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Mechanical and Cement Stabilization of Reclaimed Asphalt Pavement-Gravely soil Blends for Sustainable Road Subbase Applications in Kenya

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Abstract - The increasing depletion of natural gravel resources and the growing accumulation of reclaimed asphalt pavement (RAP) materials have intensified the need for sustainable alternatives for road construction. This study evaluated the engineering performance of gravely soil mechanically stabilized with RAP and chemically stabilized with Ordinary Portland Cement (OPC) for use as road subbase material. Gravely soil and RAP obtained from Kiambu County, Kenya, were blended at RAP contents of 20, 40, 60, and 80% by dry weight, followed by stabilization with 2–5% OPC. Laboratory testing included particle size distribution, Atterberg limits, moisture content, specific gravity, Modified Proctor compaction, swell, soaked California Bearing Ratio (CBR), Unconfined Compressive Strength (UCS), and direct shear tests in accordance with relevant British Standards and the Kenya Road Design Manual. RAP incorporation improved grading characteristics, increased maximum dry density, reduced optimum moisture content, and significantly lowered plasticity and swell while enhancing bearing capacity. Cement stabilization further improved the engineering performance through the formation of cementitious bonds, resulting in higher strength and greater dimensional stability. The optimum mixture, comprising 60% RAP, 40% gravely soil, and 4% OPC, achieved a Plasticity Index of 13.4%, swell of 0.4%, soaked CBR of 120%, and UCS of 3.1 MPa, satisfying the requirements for cement-stabilized subbase materials. The findings demonstrate that RAP-Gravely–cement stabilization is an effective and sustainable approach for upgrading marginal gravely soils into durable pavement materials, reducing dependence on natural aggregates, minimizing construction waste, and supporting sustainable road infrastructure development.

Key words*:* Reclaimed Asphalt Pavement (RAP), gravely soil, subbase, cement stabilization, road subbase, Sustainable pavement materials

1.0 INTRODUCTION

Road transportation infrastructure is fundamental to economic growth, regional integration, and social development. The long-term performance of road pavements largely depends on the engineering quality of the base and subbase layers, which distribute traffic loads and provide structural support to the pavement system. Traditionally, these layers have been constructed using high-quality natural gravel and crushed stone because of their favorable strength and drainage characteristics. However, rapid urbanization, increasing road construction activities, and depletion of natural aggregate resources have significantly increased construction costs and intensified the environmental impacts associated with quarrying. Consequently, sustainable alternatives capable of reducing dependence on virgin materials while maintaining satisfactory engineering performance have become a major research priority in pavement engineering [1].

In Kenya, the demand for road construction materials has increased considerably due to the expansion of the national road network and the implementation of infrastructure development programs. While high-quality gravel remains the preferred material for pavement layers, its availability is becoming increasingly limited in many regions. Consequently, attention has shifted towards the utilization of marginal materials and recycled construction waste as sustainable alternatives to conventional aggregates. [2] recognizes the need for exploring alternative materials capable of meeting the required engineering standards while minimizing environmental degradation and construction costs.

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Among the various recycled construction materials, Reclaimed Asphalt Pavement (RAP) has received considerable attention. This is because it contains high-quality mineral aggregates coated with aged asphalt binder recovered during pavement rehabilitation and reconstruction. The reuse of RAP reduces landfill disposal, conserves natural aggregate resources, lowers construction costs, and supports circular economy principles. Recent reviews indicate that although RAP has been extensively incorporated into asphalt mixtures, its application in pavement foundation layers remains comparatively underutilized despite the greater potential of base and subbase layers to consume large quantities of recycled materials [3]. Expanding RAP utilization in these layers therefore represents an effective strategy for improving resource efficiency and reducing the environmental footprint of road construction [4].

Previous studies have demonstrated that RAP can significantly improve the engineering properties of marginal soils through mechanical stabilization [5]. The angular aggregate particles in RAP enhance particle interlocking, improve compaction characteristics, reduce plasticity, and increase bearing capacity when blended with fine-grained soils. These improvements are generally attributed to the replacement of moisture-sensitive clay particles by relatively non-plastic, asphalt-coated aggregates that exhibit lower water absorption and greater frictional resistance [6]. Nevertheless, high RAP contents may reduce cohesion and stiffness because the aged asphalt coating limits interparticle bonding, indicating that mechanical stabilization alone may not always provide sufficient structural performance for heavily loaded pavement applications [7].

To overcome these limitations, chemical stabilization using cementitious binders has increasingly been investigated [8]. Ordinary Portland Cement (OPC) remains the most widely used stabilizing agent because hydration reactions generate calcium silicate hydrate (C–S–H) and calcium aluminate hydrate (C–A–H) gels that bind soil and aggregate particles into a dense and durable matrix. Cement stabilization has consistently been shown to reduce plasticity and swell while substantially increasing compressive strength, stiffness, and bearing capacity of pavement materials [9]. Recent reviews further demonstrate that combining recycled aggregates with cementitious binders provides an effective means of improving the durability and long-term performance of pavement foundation layers while reducing the consumption of natural resources [10].

Recent research has also expanded beyond conventional cement stabilization to investigate geopolymer binders, alkali-activated materials, industrial by-products, and other sustainable stabilizers for RAP-based pavement layers [11]. These alternative binders have demonstrated promising improvements in compressive strength, resilient modulus, and durability while lowering carbon emissions associated with Portland cement production. Despite these advances, most studies remain focused on recycled asphalt mixtures or stabilized base materials using conventional crushed aggregates, whereas relatively limited attention has been directed toward the stabilization of naturally occurring marginal gravely soils that are widely used in low- and medium-volume roads, particularly in developing countries.

In Kenya, gravely soils constitute one of the most abundant naturally available construction materials and are widely used in road infrastructure because of their accessibility and relatively low cost. However, many of these soils exhibit high plasticity, excessive moisture susceptibility, low bearing capacity, and inadequate durability, making them unsuitable for direct use as pavement subbase materials without stabilization. Although the Kenya Road Design Manual recognizes the need to utilize alternative construction materials, limited published research has systematically evaluated the combined effects of RAP and cement stabilization on the engineering behavior of locally available gravely soils under conditions representative of Kenyan road construction practice.

Despite extensive research on RAP utilization in pavement engineering, most published studies have focused on its incorporation into asphalt mixtures or its stabilization with conventional granular materials, with relatively limited attention given to the combined mechanical and cement stabilization of gravely soils commonly encountered in tropical regions. Furthermore, existing studies have largely focused on RAP-gravely soil mixtures to satisfy the engineering requirements of stabilized subbase layers. This study advances existing knowledge by integrating RAP and Ordinary Portland Cement (OPC) to improve locally available gravely soils for road subbase applications and by identifying an optimum mixture that satisfies the engineering requirements of the Kenya Road Design Manual. By linking material characterization, compaction behavior, plasticity, swell, bearing capacity, compressive strength, and shear performance within a unified experimental framework, the study provides a comprehensive basis for the sustainable reuse of reclaimed pavement materials in low-cost road construction and supports the transition towards circular and resource-efficient pavement infrastructure.

Therefore, this study aimed to evaluate the combined effects of mechanical stabilization using RAP and chemical stabilization using OPC on the engineering performance of locally available gravely soils for road subbase applications. This enabled determination of an optimum mixture satisfying the Kenya Road Design Manual requirements.

International Journal of Engineering Research & Technology (IJERT)
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2.0 MATERIALS AND METHODS

2.1 Research design

This study adopted an experimental laboratory-based research design to evaluate the engineering performance of gravely soils stabilized using RAP and OPC for road subbase construction. The investigation involved characterization of the individual materials, preparation of RAP-gravely soil blends at varying proportions, stabilization of selected blends with cement, and assessment of their engineering properties against the requirements of the Kenya Road Design Manual Part III (2025) and relevant British Standards.

The study was conducted in three phases. The first phase involved characterization of the natural gravely soil and RAP materials. The second phase involved mechanical stabilization through blending gravely soil with RAP at different proportions. The third phase involved chemical stabilization of the selected RAP-gravely soil blends using cement and subsequent evaluation of the engineering properties of the stabilized materials.

2.2 Materials

2.2.1 Gravelly soils

The gravely soils used in this study was obtained from borrow pits located in Kiambu County, Kenya located at coordinates 1°10'S, 36°50'E. The material was selected because it is widely available in the region and represents the marginal soils commonly encountered in road construction projects. Bulk samples were collected, transported to the laboratory, air dried, and prepared for testing in accordance with [12] as shown in Figure 1(a).

2.2.2 Reclaimed Asphalt Pavement (RAP)

Reclaimed Asphalt Pavement (RAP) material was obtained from milled asphalt pavement that have served for over 25 years. The RAP was generated at depths of 150 mm during milling for road rehabilitation works within Kiambu County (Figure 1(b)). The RAP was crushed to sizes in the range of 10-20 mm before screening to achieve a controlled particle size distribution consistent with subbase requirements.

(a) Collection of gravely soil

(b) sampling RAP material

Figure 1: Sourcing of materials from Kiambu County

2.2.3. Ordinary Portland Cement

Ordinary Portland Cement (OPC) grade 42.5N conforming to relevant Kenyan and British Standards was used as the chemical stabilizer. The chemical composition, as obtained from the manufacturer technical data sheet is as shown in Table 1. The cement was selected because of its widespread use in pavement stabilization and its proven effectiveness in improving strength and durability characteristics of marginal materials.

Table 1: Chemical composition of OPC (*Source*: Bamburi Cement)

Parameter	Unit	Value
Silicon Dioxide (SiO_2)	%	20.37
Aluminium Oxide (Al_2O_3)	%	4.60
Ferric Oxide (Fe_2O_3)	%	4.17
Calcium Oxide (CaO)	%	64.42
Magnesium Oxide (MgO)	%	1.34
Sulphur Trioxide (SO_3)	%	2.18
Tricalcium Silicate (C_3S)	%	64.3
Dicalcium Silicate (C_2S)	%	9.9
Tricalcium Aluminate (C_3A)	%	5.1
Chlorides	%	0.023
Loss on ignition	%	1.42

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2.3 Sample preparation

2.3.1 Preparation of RAP-gravelly soil blend

Mechanical stabilization was achieved by blending RAP and gravely soil at predetermined proportions by dry weight. The blending ratios adopted are as presented in Table 2. Each blend was thoroughly mixed to ensure uniform distribution of the constituent materials before laboratory testing.

Table 2: Summary of mechanically blended material

Mix ID	RAP (%)	Gravelly soil (%)
GS100	0	100
RAP20	20	80
RAP40	40	60
RAP60	60	40
RAP80	80	20
RAP100	100	0

2.3.2 Cement stabilization

Based on the results of the mechanical stabilization phase, the most promising RAP-gravely soil blends were selected for further improvement through chemical stabilization using OPC. Cement was added at varying percentages by dry weight from 2 to 5% at intervals of 1%. The required quantity of cement was dry-mixed with the RAP-gravely soil blend before adding water. Water was then added gradually until the optimum moisture content was achieved. The mixtures were thoroughly mixed and compacted immediately to prevent premature hydration of the cement.

2.3.3 Material and sample testing

Laboratory tests were conducted on the natural gravely soil and RAP materials to determine their physical and engineering properties according to [2] and [12]. For each test, three samples were tested to determine natural moisture content, particle size distribution, specific gravity, Atterberg limits, maximum dry density (MDD), California Bearing Ratio (CBR), swell and strength characteristics.

3.0 RESULTS AND DISCUSSION

3.1 Characterization of the constituent materials

3.1.1 Particle size distribution

The grading curve shown in Figure 2 indicate that the natural gravely soil contained a relatively high proportion of fine particles, whereas RAP was predominantly composed of coarse and medium-sized aggregates coated with aged asphalt binder. Blending the two materials progressively modified the overall grading, producing mixtures with a more continuous particle size distribution that approached the grading envelope specified for road subbase materials.

The natural gravely soil exhibited excessive percentages passing the finer sieves, particularly the 0.425 mm and 0.075 mm sieves, indicating a considerable proportion of fines. Such grading characteristics are associated with high plasticity, increased water demand during compaction, and greater susceptibility to shrinkage and swelling. These characteristics explain the poor engineering performance of the untreated soil, which recorded a high Plasticity Index and low California Bearing Ratio, rendering it unsuitable for direct use as a pavement subbase. In contrast, the RAP material contained relatively few fines and a higher proportion of coarse particles (Figure 3), providing a stronger granular framework capable of improving the mechanical behavior of the blended material.

As the RAP content was increased to 80%, the grading curves shifted towards a well-graded aggregate distribution as shown in Figure 4. This trend demonstrates that RAP effectively reduced the excessive fine fraction while increasing the proportion of coarse particles responsible for load transfer. The improvement in grading is attributed to the complementary particle size distributions of RAP and the gravely soil, where the coarse RAP particles formed the primary load-bearing skeleton while the finer soil particles occupied the voids between larger aggregates. This resulted in improved particle packing, reduced void ratio, and a denser aggregate matrix. The findings of this study are consistent with the investigations of [13] on effects of particle sizes of RAP in the properties of HMA.

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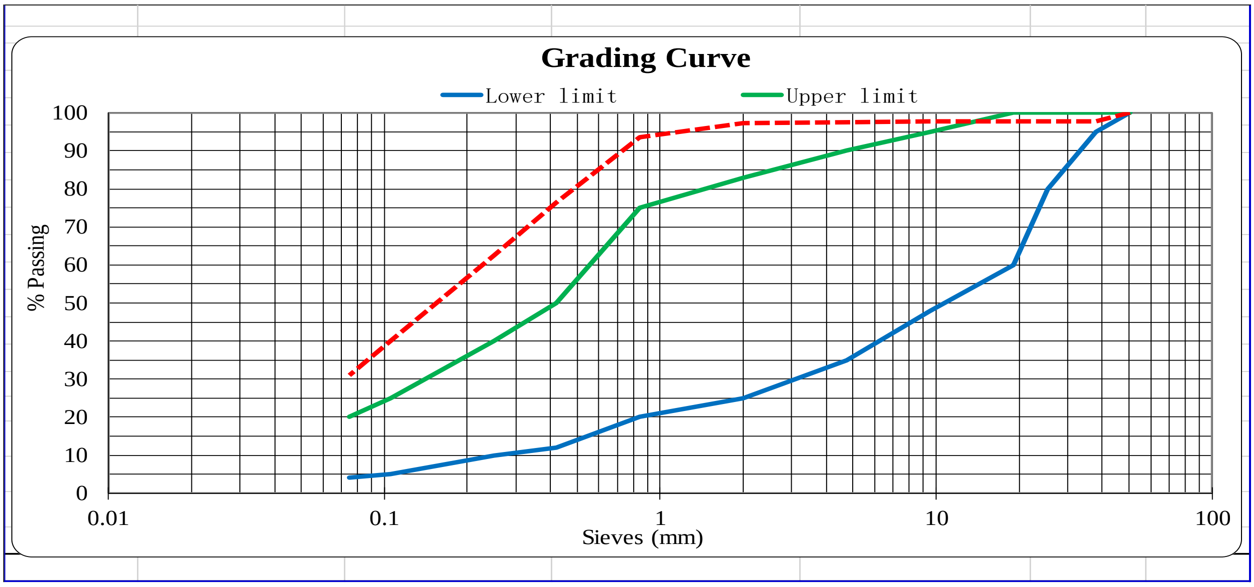

Figure 2: Grading curve for gravely soil

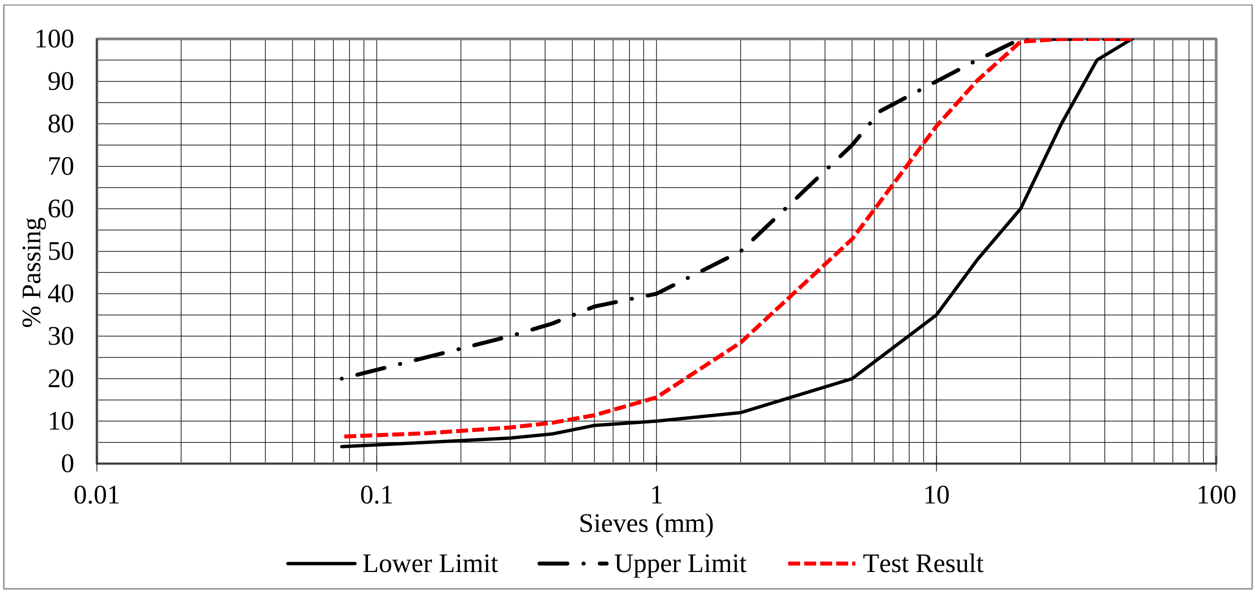

Figure 3: Grading curve for RAP

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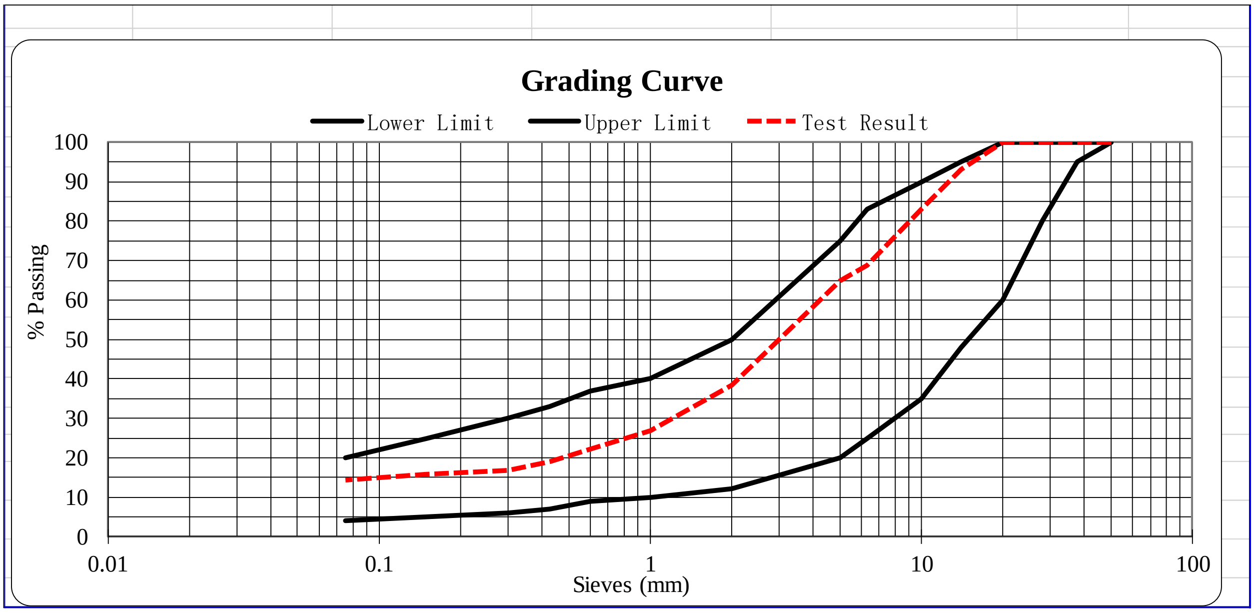

Figure 4: Grading curve for RAP-Gravely blends in the ratio of 80% and 20%

3.1.2 Moisture content and Specific gravity

Figure 5 show a progressive reduction in both moisture content and specific gravity with increasing RAP content. The high natural moisture content of the gravely soil is indicative of its relatively large proportion of fine particles and clay minerals, which possess high specific surface areas and a strong affinity for water. These fine particles retain moisture through capillary action and adsorption, making the untreated soil highly moisture-sensitive. Such soils generally require greater drying before construction, exhibit lower strength under saturated conditions, and are more susceptible to shrinkage and swelling during seasonal moisture fluctuations. This makes the natural gravely soils unsuitable for pavement construction.

The progressive reduction in moisture content following RAP incorporation can be attributed to the hydrophobic characteristics of aged asphalt binder coating the RAP aggregates as noted by [14]. Unlike clay minerals, asphalt-coated particles absorb very little water and therefore contribute minimally to the overall moisture content of the blend. In addition, the reduction in the proportion of fines with increasing RAP content decreases the total surface area available for water adsorption. Consequently, the blended materials become less moisture-sensitive and more stable under varying environmental conditions.

The decrease in specific gravity is primarily associated with the lower relative density of RAP compared with natural mineral aggregates. RAP consists of mineral aggregates coated with aged bituminous binder, whose density is lower than that of conventional silicate minerals commonly found in natural gravely soils. As RAP progressively replaced the natural soil, the average particle density of the mixtures decreased.

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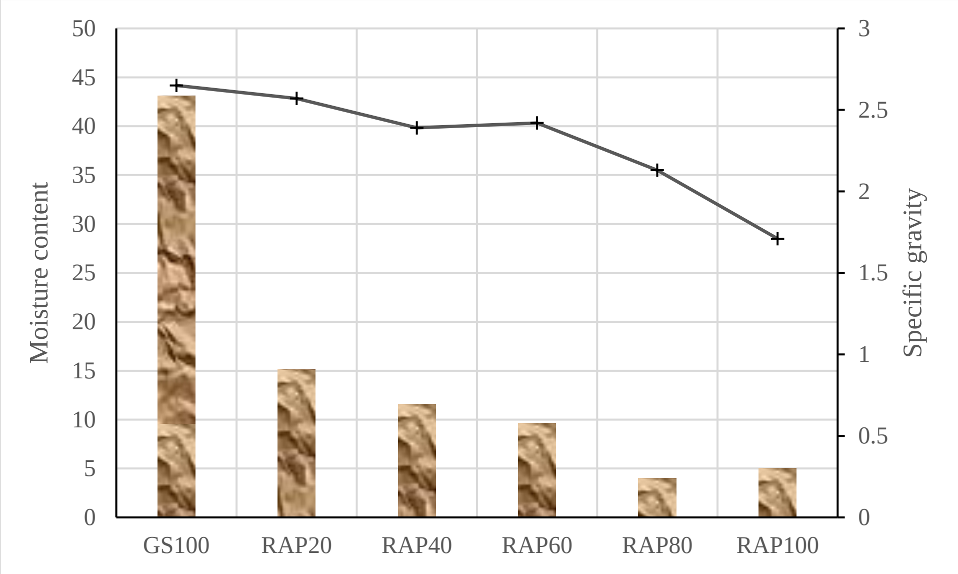

Figure 5: Moisture content and specific gravity of RAP and gravely soil blends

3.2 Compaction behavior of RAP-Gravely soil mixtures

The compaction characteristics of the RAP–gravely soil blends were evaluated using the Modified Proctor test, and the results are presented in Figure 5. A clear trend was observed in which the Maximum Dry Density (MDD) increased progressively with increasing RAP content, while the Optimum Moisture Content (OMC) decreased. The untreated gravely soil recorded the lowest MDD of 1348 kg/m³ at an OMC of 33.2%, whereas the blend containing 80% RAP achieved an MDD of 1878 kg/m³ at an OMC of 10.9%.

The increase in MDD shown in Figure 5(a) demonstrates that RAP substantially improved the packing efficiency of the blended material. RAP consists of hard, angular aggregate particles produced during pavement milling, which promote strong mechanical interlocking when compacted. As the RAP proportion increased, these particles progressively formed the primary load-bearing skeleton of the mixture, while the finer gravely soil particles filled the intergranular voids. This complementary grading reduced the overall void ratio and enabled more efficient particle rearrangement during compaction, resulting in denser mixtures suitable for road pavement sub-base application.

The reduction in OMC as shown in Figure 5(b) can be explained by the low water absorption characteristics of RAP. Unlike fine-grained soils, which require substantial amounts of water to satisfy adsorption and lubrication requirements during compaction, RAP particles are coated with aged asphalt binder that repels water. Consequently, increasing RAP content reduced the amount of water required to achieve maximum density. The transition from a fine-grained soil matrix to a predominantly granular aggregate matrix therefore resulted in progressively lower moisture requirements.

The inverse relationship between MDD and OMC observed in this study is characteristic of mechanically stabilized granular materials. Higher dry densities generally correspond to improved particle contact, increased frictional resistance, and enhanced stress transfer within the compacted layer. The RAP particles, therefore, not only improved aggregate interlocking but also reduced the percentage of moisture-sensitive fines within the mixture. This dual effect enhanced compaction efficiency while simultaneously reducing moisture susceptibility, thereby producing a more stable pavement material. Such behavior is particularly desirable for subbase layers, where adequate density and low permeability are essential for maintaining structural integrity under repeated traffic loading and environmental exposure.

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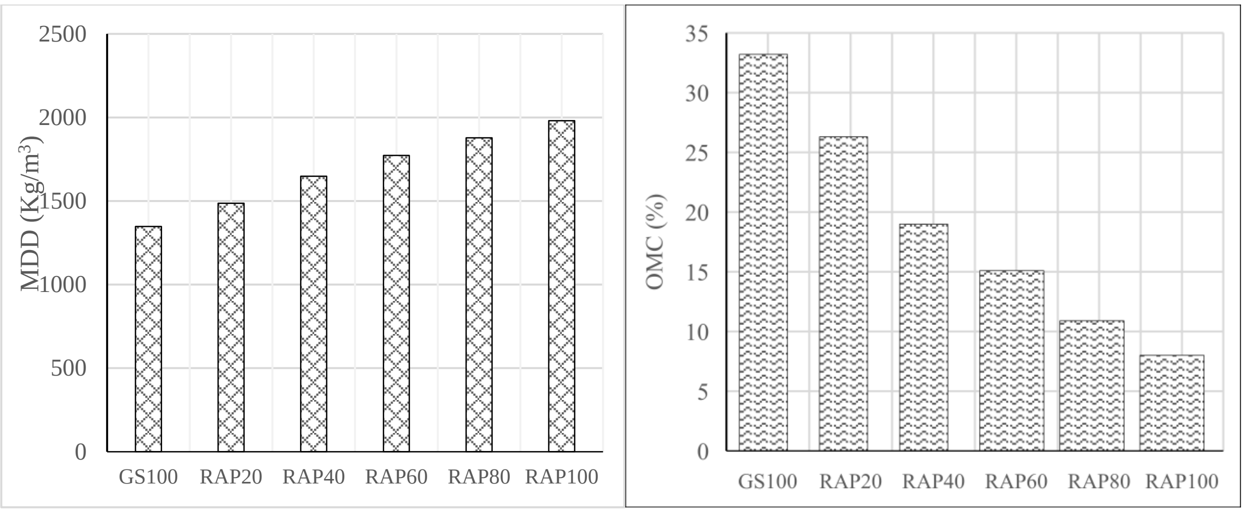

(a) MDD with varying RAP (b) OMC with varying RAP

Figure 5: Variation of MDD and OMC on RAP replacement

3.3 Plasticity characteristics

The Atterberg limits results (Figure 6) indicate that both RAP incorporation and cement stabilization significantly reduced the plasticity of the gravely soil. The untreated soil exhibited a Plasticity Index (PI) of 36.2% and a Plastic Modulus (PM) of 2770, exceeding the maximum allowable limits for subbase materials specified in the [2]. These values reflect the high clay content and moisture sensitivity of the natural soil, making it unsuitable for direct pavement applications.

Increasing RAP content progressively reduced the PI from 36.2% to 14.1%, while the PM decreased from 2770 to 266. This improvement is attributed to the replacement of plastic clay particles with non-plastic, asphalt-coated RAP aggregates, which reduced the active clay fraction and moisture absorption while promoting a stronger granular skeleton. Consequently, the material behavior shifted from clay-dominated to friction-dominated, resulting in lower plasticity and improved dimensional stability.

Further reductions in plasticity were achieved through cement stabilization. The hydration products formed during cement curing bound the soil and RAP particles together, reducing clay activity and restricting moisture-induced deformation. This is consistent with the findings of [10]. The optimum mixture containing 60% RAP, 40% gravely soil, and 4% OPC achieved a PI of approximately 13.4% and a PM of 248, satisfying the requirements for stabilized subbase materials.

International Journal of Engineering Research & Technology (IJERT)
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Vol. 15 Issue 08 , August - 2026

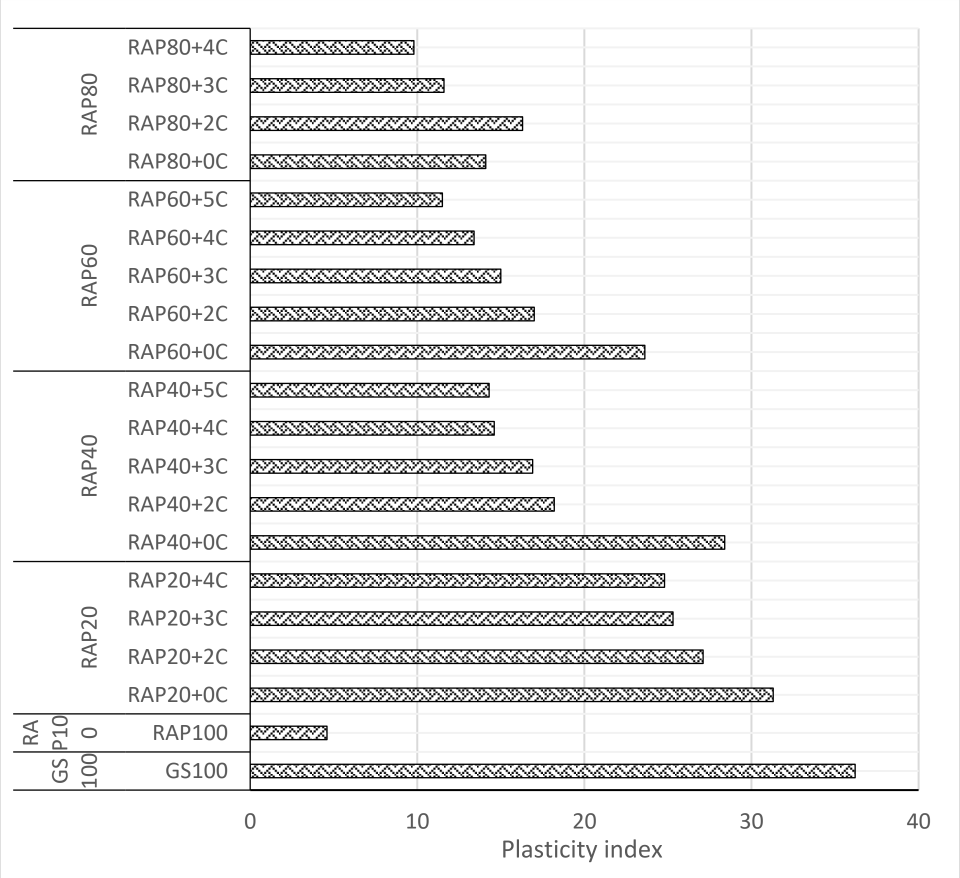

Figure 6: Effect of RAP and cement stabilization on plasticity index of the mixture

3.4 Swell behavior

The swell test results (Figure 7) demonstrate that both RAP incorporation and cement stabilization substantially reduced the expansion potential of the gravely soil. As found by [15], untreated gravely soil exhibits high swell due to its high proportion of moisture-sensitive clay minerals, which absorb water and undergo volumetric expansion. Such behavior is undesirable in pavement subbase layers as it can induce heaving, cracking, and loss of structural integrity under seasonal moisture fluctuations.

Mechanical stabilization through RAP blending progressively decreased the swell values with increasing RAP content. This reduction is primarily attributed to the replacement of expansive clay particles with non-plastic, asphalt-coated RAP aggregates, which exhibit low water absorption and reduce the overall moisture susceptibility of the mixture. The improved particle-size distribution and denser granular framework also restricted the ingress of water and minimized volumetric changes during soaking.

Further reductions in swell were achieved through cement stabilization of the mixture. Cement hydration products, principally calcium silicate hydrate (C–S–H) and calcium aluminate hydrate (C–A–H), bonded the RAP aggregates and soil particles into a rigid matrix, reducing pore spaces and limiting the ability of clay minerals to absorb water and expand. Consequently, the stabilized mixtures exhibited significantly greater dimensional stability than the mechanically stabilized blends.

The optimum mixture comprising 60% RAP, 40% gravely soil, and 4% OPC recorded a swell of approximately 0.4%, well below the maximum allowable limit of 2% specified in the Kenya Road Design Manual (2025) for stabilized subbase materials. This marked reduction in swell complements the observed improvements in plasticity, compaction, and strength, confirming that the combined mechanical and chemical stabilization effectively mitigated moisture-induced deformation. These findings demonstrate that RAP–cement stabilization provides an effective approach for producing durable and moisture-resistant pavement subbase materials suitable for low-volume roads.

International Journal of Engineering Research & Technology (IJERT)
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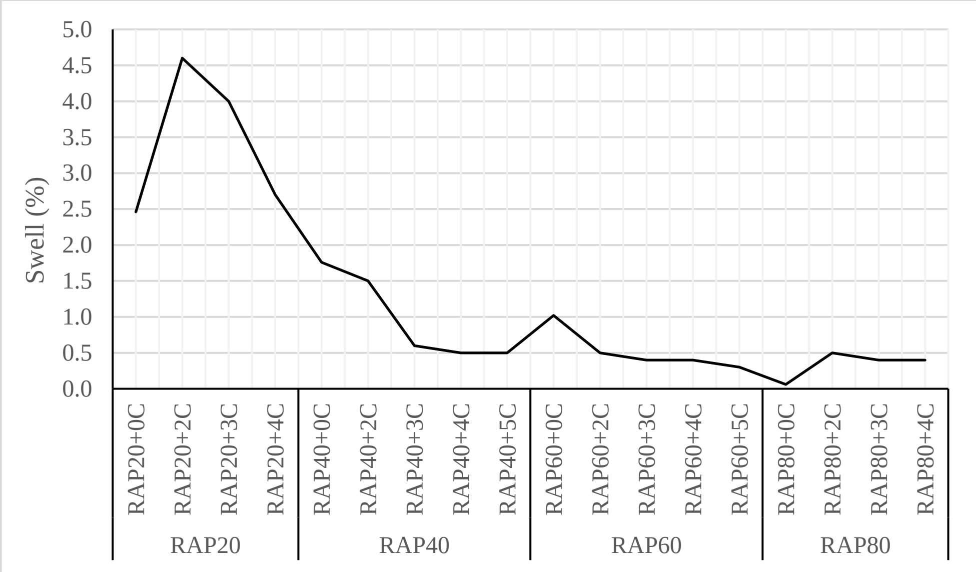

Figure 7: Effects of RAP and cement on swell

3.5 Bearing capacity

The soaked California Bearing Ratio (CBR) results presented in Figure 8 indicate a significant improvement in the bearing capacity of the gravely soil with increasing RAP content. The untreated gravely soil recorded a CBR of 8%, confirming its poor suitability as a subbase material. Progressive replacement with RAP increased the CBR due to improved aggregate interlocking, higher frictional resistance, and a reduction in moisture-sensitive fines. The well-graded RAP particles formed a stronger granular skeleton capable of distributing applied loads more efficiently than the untreated soil.

Although mechanical stabilization substantially enhanced the bearing capacity, the mechanically stabilized blends alone did not consistently satisfy the requirements for cement-stabilized subbase materials as recommended by [2]. This suggests that while RAP effectively improves the mechanical behavior of marginal soils, additional chemical stabilization is necessary to achieve the required structural performance.

Following cement stabilization, the CBR increased markedly for all RAP blends, reflecting the contribution of cement hydration products in binding soil and RAP particles into a rigid composite matrix. The optimum mixture containing 60% RAP, 40% gravely soil, and 4% OPC achieved a soaked CBR of approximately 120%, exceeding the minimum requirement of 60% specified in the Kenya Road Design Manual for stabilized subbase materials. This substantial increase demonstrates the complementary effects of RAP as a mechanical stabilizer and cement as a chemical stabilizer.

International Journal of Engineering Research & Technology (IJERT)
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Vol. 15 Issue 08 , August - 2026

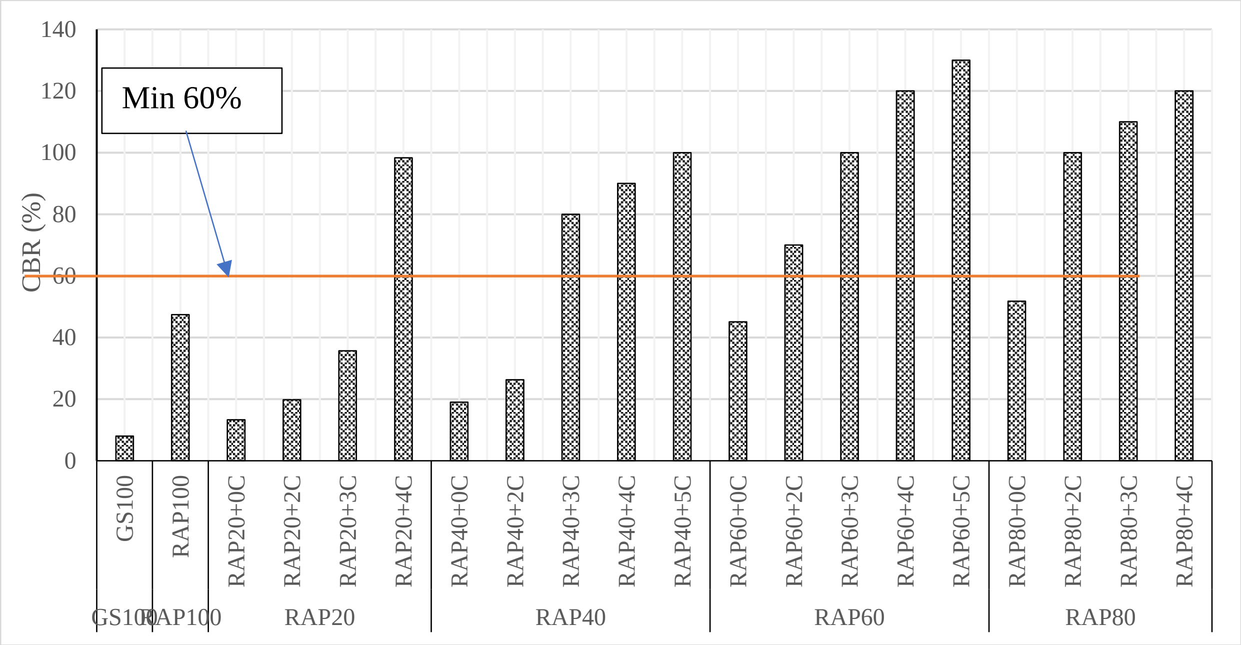

Figure 8: Soaked CBR values variation with RAP and cement stabilization

3.6 Strength characteristics

The Unconfined Compressive Strength (UCS) results (Table 3 and Figure 9) demonstrate that cement stabilization significantly enhanced the strength of the RAP–gravely soil mixtures. Strength increased consistently with increasing cement content for all RAP proportions, confirming the effectiveness of OPC in improving the structural integrity of marginal pavement materials.

The observed strength gain is attributed to the hydration of cement, which produced calcium silicate hydrate (C–S–H) and calcium aluminate hydrate (C–A–H) gels that bonded the RAP aggregates and soil particles into a dense, continuous matrix. These cementitious compounds reduced pore spaces, increased particle interlocking, and enhanced the stiffness and load-carrying capacity of the stabilized mixtures. The simultaneous improvement in compaction characteristics and reduction in plasticity further contributed to the observed increase in UCS by producing a denser and more homogeneous material.

Among the mixtures investigated, the blend containing 60% RAP, 40% gravely soil, and 4% OPC exhibited the optimum engineering performance, achieving a UCS of 3.1 MPa, which satisfies the requirements for cement-treated subbase materials. Although higher RAP contents produced greater UCS values at equivalent cement contents, these mixtures contained substantially less natural soil and may be less economical and practical for large-scale field applications. As reviewed by [16] the finding of this study provides a balance between the recommended standard for pavement subbase and economical sustainable material. Consequently, the 60% RAP blend represents the optimum balance between strength, material utilization, and construction feasibility.

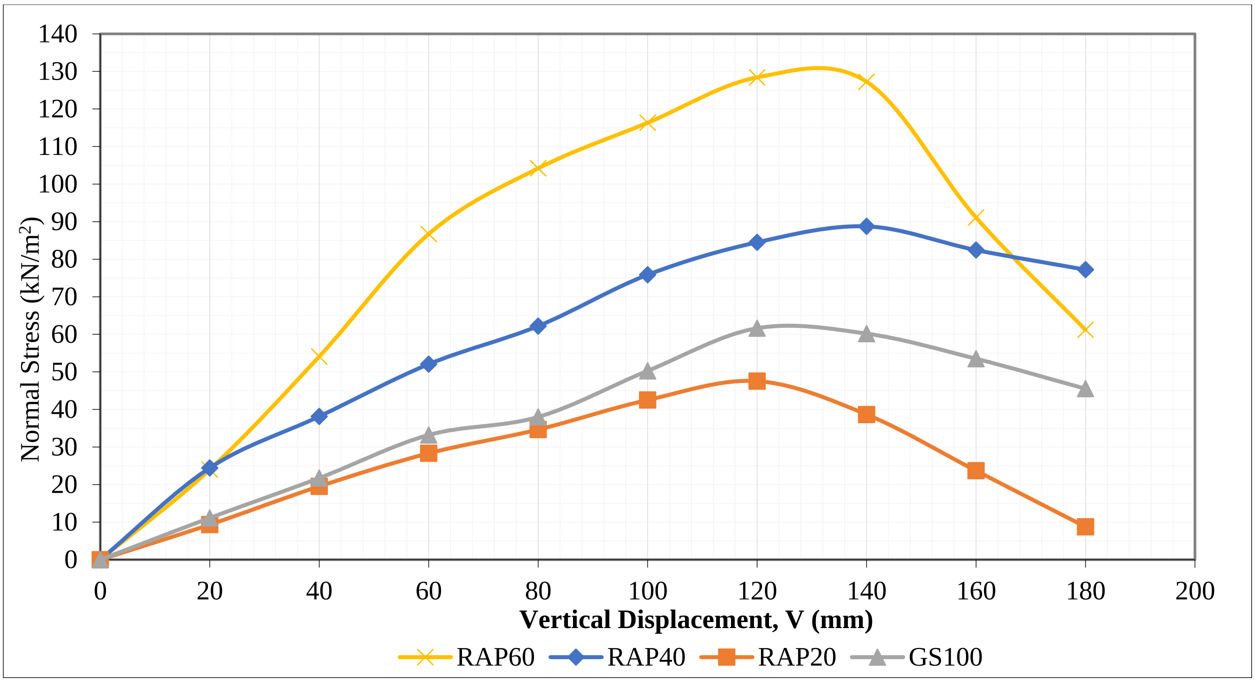

Figure 9: Unconfined compressive strength for 7day

Table 3: Unconfined compressive strength with cement stabilization

	Sample																
Property	GS100			RAP20			RAP40				RAP60				RAP80		
OPC (%)	2	3	4	2	3	4	2	3	4	5	2	3	4	5	2	3	4
UCS	0.14	0.19	0.23	0.44	0.52	0.57	0.58	1.3	2.5	2.7	1.1	1.4	3.1	3.8	5.2	5.7	8.6

3.7 Shear behavior

The direct shear test results presented in Figures 10 and 11 demonstrate that RAP exhibited higher shear resistance than the untreated gravely soil under all applied normal stresses. In both materials, shear stress increased with increasing normal stress, consistent with the Mohr–Coulomb failure criterion, which states that shear strength is governed by the combined effects of frictional resistance and particle interlocking. However, RAP developed greater peak shear stresses and lower vertical deformation than the natural gravely soil, reflecting its superior frictional characteristics and greater resistance to particle displacement.

The improved shear behavior of RAP is primarily attributed to the angularity and rough surface texture of the milled asphalt aggregates, which promote stronger interparticle friction and mechanical interlocking during loading. In contrast, the gravely soil contained a higher proportion of fine particles. The excessive fines in the natural soil reduced direct aggregate particle contact and act as weak planes during shearing, resulting in lower shear resistance and greater deformation. The smaller vertical displacement observed in RAP also indicates improved dimensional stability and reduced compressibility.

The superior shear characteristics of RAP complement the improvements observed in CBR, compaction, and plasticity, confirming that RAP contributes significantly to the load-transfer mechanism of the stabilized mixtures. Higher shear strength enhances pavement resistance to rutting and permanent deformation under repeated traffic loading, making RAP a suitable recycled aggregate for road subbase applications.

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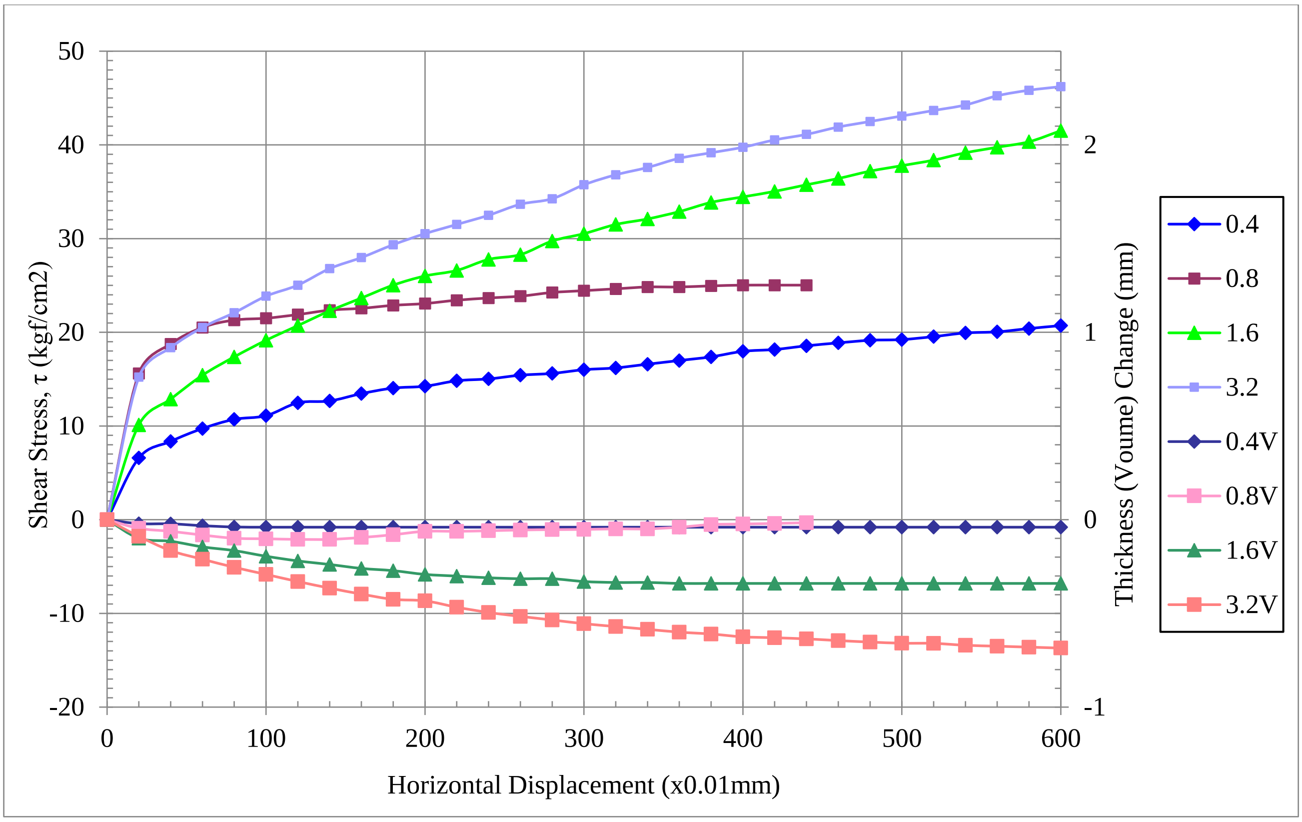

Figure 10: Direct shear stress for gravely soil

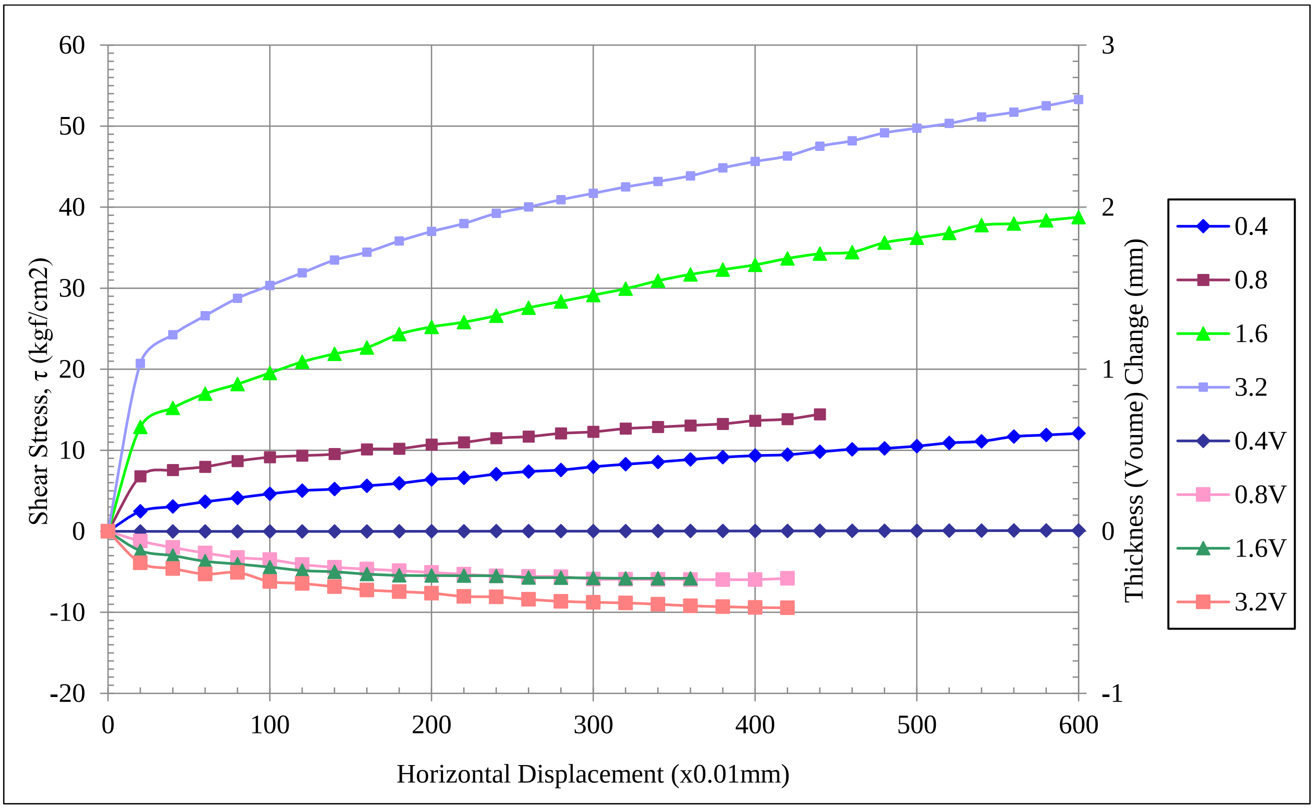

Figure 11: Direct shear stress for RAP material

International Journal of Engineering Research & Technology (IJERT)
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CONCLUSION

This study evaluated the engineering performance of gravely soil mechanically stabilized with Reclaimed Asphalt Pavement (RAP) materials and chemically stabilized with Ordinary Portland Cement (OPC) for application as road subbase material. The following conclusions were drawn from this study:

1. The untreated gravely soil exhibited high plasticity, excessive swell, low bearing capacity, and inadequate strength, rendering it unsuitable for direct pavement construction.
2. Mechanical stabilization through RAP incorporation significantly improved the mixture. These improvements were primarily attributed to the replacement of moisture-sensitive clay particles with well-graded, non-plastic RAP aggregates that formed a stronger granular skeleton.
3. The optimum mixture comprising 60% RAP, 40% gravely soil, and 4% OPC achieved a Plasticity Index of 13.4%, Plastic Modulus of 248, soaked CBR of 120%, UCS of 3.1 MPa, and swell of 0.4%, satisfying the requirements of the Kenya Road Design Manual for cement-stabilized subbase materials.

The proposed mixture offers a practical solution for conserving natural aggregate resources, reducing construction waste disposal, lowering pavement construction costs, and promoting circular economy principles in Kenya's road sector. Future research should investigate the long-term field performance, durability under cyclic traffic loading, and life-cycle environmental and economic benefits of RAP–cement-stabilized pavement layers.

REFERENCES

[1]. Ghimire, U & Bheemasetti, T. (2025). *Experimental Studies and Sustainability Assessments of Use of Reclaimed Asphalt Pavement (RAP) in Pavement Layers*. Transportation Geotechnics, Vol. 52. https://doi.org/10.1016/j.trgeo.2025.101595

[2]. Kenya Road Design Manual Part III (2025): *Materials and Pavement Design for New Roads*. https://www.scribd.com/document/953833816/RDM-3-2-Materials-Field-and-Laboratory-Testing

[3]. Rout, M. D., Biswas, S., Shubham, K., & Sinha, A. K. (2023). *A Systematic Review on Performance of Reclaimed Asphalt Pavement (RAP) as Sustainable Material in Rigid Pavement Construction: Current status to future perspective*. Journal of Building Engineering. https://doi.org/10.1016/j.jobe.2023.107253

[4]. Tsakoumaki, M., & Plati, C. (2024). *A Critical Overview of Using Reclaimed Asphalt Pavement (RAP) in Road Pavement Construction*. Infrastructures, 9(8), 128. https://doi.org/10.3390/infrastructures9080128

[5]. Pradhan, S.K. & Biswal, G. (2022). *Utilization of reclaimed asphalt pavement (RAP) as granular sub-base material in road construction*. Materials today: Proceedings. Vol 60. 288-293. Doi: https://doi.org/10.1016/j.matpr.2021.12.564

[6]. Dughaishi, H.A., Lawati, J.A., Bilema, M., Babalghaith, A.M., Mashaan, N.S., Yusoff, N.I.M., and Milad, A. (2022). *Encouraging Sustainable Use of RAP Materials for pavement Construction in Oman: A Review*. Recycling, 7(35). https://doi.org/10.3390/recycling7030035

[7]. Zhang, J., Sesay, T., You, Q., & Jing, H. (2022). *Maximizing the Application of RAP in Asphalt Concrete Pavements and Its Long-Term Performance: A Review*. Polymers, 14(21), 4736. https://doi.org/10.3390/polym14214736

[8]. Wen, P., Wang, C., Song, L., Niu, L & Chen H. (2021). *Durability and Sustainability of Cement-Stabilized Materials Based on Utilization of Waste Materials: A Literature Review*. Sustainability, 13(21), 11610. Doi: https://doi.org/10.3390/su132111610

[9]. Costa, J.O., Borges, P.H.R., Dos Santos, F. A., Cesar, A., Wim V., & Blom J. (2020). *Cementitious binders and reclaimed asphalt aggregates for sustainable pavement base layers: Potential, challenges and research needs.* Journal of construction and building materials. Vol. 265. https://doi.org/10.1016/j.conbuildmat.2020.120325

[10]. Ghanizadeh, A.R., Rahrovan, M., & Barkhordari, K. (2018). *The Effect of Cement and Reclaimed Asphalt Pavement on the Mechanical Properties of Stabilized Base via Full-depth Reclamation*. Construction and Building Materials. 161. https://doi.org/10.1016/j.conbuildmat.2017.11.124

[11]. Panda, R & Biswal, D.R. (2023). *A Systematic Review of Geo-polymer Stabilized Reclaimed Asphalt Pavement (RAP) as a Base Layer of Pavement*. Road Materials and Pavement Design, 26(2), 231-253 https://doi.org/10.1080/14680629.2024.2349021

[12]. British Standard Institute. BS 1377: Part 2 (1990). Soils for Civil Engineering Purposes: Part 2, Classification tests.

[13]. Al-Ghurabi, S.B., & Al-Humeidawi, B.H. (2021). Comparative Evaluation for the Effect of Particles of Reclaimed Asphalt Pavement (RAP) on the Properties of HMA. 2nd International conference for civil engineering science. https://doi:10.1088/1742-6596/1895/1/012025

[14]. Sukhija, M. & Coleri, E. (2025). *A systematic Review on the Role of Reclaimed Asphalt Pavement Materials: Insights into Performance and Sustainability*. Cleaner Materials. https://doi.org/10.1016/j.clema.2025.100316

[15]. Lima, D., Arrieta-Baldovino, J., & Izzo, R. L. S. (2023). *Sustainable Use of Recycled Asphalt Pavement in Soil Stabilization*. Civil Engineering Journal, *9*(9), 2315–2329. https://doi.org/10.28991/CEJ-2023-09-09-016

[16]. Alkam, R.B., Airey G.D., Thom, N. & Tajudin A.N. (2025). *Reclaimed Asphalt Pavement (RAP) in Cold Recycled Bituminous Mixtures: A Systematic Review*. Road Materials and Pavement Design. 1-46. https://doi.org/10.1080/14680629.2025.2595213