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Improving sustainability of road construction by partial replacement of natural aggregates in subbase layer with crushed brick and reclaimed asphalt pavement

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Abstract. Reducing dependent on naturally sourced materials is among the priority in improving the sustainability of road construction. The subbase layer which provides strength and stability across the road profile, comprised mainly of natural aggregates. This study aims to explore the feasibility of partial replacement of natural aggregates in subbase layer with 20% Crushed Brick (CB) and 20 to 50% Reclaimed Asphalt Pavement (RAP). California Bearing Ratio (CBR) test and Constant Head Permeability tests were carried out to determine the effect of this partial replacement on the geotechnical properties of the subbase layer. The results obtained denotes that the combination of 20% CB and 50% RAP is the optimum partial replacement of natural aggregates in subbase layer with CB and RAP. The use of CB further complements RAP in improving the stiffness and compressibility of the subbase layer while contributing significantly toward sustainability in road construction.

1. Introduction

Due to their economic effectiveness and environmental sustainability, the use of recycled materials for the building of roads, pavements, and footpaths is expanding all over the world. In fact, the building sector is responsible for nearly half of all garbage produced worldwide. Construction and demolition trash are the most common types of garbage generated by the sector. Solid wastes created by construction operations such as demolition, repair, and rebuilding of structures are referred to as construction and demolition wastes [1].

Reclaimed Asphalt Pavement (RAP), Recovered Concrete Aggregate (RCA), recycled bricks, recycled glass, and fly-ash are the most frequent recycled materials utilized in different layers of flexible pavements. To provide sustainable solutions, industrial waste should be recycled and reused in geotechnical and pavement applications. Throughout the globe, billions of tons of garbage are produced, most of which may be reused and recycled to avoid possible negative environmental consequences and landfill disposal costs. Asphalt is often removed from highways, resulting in stockpiles of wasted asphalt. Without a viable technique of repurposing this material, it will wind up in landfills. Asphalt that has been reused is referred known as RAP. RAP's performance in the field and in the lab has been described in this way [2].

Construction and demolition of buildings and other structures produce crushed brick (CB) as a by-product. CB is often made up of 70% brick and 30% other elements including asphalt, concrete, and rock. CB was retrieved from a recycling center [3]. In general, roads are normally constructed from several layers. The subbase is the layer of aggregate material directly beneath the pavement, and it is often made up of crushed aggregate, gravel, or recycled materials. Crushed rock, made of material and component particles, is used to make aggregate subbase. The material might be fresh (mined) rock or recycled asphalt. Subbase serves a multitude of functions, including relieving load on the subgrade and allowing the pavement structure to drain.

RAP has been included into pavement base and subbase applications in recent years [4]. The performance of RAP stabilised with cement binders in the pavement foundation and subbase layer has been reported to be satisfactory [5].

However, the use of RAP as an aggregate in pavement subbase has been limited due to a paucity of published laboratory and field-testing data [6]. There is no comprehensive examination of the properties of RAP to be integrated into the subbase layer in the literature [6]. This condition necessitates the development of processes or recommendations for the successful use of RAP as one of the unbound materials in the context of various highway pavement design approaches.

Finding a mean to employ Crushed Brick (CB) and Reclaimed asphalt pavement (RAP) as an alternate material for subbase would undoubtedly make road building in this nation much more sustainable. As a result, due to the limitations of COVID-19, this study will assess the geotechnical characteristics of Crushed Brick (CB) and Reclaimed Asphalt Pavement (RAP) with various mixes, and it will be confined to laboratory testing California Bearing Ratio Test (CBR) and constant head permeability test.

The objectives of this study are to determine the stiffness and compressibility in subbase layer of pavement in term of California Bearing Ratio using of Reclaimed Asphalt Pavement (RAP) and Crushed Brick (CB) and to study the impact of the permeability on the variation of mixes of RAP for the pavement subbase layer using constant head method.

2. Methodology

The methodology of the study is detailed out as follow.

2.1. Samples planning and materials selection

The materials used for the subbase layer include reclaimed asphalt pavement (RAP) and crushed waste bricks (CB). The RAP for this study will be obtained with JKR permission to verify that the RAP fulfils the subbase requirement in terms of quality. CB will be gathered at a demolition construction site or in a house restoration area.

2.2. Classifications of parameters

The specimens will be examined in two categories: test from materials and test from a combination. Two different sorts of testing will be done on the combination. The two tests are the California Bearing Ratio (CBR) Test and the Constant Head Permeability Test.

Meanwhile, the materials will be subjected to a sieve analysis test to assess their gradation in compliance with the specifications for the subbase layer of the pavement. All tests must be performed according to the standard technique and protocol indicated in table 1.

Table 1. Standard for test.

Materials/ Products Tested	Testing Types	Standard Test Methods/ Equipment/ Techniques
RAP, CB and Soil	Sieve Analysis of Fine and Coarse Aggregate	ASTM C136/C136M-14
	California Bearing Ratio (CBR) Test	ASTM D1883-16
	Constant Head Permeability Test	ASTM D2434-68 (2006)

One of the study's dependent variables is the percentage of RAP used as a replacement for natural aggregate. Crushed bricks are the constant in this study, accounting for 20% of the total, whereas most earlier experiments employed crushed bricks as a low-percentage element.

Despite the somewhat lower flexural strength, RAP may be included into subbase layers, showing less cracking propensity and enhanced fatigue performance [7]. For subbase coarse aggregates, up to 20% utilisation of coarse aggregates from CB is a viable alternative [8]. Furthermore, sustainable resources like broken bricks and discarded glass may be utilised to partially replace traditional aggregates. As a result, the constant variables in this study will be 20% crushed waste bricks.

2.3. Determination of constant, manipulated and dependent Variables

One of the study's dependent variables is the percentage of RAP used as a replacement for natural aggregate. Crushed bricks are the constant in this study, accounting for 20% of the total, whereas most earlier experiments employed crushed bricks as a low-percentage element. Despite the somewhat lower flexural strength, RAP may be included into subbase layers, showing less cracking propensity and enhanced fatigue performance [7].

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2.4. Testing stage and data management

The specimens have been prepared according to standard procedure and will now be tested. A minimum of four specimens were made for each test and percentage. Overall, including the original subbase material, a total of 48 specimens were prepared and examined. The details number of each sample is shown in table 2.

Table 2. Standard for tests

Specimens Types	RAP Content	CB Content	Sand/ Aggregates	Number of Specimens
1	0%	0%	100%	4+4
2	0%	20%	80%	4+4
3	20%	20%	60%	4+4
4	30%	20%	50%	4+4
5	40%	20%	40%	4+4
6	50%	20%	30%	4+4
			Total Specimens	48

3. Result and Discussion

3.1. California bearing ratio (CBR) test

The CBR test determines a crushed aggregate's or soil's shearing resistance under regulated moisture and density conditions. The test produces a bearing ration figure that is appropriate for the condition of the crushed aggregates or soil being examined. The CBR is calculated by dividing the unit stress necessary to cause a specified depth of piston penetration into a compacted specimen of crushed aggregate or soil at a certain water and density by the standard unit stress required to achieve the same depth of penetration on a standard sample. Figure 1 summarizes the results obtained from the CBR tests.

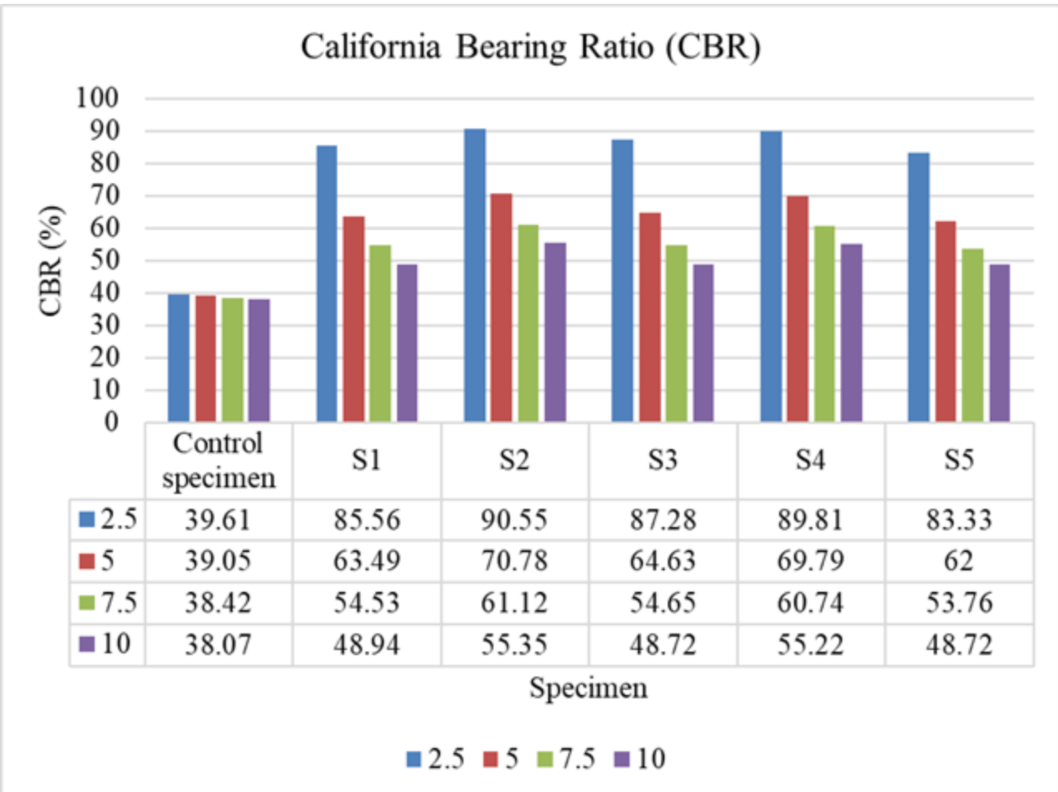


Figure 1. California Bearing Ratio value for different samples

Based on graph shown in figure 1, CBR value in all type of samples are within the range which is more than 30% that can be considered as subbase for flexible pavement. Based on [9] the CBR value at 2.5 mm penetration must be larger than at 10.0 mm penetration. From the result shown in figure 1, every sample at penetration 2.5 mm is greater than at 10.0 mm penetration, which is agreeable with the findings of [9].

Control specimen containing 100% of sand get the CBR value within the range of 38.07% to 39.61% at penetration between 2.5 mm, 5.0 mm, 7.5 mm and 10.0 mm which are suitable for the design pavement with the rating good because more than 30% of CBR value.

For specimen 1, which contains 20% of crushed brick, 0% of reclaimed asphalt pavement and 80% of sand are also in range of CBR value. Therefore, the CBR value at penetration 2.5 mm is 85.56% is larger than at 10.0 mm penetration which is 48.94%. Moreover, all samples in this specimen are over 30% of CBR value which is suitable for the design pavement with the rating excellence and good.

Among all the specimens, specimen 2 which replaces the soil aggregate with 20% of crushed brick, 20% reclaimed asphalt pavement and 60% of sand showed the best result. This is because, in this testing the CBR value get the highest value rather than other samples which is 90.55% at penetration 2.5 mm, 70.78% at penetration 5.0 mm, 61.12% at penetration 7.5 mm and 55.35% at penetration 10.0 mm. The higher the CBR value, the higher the stiffness, compressibility, and optimum dry density. Therefore, the specimens are suitable for design pavement with the excellence and good.

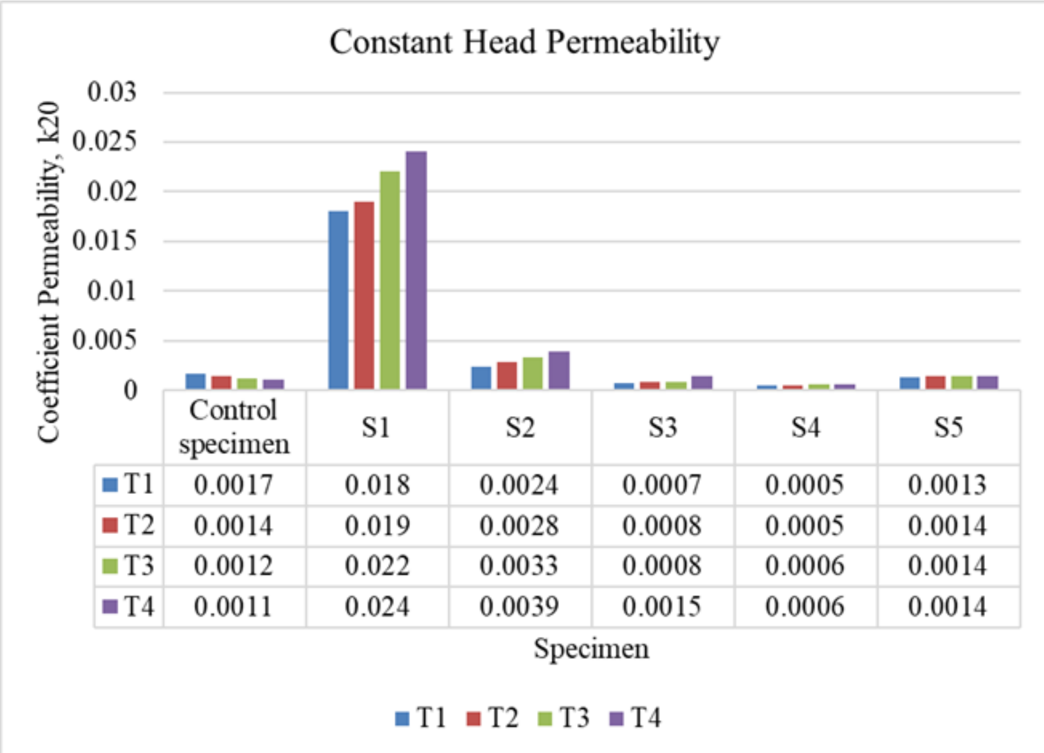
The CBR value in specimen 3 that contains 20% of crushed brick, 30% of reclaimed asphalt pavement and 50% of sand at penetration 2.5 mm is 87.28% is larger than penetration at 10.0 mm which is 48.72%, which is greater than 30%. Hence, the specimen is suitable for design pavement with the excellence and good rating.

In specimen 4, 20% of crushed brick, 40% of reclaimed asphalt pavement and 40% of sand have been replaced. CBR value at 2.5 mm penetration is 89.81% is larger than penetration at 10.0 mm which is 55.22%, which is also greater than 30%. This indicates that the specimen is suitable for design pavement with the excellence and good rating.

Specimen 5 contains 20% of crushed brick, 50% of reclaimed asphalt pavement and 30% of sand. At penetration 2.5 mm CBR value is 83.33%, 62% at penetration 5.0 mm, 53.76% at penetration 7.5 mm and 48.72% at penetration 10.0 mm. Therefore, CBR value at penetration 2.5 mm is larger than the CBR value at penetration 10.0 mm. It can be concluded that since all the samples get the CBR value upper than 30%, the specimens are suitable for design pavement with the excellence and good rating.

3.2. Constant Head Permeability test

For the laminar flow of water through soils, this test technique involves the calculation of the coefficient of permeability using a constant head method. The approach is designed to determine typical coefficients of permeability of soils that may be found in natural deposits, embankments, or as subbase courses under pavements. Figure 2 summarizes the results obtained from the Constant Head Permeability tests.



	Control specimen	S1	S2	S3	S4	S5
T1	0.0017	0.018	0.0024	0.0007	0.0005	0.0013
T2	0.0014	0.019	0.0028	0.0008	0.0005	0.0014
T3	0.0012	0.022	0.0033	0.0008	0.0006	0.0014
T4	0.0011	0.024	0.0039	0.0015	0.0006	0.0014

Figure 2. Constant Head Permeability value for different samples

Based on figure 2, the best replacement of soil aggregate is when replace it with 20% of crushed brick and no replacement of reclaimed asphalt pavement. However, based on [4], the best replacement is with 50% of reclaimed asphalt pavement. This is because, there are several factors that affecting permeability such as particle size distribution, particle shape and texture, mineralogical composition, voids ratio, degree of saturation, soil fabric, nature of fluid, type of flow and temperature. For instance, the permeability of a soil is influenced by its particle size distribution, and especially by the coarse aggregate.

The bigger the particles, the bigger the voids between them, and therefore the resistance to flow of water decreases or the permeability increase with decreasing particle size. [10] stated that, the effect of particle shape. Elongated or irregular particles create flow paths which are sharper than those around nearly spherical particles. These effects tend to reduce the rate of flow of water through the soil.

Moreover, based on [11], 50% of reclaimed asphalt pavement and 20% of crushed brick are suitable because it is a coarse gravel particle rather than sand. The probability coefficient of permeability will occur is more than 10^{-1}. Therefore, it is very pervious and high permeability as a good drainage.

Next, there are several tests to measure the permeability which are, constant head permeability, pump test in situ and estimation from grading curves. However, in laboratory just had the constant head permeability testing and that’s the reason why constant head permeability is chosen as a test to measure the permeability.

Based on the graph shown in figure 2, the highest permeability among all the specimen is 20% contains of crushed brick. As a result, errors in permeability measurements could occur. However, all the specimen is suitable to be replacement as it still meets the standards for design pavement with the rating a good drainage because of the probability average value coefficient of permeability will occur is 10^{-1} to 10^{-3} in all the specimen.

4. Conclusions

The influence of the two manipulated parameters namely the California Bearing Ratio (CBR) test and constant head permeability test towards the replacement of soil aggregate which is crushed brick and reclaimed asphalt pavement. The correlation between the parameters and the replacement of soil aggregate as specified in the objectives are emphasized through graph.

The first parameter is the California Bearing Ratio (CBR) test. Six samples testing are 100% of sand, 20% of crushed brick and 0% of reclaimed asphalt pavement, 20% of crushed brick and 20% of reclaimed asphalt pavement, 20% of crushed brick and 30% of reclaimed asphalt pavement, 20% of crushed brick and 40% of reclaimed asphalt pavement and lastly 20% of crushed brick and 50% of reclaimed asphalt pavement. Based on the test result the California Bearing Ratio (CBR) decrease as the penetration increase. For all the replacement of the soil aggregate towards the CBR test, the CBR value in all type of samples are within the range which is more than 30% that can be considered as subbase for flexible pavement.

The second parameter is the constant head permeability. A 20% of crushed brick is used for all the testing except for the control specimen. Four replacements of the reclaimed asphalt pavement in testing are 20%, 30%, 40% and 50%. From the test result it is shown that the higher the coefficient of permeability, the higher the hydraulic gradient. However, when without replacement of reclaimed asphalt pavement is tested, it may cause a low permeability than with the replacement of the reclaimed asphalt pavement. This is because, the permeability of a sand is influenced by its particle size distribution, and especially by the finer particles. The smaller the particles, the smaller the voids between them, and therefore the resistance to flow of water increases which is permeability decrease with decreasing particle size. For all specimen tested towards the constant head permeability containing 20% -50% of reclaimed asphalt pavement, the high permeability in replacement the soil aggregate is 50%.

The findings of this study denote that partial replacement of Natural Aggregates in Subbase Layer with RAP and CB can indeed contributes towards fulfilling the fundamental requirements of Subbase Layer while saving the construction costs by utilizing waste materials, thereby improving sustainability in Construction Industry by reducing the portion of naturally resourced materials.

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