STRENGTHENING SUB-SURFACE LAYERS OF FLEXIBLE PAVEMENT UTILIZING RECLAIMED ASPHALT PAVEMENT

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ABSTRACT

The transportation sector has advanced rapidly in the context of continuous global development, including in Bangladesh. The upgradation of road systems, particularly flexible pavements, generates a significant amount of Reclaimed Asphalt Pavement (RAP) material that requires efficient management due to the ongoing utilization of natural resources, particularly stone aggregates, which could result in future shortages and environmental imbalance. In recent times, there has been a gradual increase in construction and demolition waste, resulting in waste disposal challenges due to the scarcity of available landfills. In this situation, one promising approach is to utilize RAP as a sub-surface material to construct sub-surface layers of flexible pavements, given its potential use as a byproduct of old pavements. This study investigated various percentages of soil and RAP mixture ratios (100/0, 85/15, 70/30, 55/45, and 40/60) to assess their compaction and California Bearing Ratio (CBR) characteristics. The result shows that with increasing RAP proportion with soil, the maximum dry density (MDD) reached a peak value of 2.11 g/cm³. At the same time, the optimum moisture content (OMC) decreased to a minimum of 7.00% for 45% RAP inclusion, as determined by the modified Proctor test. Moreover, the CBR value improved for all soil-RAP mixtures with increasing RAP percentage, peaking at approximately 30% CBR value for heavy compaction in soaked conditions. As per the specifications outlined by RHD (Roads and Highways Department), the specified CBR value for the sub-base layer is set at 25%. It is seen from the result, that the combination of 40% soil and 60% RAP is found to be suitable for a sub-base layer of heavy-volume roads. This study highlights the potential use of RAP as a primary aggregate source to minimize the reliance on virgin aggregate, leading to improved sub-surface layers strength of flexible pavement and contributing to the development of more sustainable and efficient road infrastructures, thereby providing economic and environmental benefits.

Keywords: *RAP, Flexible pavement, Subsurface, CBR.*

1. INTRODUCTION

Bangladesh is one of the fastest-growing economic regions in the whole of South Asia where heavy industrialization is taking place continuously. With the rapid development and massive growth, sustainable development is the need of the hour. A crucial part of the construction industry's foundation is the highway sector. but the extensive use of natural resources has emerged as a significant environmental concern. Flexible pavements constitute nearly 95% of the global road network (Poon C. S., & Chan, D., 2006). In this current situation, it has become essential to investigate alternative materials instead of virgin aggregates to construct pavements. Utilizing waste materials like RAP after effective recycling can provide a suitable solution as coarse aggregate instead of stone for the construction of pavements. Recently, efforts have been undertaken to RAP into the base or sub-base layer of pavements (Montepara et al., 2012; Arshad, M., & Ahmed., 2017). The asphalt concrete removed from a pre-existing road pavement is entirely recyclable for use in construction (The European Asphalt Pavement Association. 2014). RAP can be repurposed as recycled aggregates for constructing unpaved layers in pavements (Southern African Bitumen Association. 2019). Utilizing recycled RAP materials in asphalt pavements helps conserve limited resources, reducing the need to extract new aggregates and bitumen while also reducing the amount of waste dumped in landfills (Williams et al., 2019; Vidal et al., 2013; Thieves et al., 2017). By 2013, the Japanese road sector had already demonstrated a remarkably efficient RAP recycling system, and within the subsequent two years, an outstanding 99% of the total RAP amount was effectively repurposed (West et al., 2015). The recycled RAP asphalt mixture met the necessary criteria while saving money and benefiting the environment (Guercio & McCarthy., 2015). Incorporating RAP in the subbase layer and subgrade presents a practical solution for managing the substantial volume of waste generated during maintenance and rehabilitation efforts (Hoppe et al., 2015). For more than three decades, the Wisconsin Department of Transportation (WisDOT) has been utilizing RAP as a base course(Titi et al., 2022). The University of Illinois at Urbana-Champaign researched the possible utilization of RAP as a material for pavement bases (Garg & Thompson., 1996). (Taha et al. 1999) assessed the viability of RAP in the base and subbase layers of flexible pavement RAP utilization in the subsurface indicated the possibility of substantial economic advantages. Utilizing RAP in road base and subbase materials is viable, and there were no substantial environmental issues associated with using untreated RAP without chemical stabilizers (Hoppe et al., 2015). The Virginia Transportation Center in Australia recommends incorporating a 30% blend of RAP for road base and sub-base materials (Arulrajah et al., 2017). The Texas Department of Transportation permits the utilization of 20% RAP and Recycled Concrete Aggregate (RCA) in the construction of pavement subgrade and base(Mills-Beale, J., & You, Z., 2010). Using RAP as an unbound aggregate base course offered a practical alternative (Locander., 2019). Pavements incorporating different proportions of RAP in the base course exhibited comparable strength and stiffness to those with 100% virgin aggregate base courses (Kim, W., & Labuz, J., 2007). RAP is utilized for road base courses in a minimum of 12 states across the United States (McGarrah., 2007). In 1973, RAP was initially limited in its use in asphalt mixes due to concerns about its impact on performance. Still, today, it is increasingly employed in proportions exceeding 50% to save costs, conserve resources, and recycle old asphalt pavements (Enieb et al., 2021). Evidence suggests that RAP can be efficiently utilized as a recycled component in the construction of flexible pavement layers. Through a review of the literature, we discovered that while previous studies have integrated RAP with virgin aggregate or other materials to enhance pavement strength, there is a notable absence of its utilization with soil for repurposing. To address this gap in research, we have chosen to explore the combination of soil and RAP for practical implementation. This initiative aims to make a valuable contribution to the research community and provide a foundation for future researchers to gather essential data from this study. The present study has examined a range of soil and RAP mixture ratios (100/0, 85/15, 70/30, 55/45, and 40/60) to assess different properties of RAP-soil composition to make sure the blends achieve the necessary levels of strength and longevity. With this, the specific objectives have been pointed out for this investigation.

i. To assess the properties of collected soil and RAP materials.

ii. To determine OMC and MDD for RAP and soil mixtures by Standard Proctor Test and Modified Proctor Test.
iii. To evaluate the California Bearing Ratio (CBR) value at the soaked and unsoaked condition for light and heavy compaction.

2. METHODOLOGY

Constructing a road solely with locally available soil is often impractical due to insufficient strength. To address this issue, the ongoing investigation blended RAP with locally available soil in different ratios to conduct tests on the prepared samples to validate key characteristics and ascertain the suitability of the soil-RAP mixture for reinforcing sub-surface layers. The current study has followed the workflow diagram shown in Fig. 1.

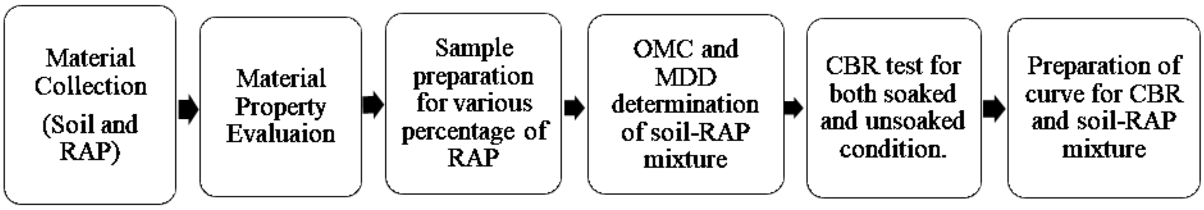

Figure 1: Workflow diagram of the present investigation

The fundamental testing procedure includes physical and mechanical property evaluation of test materials, compaction testing with the compaction test, and strength testing with the CBR test.

2.1 Materials Collection and Properties

The materials used in this research include processed RAP materials and soil. The RAP materials have been collected from Tigerpass, Chattogram City which were stored adjacent to the roadside shown in Fig. 2. The soil was collected from the opposite site of Professor's building within the premises of the CUET campus.

Figure 2: Stockpile of RAP

Prior to determining the Optimum Moisture Content (OMC) and California Bearing Ratio (CBR) values, the physical properties of both soil and Recycled Asphalt Pavement (RAP) were assessed, including specific gravity of soil following ASTM D 854-06, the specific gravity of RAP using ASTM C127, Aggregate Impact Value (AIV), and Aggregate Crushing Value (ACV) tests on RAP in accordance with BS 812, Los Angeles Abrasion Value (LAAV) test per ASTM C131, and the Elongation and Flakiness Index test on RAP following BS 821, Binder contest test of RAP according to contributing to filtration and drying process a comprehensive evaluation of material properties throughout the study.

After pulverizing the collected samples, grain size distribution analysis was conducted according to ASTM C-136 standard which is shown in Fig. 3 and Fig. 4 respectively.

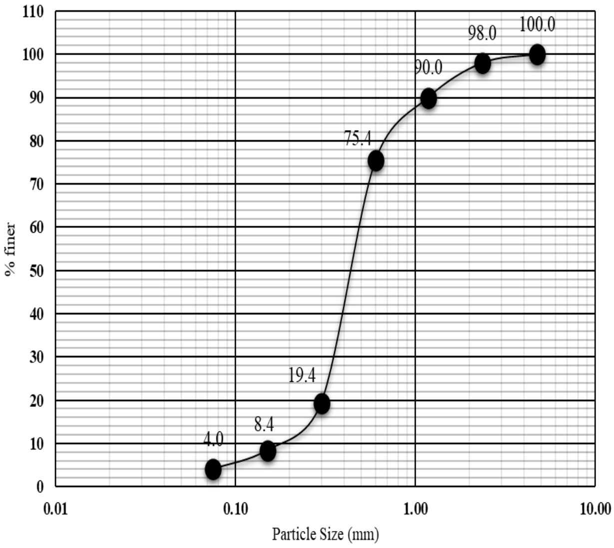

Figure 3: Grain size distribution of soil

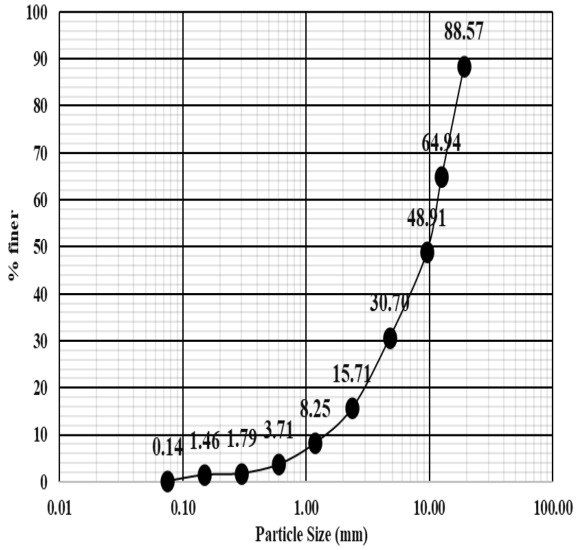

Figure 4: Grain size distribution of RAP

2.2 Materials Mixing

Both soil and RAP samples were graded as required before sample preparation specified by ASTM standards. Samples have been prepared at various mixing proportions of RAP materials with soil as 0% RAP+100% soil, 15% RAP+85% soil, 30% RAP+70% soil, 45% RAP+55% soil, and 60% RAP+40% soil. These blends were selected arbitrarily to demonstrate the diverse behavior of RAP and to formulate a correlation between RAP and soil for future study purposes, with higher RAP percentages being excluded based on a review of the literature. Hence, both researchers and field professionals can utilize this correlation for both research and practical applications. Each test was performed thrice including physical properties of RAP as well as soil, compaction test, and CBR test, with the final outcome assessed by calculating the average of the three results, ensuring that the variation among the results did not exceed 10%.

2.3 Compaction Test

The compaction tests have been conducted for 0%, 15%, 30%, 45%, and 60% RAP content with soil according to ASTM D-698 and ASTM D-1557 for standard proctor and modified compaction tests respectively to determine dry density and optimum moisture content needed to conduct CBR test. Any particles larger than 19 mm were excluded from the mixture and substituted with an equivalent weight of particles smaller than 19 mm.

2.4 California Bearing Ratio (CBR) Test

The CBR test was conducted in the laboratory to assess the load-bearing capacity of soil and soil-RAP blends when compacted at their specific optimal moisture levels. CBR test samples have been prepared at their respective OMC following the ASTM D-1883 standards, employing both light and heavy compaction for soaked and unsoaked conditions.

2.5 Preparation of Design Curve

Following the completion of the processes, the design CBR curve was generated through linear regression modeling. Simple linear regression analysis (SLRA) was employed for all four test conditions to establish a correlation between the CBR value and the soil-RAP mixture.

3. EXPERIMENTAL INVESTIGATION

3.1 Properties of Materials

The physical and mechanical properties of the soil and RAP materials from the experimental investigations are presented in Table 1.

Table 1: Investigation result of the collected sample.

RAP				Soil		
Properties	Test Standards	Result	Allowable value for sub-base (RHD)	Properties	Test Standards	Test Result
Specific Gravity	ASTM C127	2.57	–	Specific Gravity	ASTM D854	2.52
Los Angeles Abrasion Value (LAAV)	ASTM C131	22.4%	<60%	Finess Modulus	ASTM C33	2.08
Aggregate Crushing Value (ACV)		14%	<40%	Liquid Limit	ASTM D 4318	24.2%
Aggregate Impact Value (AIV)	BS 812	5.21%	<50%	Plastic Limit	ASTM D 4318	16.5%
Flakiness Index		22.4%	>15%	Plasticity Index	ASTM D 4318	7.7%
Elongation Index		0.5%	<15%			
Absorption Capacity	ASTM D-4318	0.3%	<3%			
Binder Content		3.5%				

From Table 1, it can be easily comparable whether RAP is suitable or not for utilization in sub-surface layers of pavement according to the RHD standard value as all experimental results are shown along the RHD standard value. From Table 1 it is found that the obtained RAP sample result is significantly higher than the specified criterion and meets all the requirements for its suitability according to the RHD standard value for use in flexible pavement sub-base construction. Due to the significantly low FM value of the soil sample, it is deemed unsuitable for the construction of flexible pavement layers in roadways, necessitating the need for stabilization. The weak soil has been stabilized through the utilization of RAP.

3.2 Compaction Test Results

The compaction tests have been conducted for various proportions of soil and RAP mixture following both standard proctor and modified proctor tests. The findings of the conducted experiments have been tabulated in Table 2.

Table 2: Compaction Test Results for Different Proportions of RAP

RAP Content (%) in soil		0	15	30	45	60
Standard	OMC (%)	12.7	11.1	10.5	8.9	7.9

Proctor Test	MDD (g/cm3)	1.81	1.89	1.94	1.97	2.00
Modified Proctor Test	OMC (%)	10.8	9.5	8.6	7.00	6.4
	MDD (g/cm3)	1.93	1.98	2.01	2.11	2.07

Based on the data presented in Table 2, a noticeable trend is visible in the gradual reduction of OMC value as the RAP content increases in soil-RAP mixtures for both types of compactions. However, modified compaction shows a lower OMC value compared to standard compaction. RAP aggregates, having lower surface area and water-holding capacity than finer particles, efficiently pack together due to their angular shape. This efficient packing reduces the water needed to achieve optimum moisture content for compaction, resulting in a lower optimum moisture content value. An opposite pattern is evident in the MDD values, where they increase as RAP content rises, but with modified compaction consistently yielding higher MDD values compared to standard compaction. As the percentage of RAP aggregate rises, the larger particles fill the gaps between the finer ones, promoting a more compact structure. This compaction enhances the contact between particles, minimizing air voids within the soil matrix during the compaction process. The increased contact between particles and the decreased void spaces are factors that contribute to higher maximum dry density values. As the MDD value rises, there is a corresponding increase in strength, as indicated by the CBR value.

3.3 CBR Test Results

This study primarily focused on determining CBR values for assessing the suitability of soil-RAP mixture for sub-surface layers of flexible pavement. Within the research, CBR values were calculated for different combinations of soil and RAP content under both soaked and unsoaked conditions, utilizing both heavy and light compaction methods by the specified code. The results of the various tests have been presented in Table 3.

Table 3: CBR Test Results for Different Proportions of RAP

RAP Content (%) in soil			0	15	30	45	60
CBR Value (%)	Light Compaction	Unsoaked	3.4	5.8	8.7	12.5	18.3
		Soaked	2.8	4.5	6.9	10.2	14.7
	Heavy Compaction	Unsoaked	5.0	8.8	12.7	17.5	26.8
		Soaked	5.8	9.9	15.4	22.6	30.2

It is seen from Table 3, during light compaction under unsoaked conditions CBR value shows a better result with the highest CBR value of 18.3%. Conversely, heavy compaction under soaked conditions results in higher CBR values, with a maximum CBR value of 30.2%. The CBR requirement varies for different layers of flexible pavement. According to the RHD material specification, the sub-base layer's CBR value, should not be lower than 25%. The soil-RAP mixtures that have been examined show the highest CBR value, 30.2% after a four-day-soaked condition, meeting the requirements for the sub-base layer of high-traffic volume roads.

3.4 Preparation of Design Curve

From Table-3, regression models are generated for both soaked and unsoaked conditions, through heavy and light compaction. The regression models have been visually represented in Fig. 5 and Fig.6 respectively that are obtained from CBR values**.** The models were generated based on RAP with an approximate binder content of 3.5% (Table 1), and the RAP utilized in this research had a service life of roughly 12 years before repurposing.

However, it's important to note the study's limitations, including the fact that the chosen soil type does not encompass all soil categories and their interactions with the RAP sample. The experiment results are validated specifically for the soil and RAP categories utilized in our research, and this validation may not extend to all types of soil and RAP.

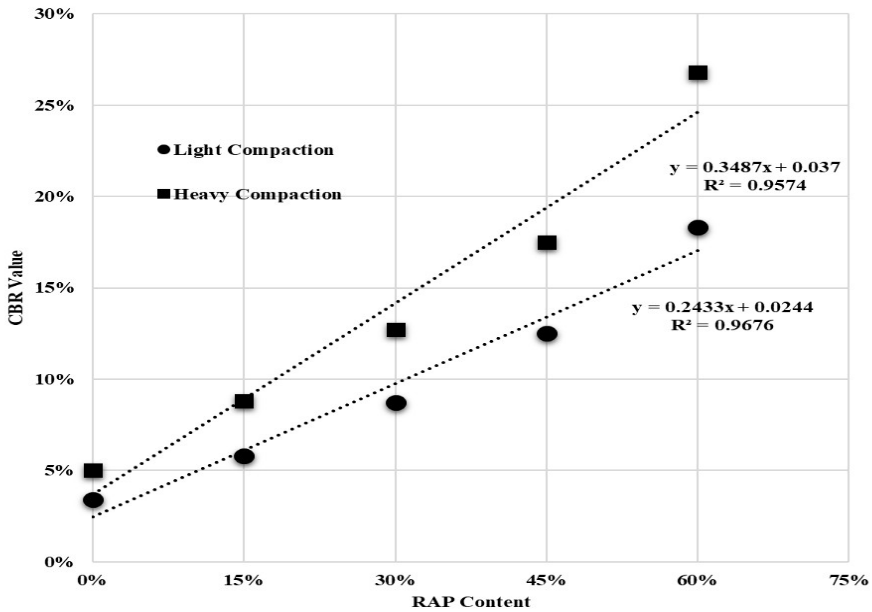

Figure 5: Correlation between CBR and RAP Content (Unsoaked Condition)

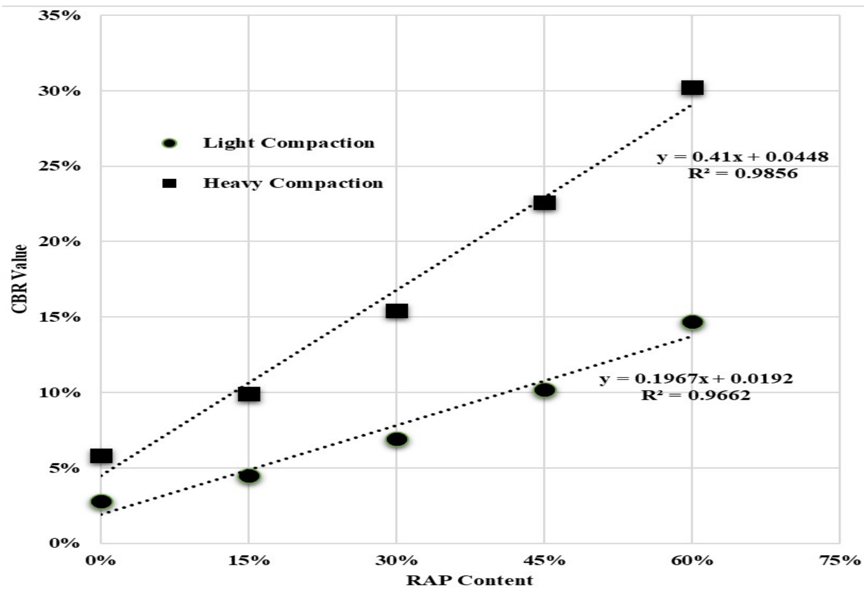

Figure 6: Correlation between CBR and RAP Content (Soaked Condition)

The curves illustrate how CBR values change for both soaked and unsoaked conditions when using heavy and light compaction with various soil-RAP combinations. These curves simplify the process of calculating the required RAP content to reach a targeted CBR value. The 'y' value represents the specific CBR value, and it can be determined by solving the equation to find the 'x' value, which indicates the required amount of RAP content. The equations of the design curves developed in this research are given below.

- Soaked CBR (Heavy Compaction), $Y = 0.41x + 0.0448$; $R^2 = 0.9856$-----------------------------i
- Soaked CBR (Light Compaction), $Y = 0.1967x + 0.0192$; $R^2 = 0.9662$---------------------------ii
- Unsoaked CBR (Heavy Compaction), $Y = 0.3487x + 0.037$; $R^2 = 0.9574$------------------------iii
- Unsoaked CBR (Light Compaction), $Y = 0.2433x + 0.0244$; $R^2 = 0.9822$------------------------iv

An R-value closer to 1 designates a good correlation between the data points obtained.

4. CONCLUSION

Although the RAP is considered waste material, properties of RAP, show the adequacy of use as coarse aggregate in the underlying layers of flexible pavement. Additionally, the CBR values demonstrate an upward trend as the proportion of RAP content increases in the soil-RAP mixture which indicates the strength of soil substantially improved. On the other hand, a significant quantity of RAP is continuously produced as a by-product during flexible pavement reconstruction and maintenance, presenting a future challenge in managing this large volume of RAP. Thus, it can be concluded that-

1. Incorporating RAP into the sub-surface layer of flexible pavement significantly minimizes construction expenses, and reduces the need for virgin aggregate especially valuable stone aggregates. RHD specification requires a CBR value of 25% for the sub-base layer of heavy-volume roads, traditionally attained through a combination of expensive sand and virgin aggregate, whereas using cost-effective soil and RAP materials provides the same CBR value like as blend of virgin aggregate and sand. Ultimately reducing the financial burden on the government as well as virgin aggregate.
2. RAP is classified as a third-class environmentally hazardous material due to its need for significant disposal areas; therefore, using RAP in the sub-surface layer of roads offers a realistic and environmentally beneficial solution to this problem.

So, experienced engineers can utilize the design curve to determine the amount of RAP content required to achieve the desired CBR value, and this information can be an informative resource for future researchers in their research projects.

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