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A comprehensive analysis of geotextile reinforcement in pavement design

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Abstract

For pavement structure, geotextiles have been heavily suggested. However, there aren't enough fully-scaled, instrumented studies to look into how geotextile reinforcement affects pavement design. In this investigation, eight lanes of pavement test sections underwent full-scale expedited tests. Based on significant advancements in the studies regarding dry compaction on a sand base, design parameters, structure combination of subgrade and pavement, stabilization analysis of sand base strengthened with geotextile, and an entire set of construction techniques, several key technical issues in the construction of the Desert Highway have been satisfactorily solved. In this study, a thorough life cycle cost analysis framework was created and utilized to calculate the current and future costs of 25 sample low-volume road design choices. The subgrade must be firm, stable, well-drained, and devoid of volume variations brought on by changes in moisture. If not, the pavement will eventually fail. Normally, there are ways to measure the benefits of utilizing geotextiles in pavements. However, from an economic standpoint, a pavement's entire life cycle shows that it fails for causes including structural, functional, or material failure, or a combination of these. However, it is noted that the pavement breakdown in the research region falls into the category of structural failure.

***Keywords**:* Cost analysis; geotextile; life-cycle; pavement material.

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1. Introduction

The use of geosynthetics by the transportation industry, including organizations for roads, airports, railroads, and waterways, has garnered a lot of interest over the past three decades. Particularly geosynthetic uses in flexible pavements have grown significantly over time [1]. However, the idea of using produced material to improve pavement performance is not new. In the 1920s, for instance, the state of South Carolina used a cotton textile to stabilize the supporting elements of a road with subgrade soil that had a constrained bearing capacity [2]. Due to their vulnerability to deterioration and inability to effectively provide a barrier between the base and the pavement, synthetic polymers have taken the place of cotton fibers, which can tolerate harsh conditions better [3].

performance of a pavement over a soft subgrade. the aggregate layer and the natural subgrade. After recognizing the importance of geosynthetic materials in pavements [4] , the question of whether the technique is cost-effective must be addressed. The benefit-cost ratio of using geosynthetics in pavements must therefore be determined by a rigorous life-cycle cost analysis (LCCA). The initial costs of construction, upkeep, and user fees should all be taken into account in this analysis. LCCA is a useful economic tool for thinking through certain transport investment decisions.

In the 1986 version of the American Association of State Highway and Transportation Officials (AASHTO) Guide for the Design of Pavement Structures [5], the use of LCCA was encouraged and a method for evaluating the cost-effectiveness of various pavement designs was offered.

The approach for evaluating the benefits of using geotextiles with flexible pavement is provided in this essay. Two models created by Al-Qadi and colleagues [6,7], Perkins [8], and Perkins and Edens [9,10] were used to incorporate geosynthetics into pavement designs. The method considers a modified version of the Schonfeld and Chien [11] user cost model in addition to the original building costs.

1.1. Conceptual background

This course covers physical properties, functions, design methods, design details, and construction procedures for geo-textiles as used in pavement design and drainage applications. Geo-textile functions described include pavements, filtration, and drainage. This course does not cover the use of other geo-synthetics such as geo-grids, geo-nets, geo-membranes, plastic strip drains, composite products, and products made from natural cellulose fibers.

An industrial textile class known as a geotextile is made up of polypropylene or polyester resin and threads that have been needle punched, woven, knitted, thermally or chemically bonded, or thermally or chemically bonded to form a flat permeable sheet. Other examples of industrial textiles are pool covers, trampolines, carpet backing, and car trunk liners. Over the last fifteen years, these particular geosynthetic materials have grown in popularity. Due in large part to its resilience to biodegradation, it has more than 80 applications. Although not in the conventional sense of the word, geotextiles are textiles nonetheless. They are not organic materials like silk, wool, or cotton. Synthetic fibers known as geotextiles can be used to create flexible, porous, nonwoven needle-felt fabrics.

The Pharaohs were the first to cover roads with textiles. Even they battled with rutted or washed-away soils that were unstable. When blended with soil, especially unstable soils, natural fibers, textiles, or vegetation were proven to improve the quality of roads. Separation, drainage, filtration, and reinforcing are the four primary uses of geotextiles in pavements. The present worth (PW), technique (of benefits, costs, benefits, and costs-NPV), and comparable uniform annual cost are among the various economic indicators frequently employed in the LCCA procedure. (EUAC), internal rate of return (IRR), and the benefit-cost ratio (BCR).

LCCA can be perceived as an analysis technique used to evaluate the overall long-term economic efficiency of different alternative investment options. This is a decision support tool that helps to choose a cost-effective alternative from several competitive alternatives (table I).

TABLE I

ADVANTAGES AND DISADVANTAGES OF ECONOMIC ANALYSIS METHODS

Analysis Method	**Advantages**	**Disadvantages**
Present worth	Simple and easy to understand	Benefits and costs might not be distinguished enough
Net present Value	The benefits and costs for a project are related and expressed by a single value.	When there is only a single alternative the benefits cannot be calculated and NPV cannot be applied in this case.
The equivalent uniform annual cost	Simple and easy to understand	If vehicle operating costs are among the alternatives, then this assumption becomes questionable.
Benefit-Cost ratio	High public appeal due to the emphasis on benefits	The benefit-cost ratio is abstract and can be difficult to comprehend

1.2. Literature review

The roadway considered in this study is a secondary road system. It is hypothesized that geotextiles work as a cost-effective separator between the granular base layer and the natural subgrade of the pavement. It is reported that geotextiles improve pavement performance by preventing the intermixture of subgrade fines and base layers. If, in the absence of a geotextile at the subgrade/base course interface, aggregate contamination by the subgrade fines occurs, the overall strength of the pavement system will be weakened. As for cost considerations, vehicles keep a uniform speed through the work zone. The vehicle arrival and discharge rate from the queue remains constant. The user delay costs must be represented by a constant average per vehicle hour. In addition, the traffic volume for both directions is available; the maintenance or rehabilitation cost is a linear function of the work zone length. The time required to maintain or rehabilitate a work zone is also a linear function of the work zone length. The combined traffic volume from both lanes should be smaller than the capacity of one lane

Dhule et al. [12] presented an "Improvement of flexible pavement with use of geo-grid" which says that Geogrid +murrum –increase CBR value and factors affecting the compaction characteristics are shear strength and low permeability. Geotextiles have high shear strength [13,14]. CBR value depends upon the degree of compaction.

Choudhary et al., [15] presented "Improvement in CBR values of expansive soil sub-grades using geo-synthetics" which says that the expansion ratio decreases when several reinforcing layers are increased. CBR value increases by increasing the number of reinforcing layers. Reinforcing efficiency: Geo-grid is better than jute geotextile. Rajagopal et al., [16] presented a "Studies on Geosynthetic reinforced road pavement structures" which says that by using geosynthetic material there is improvement in strength and stiffness and shows better performance under repeated loads (fatigue condition). Under monotonic loading, the modulus improvement factor is higher.

Gor et al. [17] presented a "Study of typical characteristics of the expansive subgrade with geotextiles and cushion materials" which concludes that by Addition of metakaolin, the swelling pressure of black cotton soil reduces but the further increment in the amount of meta kaolin results in an increase in swell pressure. An increase in unconfined compressive strength has been noticed. Stabilized metakaolin expansive soil CBR value is higher compared to expansive soil without metakaolin.

Lyons et al., [18] conducted a plate load test to study "the variation of load carrying capacity for both reinforced and unreinforced pavements". It was observed that the bearing capacity improved by providing coir geotextiles as reinforcement. She reported an increase in bearing capacity by 1.83 times for reinforced pavement compared to unreinforced pavement. Since the usefulness of geosynthetic materials in pavements has been recognized [19,5], the next question to answer is whether or not this material is cost-effective. Therefore, a comprehensive Life Cycle Cost Analysis (LCCA) is needed to quantify the cost-effectiveness of geotextile applications in the pavement. Such analysis should include initial construction, rehabilitation, and user costs.

1.3. Purpose of study

This study's major goal is to determine whether utilizing geotextiles, the most popular geosynthetic in pavements, at the subgrade-granular material interface is cost-effective. The usage of geotextiles will be researched to improve the pavement system to meet this goal. This study will include an efficient user cost model, a maintenance and rehabilitation timetable, and a synthetically stabilized pavement performance prediction model. Finally, a sensitivity analysis will be performed to determine how various cost parameters may affect this study.

2. Materials and method

In this study, a thorough life cycle cost analysis framework was created and utilized to calculate the current and future costs of 25 sample low-volume road design choices. The subgrade needs to be stable, firm, well-drained, and free of moisture-induced volume oscillations. The pavement will finally fail if this isn't the case. Generally, it is possible to quantify the advantages of using geotextiles in pavements. However, a pavement's whole life cycle demonstrates that, from an economic perspective, it fails for a variety of reasons, such as structural, functional, or material failure, or a combination of these. To evaluate the advantages of employing geotextile in secondary road flexible pavement, however, it is urgently necessary to conduct a thorough life cycle cost analysis (LCCA), which takes into account both expenses to agencies and costs to users.

3. Results

3.1. Definition of terms

Sub Grade: The term "subgrade" typically refers to the natural or prepared ground below a construction project such as a road, building, or other infrastructure. It is the layer of soil or rock that provides a stable foundation for the construction above it. The subgrade is typically compacted and graded to ensure a uniform and stable surface that can support the weight and load of the structure. In civil engineering, the subgrade is an important component of any construction project as it provides the basis for the stability and durability of the structure [20].

Sub-base course: A sub-base course is a layer of material placed on top of the subgrade and below the base course of a road or other construction project. The sub-base course serves as a transition layer between the subgrade and the base course, providing additional support and stability to the road or structure above. The purpose of the sub-base course is to provide a uniform and stable surface for the base course to rest upon and to distribute the load of the structure evenly across the subgrade.

The materials used for the sub-base course can vary depending on the specific project and the soil conditions of the subgrade. Typically, materials such as crushed stone, gravel, or recycled concrete are used. The sub-base course is typically compacted to ensure a uniform surface that can support the weight and load of the structure above it. Proper compaction of the sub-base course is critical to ensure the overall stability and durability of the road or structure.

Base course: A base course is a layer of material that is placed on top of the subgrade and the sub-base course in a road or other construction project. The purpose of the base course is to provide a stable and durable foundation for the surface course or pavement that will be placed on top of it. The materials used for the base course can vary depending on the specific project and the traffic requirements of the road. Generally, materials such as crushed stone, gravel, or asphalt concrete are used for the base course. The base course is typically thicker than the subbase course and is designed to withstand heavier loads and traffic.

The base course is constructed by placing and compacting the material in layers, typically between 4 and 10 inches thick until the desired thickness and compaction level are achieved. Proper compaction is critical to ensure the stability and durability of the base course. Once the base course is in place, the surface course or pavement can be placed on top of it (figure 1). The quality of the base course is crucial for the long-term performance of the road or structure, as it provides the foundation for the surface that will be exposed to traffic and other stresses [21].

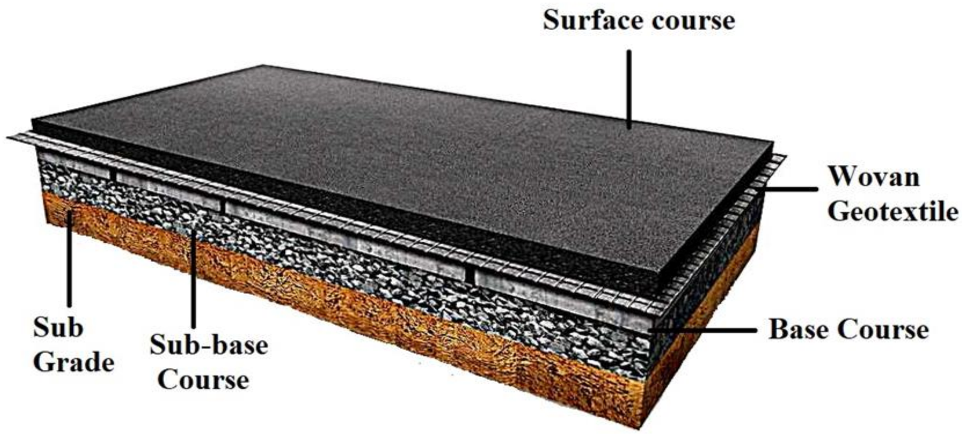

Fig 1. Section of the road that uses woven geotextile

Woven geotextile: A woven geotextile is a type of geosynthetic material that is made by weaving polypropylene, polyester, or other synthetic fibers together into a stable, durable fabric. The fabric has a unique structure that allows water to pass through while retaining soil particles and other materials. Woven geotextiles are commonly used in civil engineering and construction projects as a separation, reinforcement, or filtration layer.

In separation applications, woven geotextiles are used to separate two layers of soil or other materials that have different properties or that may mix if not separated. For example, a woven geotextile may be placed between a layer of soft soil and a layer of aggregate to prevent the soil from mixing with the aggregate and compromising the structural integrity of the construction.

In reinforcement applications, woven geotextiles are used to reinforce the ground and improve its stability. This is achieved by placing the geotextile in a layer of soil and then compacting the soil on top of it. The geotextile helps distribute the load of the construction more evenly across the soil, reducing the potential for settlement and improving the overall stability of the structure.

In filtration applications, woven geotextiles are used to allow water to pass through while retaining soil particles and other materials. This is often used in drainage systems to prevent clogging and ensure the proper flow of water. Overall, woven geotextiles are versatile and useful materials that can improve the performance and durability of construction projects.

Surface Course: The surface course, also known as the wearing course, is the top layer of a road or pavement that is designed to provide a smooth, safe, and durable surface for vehicular or pedestrian traffic. The surface course is visible. A layer of the pavement is the layer that is exposed to the wear and tear of daily use. The materials used for the surface course depend on the specific requirements of the road or pavement, including the expected traffic volume, the climate, and the type of vehicles that will use the road. Materials commonly used for the surface course include asphalt concrete, concrete, or composite materials.

Asphalt concrete is a popular choice for surface courses due to its durability, flexibility, and ease of construction [22]. It is made by mixing asphalt binder with sand, gravel, or crushed stone aggregates. Concrete, on the other hand, is a more rigid material that allows water run-off and is commonly used in high-traffic areas such as airports, industrial parks, and interstates [23].

In addition to providing a smooth and durable surface, the surface course is also designed to provide skid resistance and water drainage. Skid resistance is important to prevent accidents and improve safety, while water drainage is essential to prevent ponding or water buildup that can lead to hydroplaning or other hazards. Overall, the surface course is an essential component of any road or pavement, and its proper design and construction are critical to ensure the safety, durability, and long-term performance of the infrastructure.

3.2. CBR Test

The California Bearing Ratio or CBR test is performed in construction materials laboratories to evaluate the strength of soil subgrades and base course materials. The test results are seen in Table I, whereas the experiment is displayed in Table III. They are graphically displayed in Figures 2 and 3 as well. Those who design and engineer highways, airport runways and taxiways, parking lots, and other pavements rely on CBR test values when selecting pavement and base thicknesses.

TABLE II

TEST RESULTS

Particulars	Sample A	Sample B
Liquid Limit (%)	36.12	43.70
Plastic Limit (%)	19.50	29.30
Plasticity Index (%)	13.10	14.20
Moisture Content (%)	18.30	19.40
Optimum Moisture Content (O.M.C) (%)	14.60	12.20
Max. Dry Density(g\cm^3)	1.28	1.36
Specific Gravity	2.73	2.61
CBR (%) 2.5 mm	3.5	3.9
CBR (%) 5 mm	5.8	6.6

TABLE III

CBR EXPERIMENT

Sample	Without Non-Woven		CBR (%)	With Non-Woven		CBR (%)
	2.5mm	5mm		2.5mm	5mm	
A	3.5	3.9	3.8	14.1	14.9	15.0
B	5.8	6.6	6.9	20.2	17.2	21.0

$$\text{C.B.R.} = (PT/PS) \times 100$$

Where PT = Corrected test load corresponding to the chosen penetration from the load penetration curve. PS = Standard load for the same penetration

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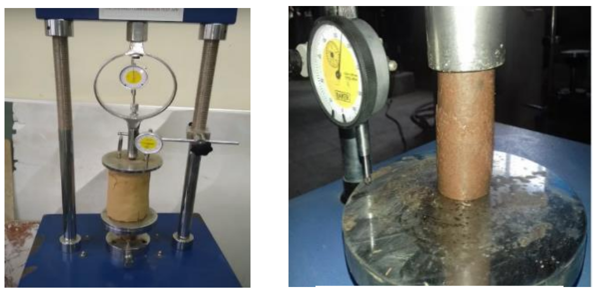
Fig 2. Soil sample



Sample 01 **Sample 02**

Fig 3. Experiment

4. Conclusion

In conclusion, the proper construction of a road requires a systematic approach and adherence to specific guidelines. The subgrade layer needs to be excavated to a depth of 150-290mm to ensure stability and a firm foundation. The sub-base layer is then laid with a thickness of 100-300mm, providing additional support to the road. The installation of a layer of woven geotextile acts as a barrier between the subbase and base course, preventing the mixing of materials and maintaining the stability of the road. The base course is then laid with a depth of 90-300mm, distributing the load evenly across the subgrade and providing additional stability to the road.

Finally, the surface course is laid with a thickness of 25-50mm, providing a smooth and durable driving surface. This layer is responsible for withstanding the stresses of regular use and environmental factors, while also providing skid resistance to ensure safety. It is important to keep in mind that the density of every stratum could fluctuate contingent on project prerequisites and regional stipulations. However, following these guidelines can ensure the construction of a long-lasting and safe road. Employing appropriate construction methods not only renders a seamless motoring encounter but also secures monetary savings over time since they minimize the necessity for recurrent upkeep and renovations

When a road is constructed, it necessitates meticulous and thoughtful planning while staying committed to the strict principles outlined in the guidelines. These precautions are of the utmost importance as they guarantee that a durable outcome will be achieved without any jeopardy or risks involved. The implementation of geosynthetic materials, such as those with a textile-like structure, has been empirically shown to be an efficacious technique for the assembly of roadways. This method affords an extra stratum of constancy whilst obviating any adulteration between various elements involved in construction.

References

[1] L. Luo, G. Yang, Z. Liu, Y. Tang, J. Chu, W. Wen, A. Chen, & J. Guo, "Field Experiment on Vegetation-Wicking Geotextile Reinforced Base for Permeable Sidewalk," *Frontiers in Built Environment*, vol. 10, p. 1333937, 2024. https://www.frontiersin.org/articles/10.3389/fbuil.2024.1333937/full

[2] W. K. Beckham, & W. H. Mills, (1935). Cotton-fabric reinforced roads. *Engineering News Record*, vol. 114, no. 14, pp. 453-455.

[3] B. Hong, G. Lu, T. Li, J. Lin, D. Wang, D. Liang, & M. Oeser, "Gene-editable materials for future transportation infrastructure: A review for polyurethane-based pavement," *Journal of Infrastructure Preservation and Resilience*, vol. 2, pp. 1-14, 2021. https://link.springer.com/article/10.1186/s43065-021-00039-w

[4] W. S. Tsai, & R. D. Holtz, "Rut prediction for roadways with geosynthetic separators," In *Proceedings of Sixth International Conference on Geosynthetics* Industrial Fabrics Association International, North American Geosynthetics Society Publ., Atlanta, GA, USA, 1998, pp. 939-944.

[5] Transportation Officials. *AASHTO Guide for Design of Pavement Structures,* Vol. 1, Aashto, 1993.

[6] I. L. Al-Qadi, T. L. Brandon, R. J. Valentine, and T. E. Smith. "Laboratory Evaluation of Geosynthetic Reinforced Pavement Sections, In Transportation Research Record," *Journal of the Transportation Research Board*, No. 1439, pp. 25-31, 1994.

[7] A. Loulizi, I. L. Al-Qadi, S. A. Bhutta, & G. W. Flintsch, "Evaluation of geosynthetics used as separators," *Transportation Research Record*, vol. 1687, no. 1, pp. 104-111, 1999. https://journals.sagepub.com/doi/abs/10.3141/1687-12

[8] S. W. Perkins, "Mechanistic-Empirical Modeling and Design Model Development for Geosynthetic Reinforced Flexible Pavements (No. FHWA/MT-01-002/99160-1A)," Dept. of Transportation. Research Section. Montana, 2001. https://rosap.ntl.bts.gov/view/dot/44037

[9] S. W. Perkins, & M. Q. Edens, "Finite element and distress models for geosynthetic-reinforced pavements," *International Journal of Pavement Engineering*, vol. 3, no. 4, pp. 239-250, 2002. https://www.tandfonline.com/doi/abs/10.1080/1029843021000083504

[10] S. W. Perkins, & M. Q. Edens, "A design model for geosynthetic-reinforced pavements," *International Journal of Pavement Engineering*, vol. 4, no. 1, pp. 37-50, 2003. https://www.tandfonline.com/doi/abs/10.1080/1029843031000097562

[11] P. Schonfeld, & S. Chien, "Optimal work zone lengths for two-lane highways," *Journal of Transportation Engineering*, vol, 125, no. 1, pp. 21-29, 1999. https://ascelibrary.org/doi/abs/10.1061/(ASCE)0733-947X(1999)125:1(21)

[12] S. B. Dhule, S. S. Valunjkar, S. D. Sarkate, & S. S. Korrane, "Improvement of flexible pavement with use of geogrid," *Electronic Journal of Geotechnical Engineering*, vol. 16, pp. 269-279, 2011. https://www.researchgate.net/profile/Shriniwas-Valunjkar/publication/267990573_Improvement_of_Flexible_Pavement_With_Use_of_Geogrid/links/55538f1f08ae980ca608582c/Improvement-of-Flexible-Pavement-With-Use-of-Geogrid.pdf

[13] M. Mohamadi Merse, I. Hosseinpour, M. Payan, R. Jamshidi Chenari, & S. R. Mohapatra, "Shear Strength Behavior of Soft Clay Reinforced with Ordinary and Geotextile-Encased Granular Columns," *International Journal of Geosynthetics and Ground Engineering*, vol. 9, no. 6, p. 79, 2023. https://link.springer.com/article/10.1007/s40891-023-00492-5

[14] K. Salehi, H. Mohammad Eisa, & K. Badv, "Reinforcement effect of geotextiles on shear strength of peat soil: a case study on Urmia peat," *Bulletin of Engineering Geology and the Environment*, vol. 80, pp. 6799-6812, 2021. https://link.springer.com/article/10.1007/s10064-021-02372-6

[15] A. K. Choudhary, K. S. Gill, & J. N. Jha, "Improvement in CBR values of expansive soil subgrades using Geosynthetics," Guru Nanak Dev Engineering College Ludhiana (Punjab), vol. 141006, p. 155, 2011. https://www.academia.edu/download/36790647/SDP_proceeding.pdf#page=161

[16]K. Rajagopal, S. Chandramouli, A. Parayil, & K. Iniyan, "Studies on geosynthetic-reinforced road pavement structures," *International Journal of Geotechnical Engineering*, vol. 8, no. 3, pp. 287-298, 2014. https://www.tandfonline.com/doi/abs/10.1179/1939787914Y.0000000042

[17]V. S. Gor, L. S. Thakur, & K. R. Biyani, *Study of Typical Characteristics of Expansive Subgrade with Geotextiles and Cushion Materials*. (2013). https://scholarsmine.mst.edu/icchge/7icchge/session_06/37/

[18]C. K. Lyons, & J. Fannin, "A comparison of two design methods for unpaved roads reinforced with geogrids," *Canadian Geotechnical Journal*, vol. 43, no. 12, pp. 1389-1394, 2006. https://cdnsciencepub.com/doi/abs/10.1139/t06-075

[19]J. H. Holtz, J. S. Holtz, C. H. Munro, & S. A. Asher, "Intelligent polymerized crystalline colloidal arrays: novel chemical sensor materials," *Analytical Chemistry*, vol. 70, no. 4, pp. 780-791, 1998. https://pubs.acs.org/doi/abs/10.1021/ac970853i

[20]T. G. Sitharam, R. Jakka, & S. Kolathayar, (Eds.). *Latest Developments in Geotechnical Earthquake Engineering and Soil Dynamics*. Springer Singapore, Imprint: Springer, 2021. https://link.springer.com/book/10.1007/978-981-16-1468-2

[21]D. Nie, S. Wang, P. Sun, & C. Huang, "Study on anti-crack effect of semi-rigid base pavement with stress absorbing layer," *Journal of Engineering and Applied Science*, vol. 70, no. 1, pp. 1-15, 2023. https://jeas.springeropen.com/articles/10.1186/s44147-023-00217-5

[22]L. Choudhary, S. Bansal, M. Kalra, & L. Dagar, "Mechanical evaluation of recycled aggregate mixes and its application in reclaimed asphalt pavement (RAP) stretch," *Beni-Suef University Journal of Basic and Applied Sciences*, vol. 11, no. 1, p. 127, 2022. https://link.springer.com/article/10.1186/s43088-022-00302-3

[23]J. Zhang, H. Sun, X. Shui, & W. Chen, "Experimental Investigation on the Properties of Sustainable Pervious Concrete with Different Aggregate Gradation," *International Journal of Concrete Structures and Materials*, vol. 17, no. 1, p. 64, 2023. https://link.springer.com/article/10.1186/s40069-023-00625-0