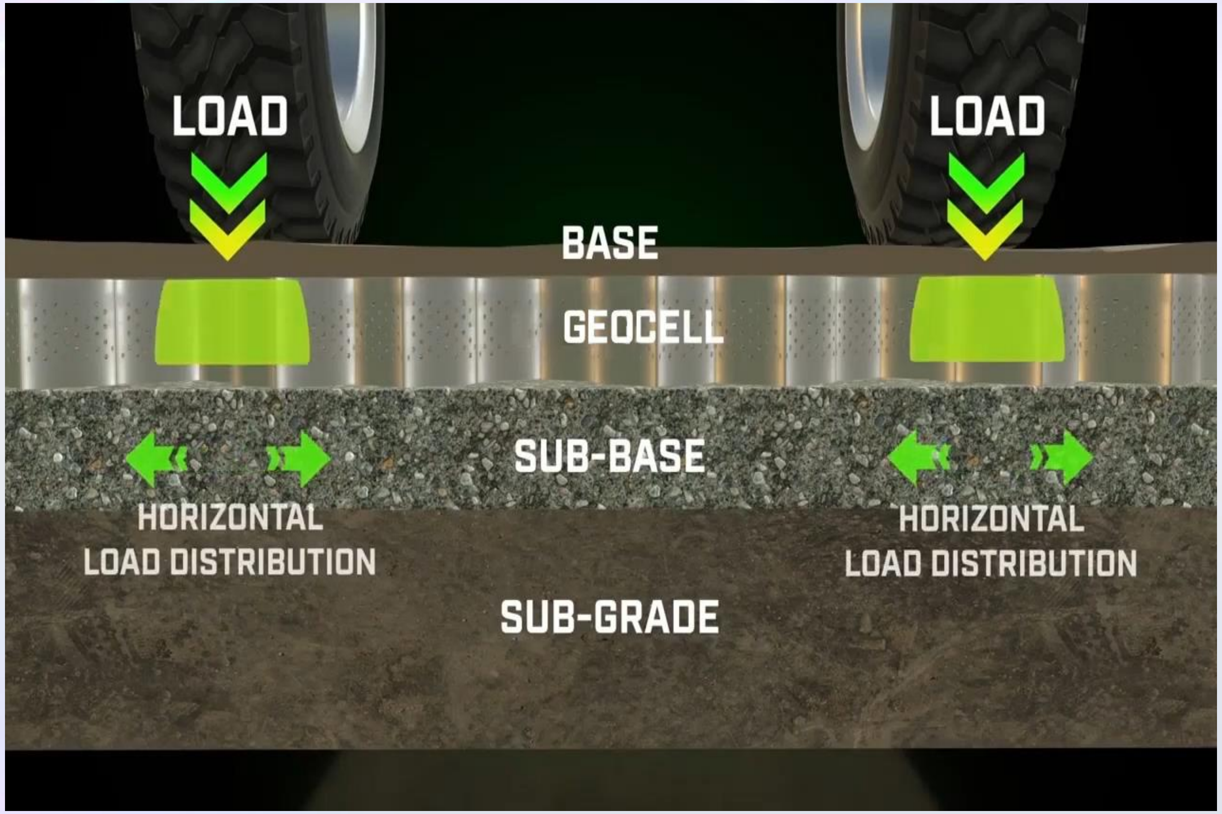
When foundation bases experience vertical loading, the material within these bases tends to spread outward. This can lead to concentrated loading on the soft subgrade soil, resulting in shear failure and ultimately bearing capacity failure. The installation of a geocell mitigates this issue by creating interlayer contact between the geocell walls and the infill material, preventing lateral spread of the infill. Consequently, shear stresses are mobilized within the foundation bases, with these stresses acting upwards to counteract vertical loading to some extent.



2- Load Distribution and Wider stress dispersion area Performance

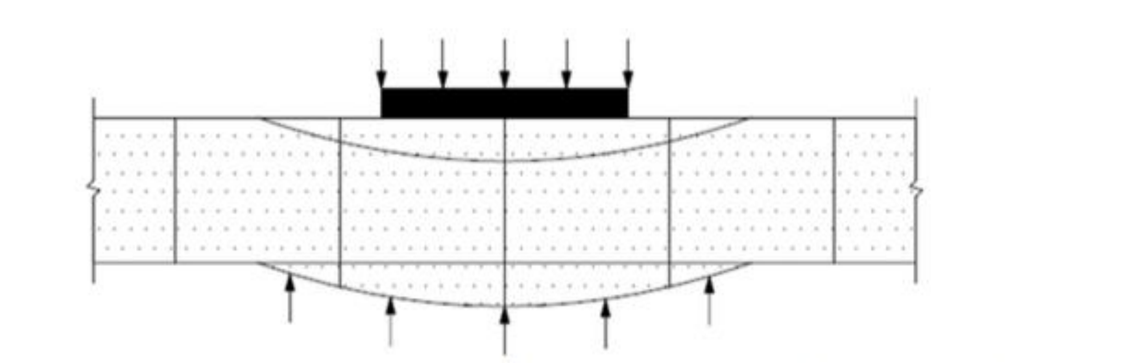
The mattress effect describes how the infill-geocell system distributes lateral earth forces through a network of interconnected cells. The geocell's discrete elements and the properties of the infill material—such as particle size and density—work together to enhance ground performance.

Factors affecting this system include geocell geometry, the number of adjacent cells responding to loads, and component stiffness. Higher cell density around a load leads to more uniform horizontal pressure distribution. Emersleben and Meyer noted that this effect allows a single cell's pressure to be shared with 24 surrounding cells, increasing the reinforced layer's stiffness and reducing vertical settlement. This collaboration minimizes both overall and differential settlement.

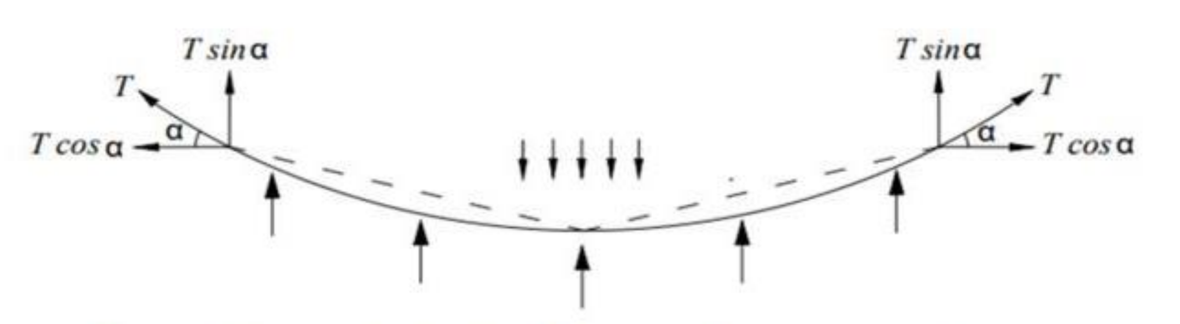


3-Tension membrane effect: Vertical Load Resistance and Tensioned Membrane Effect

The vertical load is supported by the stress generated in the curved geocell-reinforced cushion, known as the tensioned membrane or beam effect. For the structure to effectively exhibit the tensioned membrane effect, it must bend sufficiently, as illustrated in figure 14. The bending portion of the geocell-reinforced layer exerts forces upward, counteracting the forces acting on the subgrade. To achieve separation, basal reinforcement such as geogrid or geotextile is placed beneath the geocell. As depicted in figure 15, this basal reinforcement often demonstrates a tension membrane effect when substantial settlement occurs.



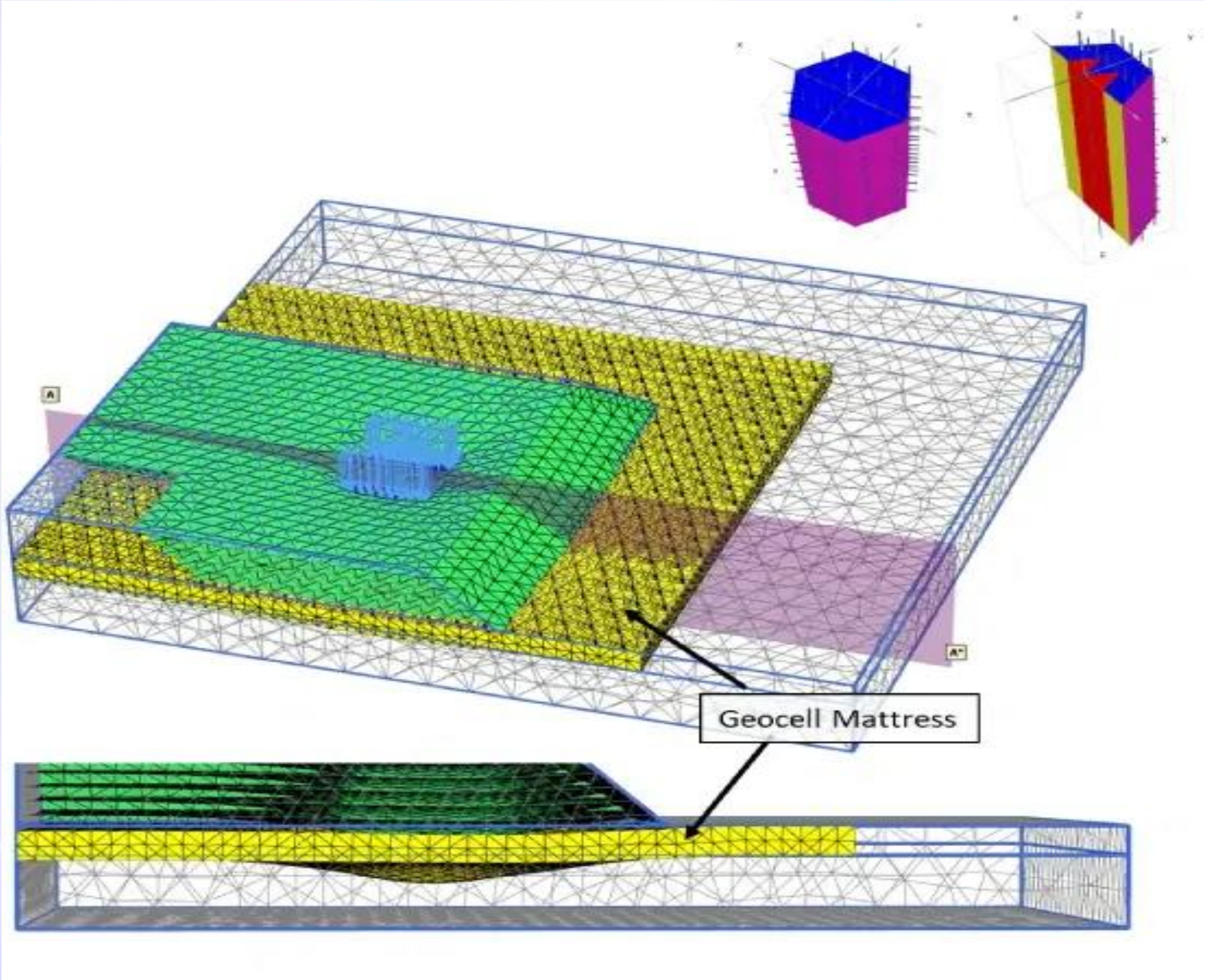
Upward stresses due to mobilization of tension membrane effect in geocell



Upward stresses due to mobilization of tension membrane in basal reinforcement (geogrid/geotextile).

5- Functionality and the Mattress Effect

The hoop material forming the cell walls, along with the enhanced lateral support from neighboring cells (known as the slab/mattress effect), provides lateral restraint or confinement for the infill material. The suitability of geocells in specific design cases and the level of confinement they provide depend on factors like cell geometry, the geocell layer's position within the geotechnical structure, and the material properties.



Geocell design programs

- My das 3D
- Midas GTS NX
- Plaxis 2D-3D
- GEO Studio
- ABAQUS
- FLAC
- MSE WALLS (Mechanically Stabilized Earth)
- Finite element analysis (FEA)

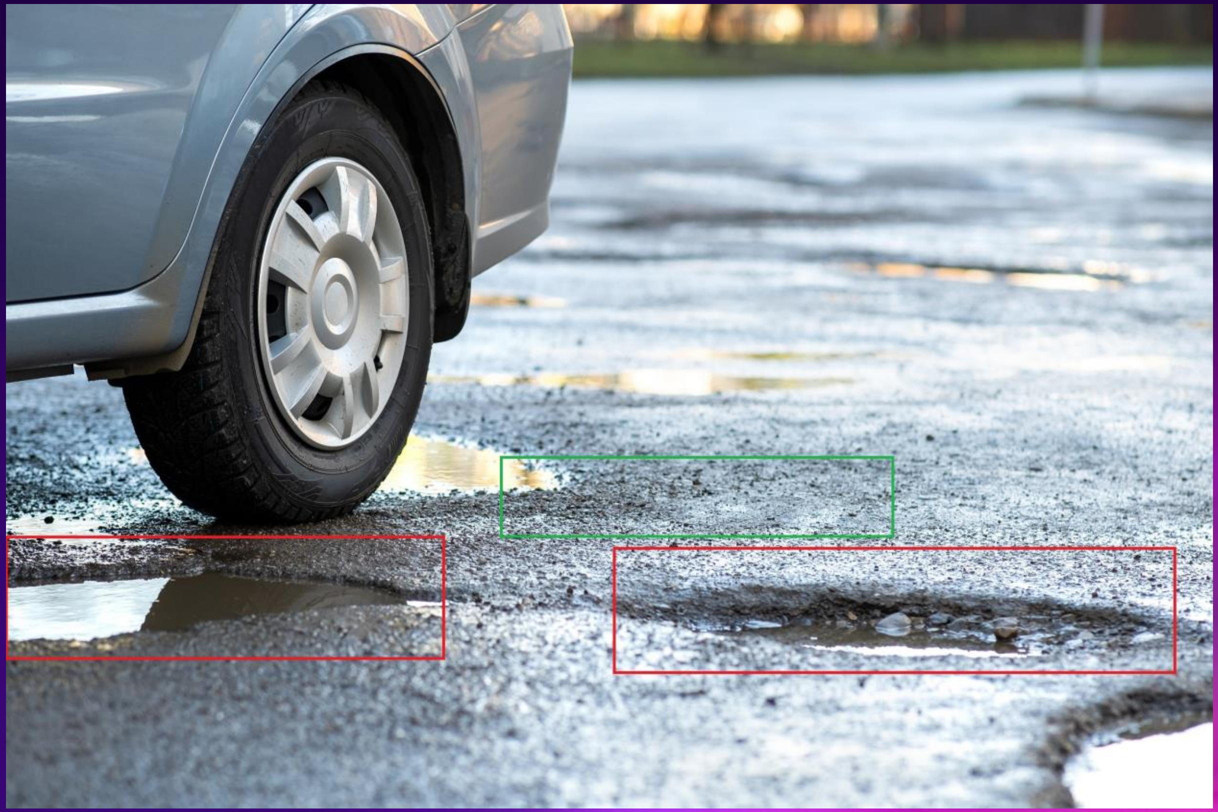
Geocell Reinforced Pavement Structures

Pavement structures often fail prematurely due to factors such as poor construction materials, inadequate compaction, insufficient subgrade preparation, and overloading. To enhance pavement longevity, two primary design options are considered: increasing the thickness of pavement layers or improving the rigidity of these layers to reduce stress on lower layers. It is widely observed that enhancing the strength and rigidity of pavement layers is more effective in lowering stresses and extending pavement life. This research investigates how geocell confinement improves the strength and stiffness of the sub-base layer in flexible pavements. Field plate load tests and laboratory tests were conducted to compare sections with and without geocell reinforcement. The study demonstrates that geocell confinement increases the modulus of the pavement section, contributing to greater durability.

Traditional Roads Maintenance:

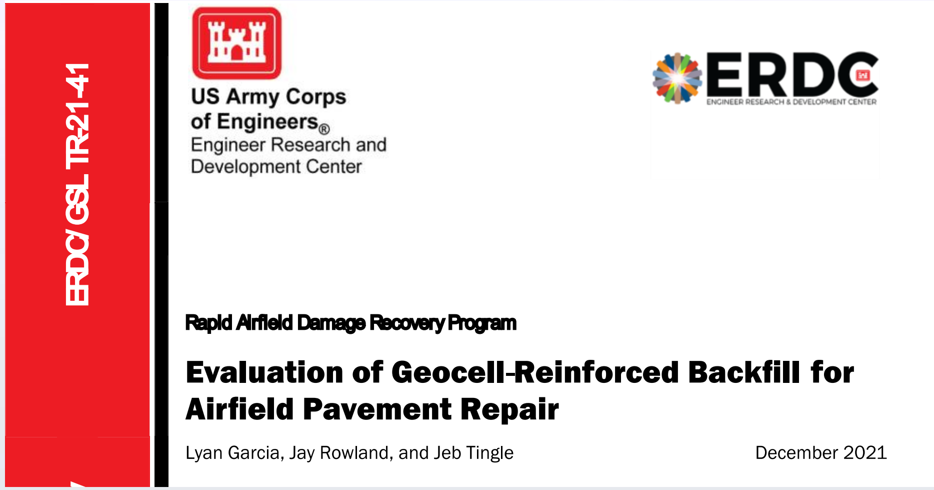
Maintaining a reliable transport network is crucial for any community, with the goal of minimizing traffic disruption both during initial construction and ongoing maintenance. Opting for a durable road surface material that can support traffic throughout its service life is ideal. Concrete pavements, known for their longevity and minimal maintenance needs, are the most durable but come with a high construction cost, approximately 3 to 4 times more than asphalt pavements. While asphalt surfaces require regular upkeep, including periodic resealing, they are easier and less costly to maintain. Asphalt can be recycled during resurfacing, and various additives and reinforcement products can extend its lifespan, reducing overall life-cycle costs.

In the United States, as reported by the Federal Highway Administration (FHWA), there are around 4,071,000 miles (6,552,000 km) of roads, with 2,678,000 miles (4,310,000 km) paved and 1,394,000 miles (2,243,000 km) unpaved. Maintaining these roads is labor-intensive and requires a range of maintenance techniques.



Roads Maintenance using Geocell according to US Army Corps of Engineers

The report discussed the experimental program and results of laboratory-scale and full-scale testing of geocells and geocell-reinforced backfill pavement repairs. The project objectives were to perform (1) a market survey of traditional and new geocell products commercially available, (2) laboratory testing to characterize the different geocell materials and geometries, and (3) field experiments to characterize how geocell material, geometry, and various backfill soil types affect repair performance under simulated aircraft loads.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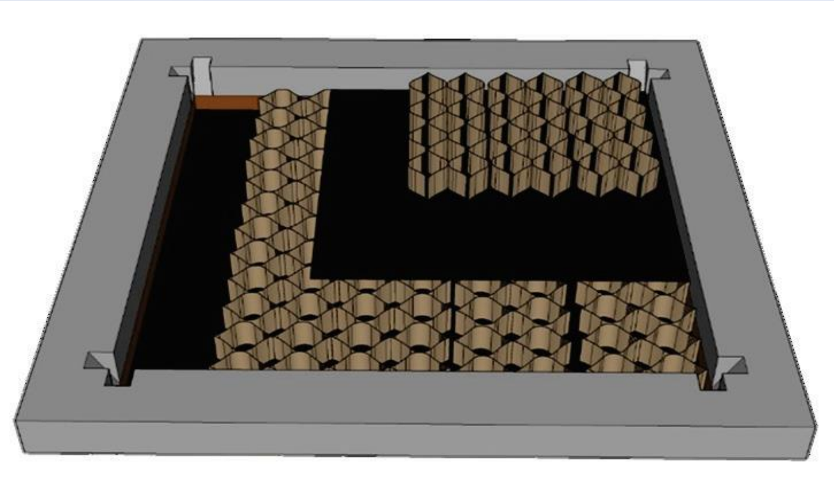
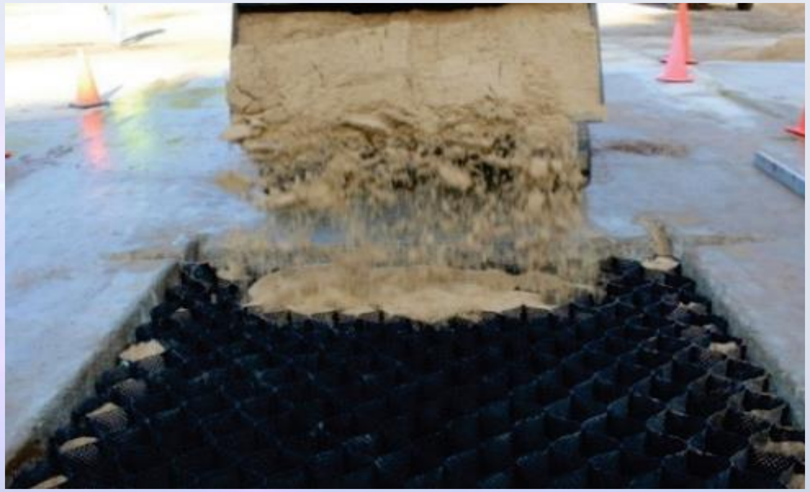
Rapid Airfield Damage Recovery Program

Evaluation of Geocell-Reinforced Backfill for Airfield Pavement Repair

Lyan Garcia, Jay Rowland, and Jeb Tingle

December 2021





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The impact of geocells on cost analysis

Cost Reduction in Asphalt and Concrete Roads Geosynthetic Materials By (Geocell)

1- Asphalt is the most widely used human-made material, with aggregates having a life expectancy of hundreds of years. However, the bitumen binder, comprising just 6% of asphalt, deteriorates quickly, causing roads to fail on average every 10 years. Traditionally, worn-out asphalt is discarded, leading to the waste of billions of tones of valuable material. Although asphalt surfaces offer a better cost-environment-functionality profile compared to other surfaces, the standard practice of replacement and disposal is both economically and environmentally inefficient. To address this, the Durability technology extends the lifespan of asphalt surfaces and allows for 100% recycling of old material, presenting a more sustainable and cost-effective solution.

2- Geosynthetics can reduce initial construction costs by allowing for thinner pavement layers, particularly on low-quality subgrades. While a life-cycle cost analysis can be beneficial, focusing on immediate savings from thickness reduction or extending the pavement's life can provide significant financial advantages. For mild subgrades, initial cost reductions are evident in thickness savings. If the basic cost approach does not show clear benefits, evaluating life-cycle costs is recommended. Additionally, the long-term financial savings from increased design life and other unquantifiable benefits should be considered.

3- Initial construction costs can be lower with geosynthetics. For example, a 2mm polypropylene woven geotextile in India costs around 30 INR per square meter. Using this material can lead to substantial savings in road construction. For a 1 km long, 10 m wide road with a 1 m excavation depth, employing geosynthetics can save both money and time during the initial build.

Harnessing Building Information Modeling (BIM) for Efficient Road Design and Construction

BIM-Based Approach for Road Pavement Maintenance

Recent advancements in road pavement survey technologies now allow for highly accurate and detailed data collection on functional and structural indicators, including surface distress, with minimal traffic disruption. However, processing and analyzing this vast amount of data efficiently for maintenance planning remains a challenge. The adoption of Pavement Management Systems (PMS) is limited due to their complexity. Simplifying the pavement maintenance process with smart tools is essential. Building Information Modeling (BIM), already successful in structural fields, has recently been applied to infrastructure design, improving clarity, reducing errors, and saving costs. Despite its advantages in design, BIM has not yet been widely utilized in pavement maintenance. This paper proposes a new BIM-based approach to manage pavement maintenance by creating user-friendly "smart objects" based on relational databases.

I-BIM (Based Approach for Infrastructures)

Infrastructure engineering is inherently complex, requiring a multidisciplinary approach due to diverse and simultaneous factors like economic, environmental, and social constraints. Traditional methods often lead to high uncertainty, resource consumption, and risk of errors. Recent efforts focus on developing tools and algorithms to improve decision-making and optimize technical solutions. Innovations like decision support algorithms and the BIM revolution have transformed civil engineering. BIM technologies, through advancements in hardware and software, offer a new perspective on design, construction planning, and maintenance, ensuring precision, efficiency, and reduced error risk. BIM operates in a shared software environment, enhancing real-time collaboration and information sharing, which improves accuracy and team effectiveness.

Harnessing Building Information Modeling (BIM) for Efficient Road Design and Construction

I-BIM Environment Ideas and Preliminary Tests for Road Maintenance

While I-BIM methods have advanced in design and execution phases, they have yet to achieve similar progress in road maintenance (Chong et al. 2016). Nonetheless, I-BIM tools offer significant potential for integrating with traditional methods used in road maintenance, from surveying to identifying optimal strategies. The authors propose a hybrid approach to enhance Pavement Management Systems (PMS) by incorporating BIM principles. This method would improve the architecture of PMS, making it more interoperable, dynamic, and efficient for handling and analyzing data. Specifically,

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Methodology and Comparison of Maintenance Activities in I-BIM

Preliminary applications show that BIM procedures can significantly simplify road maintenance management, contrasting sharply with the complexity and user-unfriendliness of traditional PMS systems. BIM's capabilities offer a streamlined approach, potentially revolutionizing maintenance management by enhancing rapidity and operational flexibility. These initial results suggest that BIM could effectively address the broader challenges of road maintenance, encouraging widespread adoption of these advanced methodologies and tools.

Conclusion

Traditional Road types, namely flexible and rigid pavements, each have their disadvantages, leading to the need for innovative solutions like geocells. Geocells significantly enhance road performance by improving load-bearing capacity, reducing section depth, and distributing loads more effectively. They also decrease subgrade pressure and control erosion, which is particularly valuable in areas with heavy rainfall. Beyond their structural benefits, geocells contribute to sustainability by lowering construction costs, reducing the need for non-renewable materials, and supporting groundwater recharge and dust control. Their durability, cost-effectiveness, and ability to extend road foundation lifespans make them ideal for reinforcing weak subgrades and for road repair; an application first used by the U.S. Army to fix airfields damaged by bombs. This paper also highlights the importance of Building Information Modeling (BIM) technology in road construction and envisions future advancements where BIM can predict and address potential failures before they occur.

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