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Bitumen Stabilised Open Graded Base Materials

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ABSTRACT: Roads play a crucial role in fostering economic growth and providing social advantages in every nation. However, over time, road infrastructure can become outdated. According to studies conducted by World Highways, a road may seem to be in good condition on the surface while hiding a severe issue beneath. As a result, periodic maintenance, repairs, or modernization may be necessary for road structures. The primary purpose of this project was to investigate the effects of permeability on road base materials by removing particles and restoring strength through stabilization with bitumen. Optimum grade 60/70 bitumen was used in compliance with Malaysia JKR specifications to create a realistic case scenario. The formulation excluded open-graded road base material with particles smaller than 1.18 mm or 2.0 mm, and bitumen stabilization levels of 0%, 2%, 2.5%, and 3% were implemented to reduce the decrease in mechanical strength. The mechanical strength was determined using the California Bearing Ratio (CBR) test, while a Constant Head Method Permeability test was conducted to identify the optimal design mix with the maximum achievable permeability coefficient. The results showed that bitumen stabilization increased the mechanical strength of the road base material, with the highest result compensating for the drop by 8.7%. With open-graded road base material, the permeability can be increased by up to 17.2%. Therefore, open-graded road foundation material with bitumen as a binder for stabilization can be used in the construction of pavements in Malaysia, an area with relatively high rainfall intensity.

KEYWORDS: Open graded; road base; bitumen; stabilisation; permeability; California bearing ratio.

1. Introduction

Climate change has been shown to have a significant impact on the weather patterns in Malaysia, resulting in rising temperatures and changes in rainfall patterns that lead to more extreme weather events like floods and landslides. Furthermore, Malaysia is susceptible to tropical storms and typhoons, particularly along the eastern coast of the peninsula and in Sabah and Sarawak. These weather patterns can significantly impact the country's infrastructure, including roads, bridges, and buildings, highlighting the need to incorporate climate resilience measures in construction and planning processes [1].

Due to the unpredictable nature of precipitation intensity, the functional capacity of road structures is insufficient, especially for road drainage functionality. The poor permeability of road structures causes water to accumulate on the road surface during sudden downpours. This stagnant water accelerates the structure's deterioration relative to natural aging [2, 3]. The road base is one of the pavement's layers, consisting of aggregates, crusher run, and occasionally quarry dust. Coarse and fine particles are compressed at this layer, with fines used to fill the spaces between coarse aggregates [4, 5]. The layer is generally compacted in compliance with state-specific norms, which can reduce the mobility of aggregates. Good compaction is necessary to minimize the sliding of coarse aggregates against one another, which can reduce the structure's lifespan. The base layer of a pavement provides structural support, strength, and drainage, with spaces in the subsurface layer facilitating drainage. Fine aggregates maximize structural strength support by minimizing the sliding of coarse aggregates against one another [6, 7].

Open graded materials are commonly used in road construction, particularly in areas with high rainfall or poor soil conditions, as they effectively drain water away from the road surface and prevent water damage to the underlying layers of the road. Additionally, open graded materials are known to reduce the risk of hydroplaning, which occurs when a layer of water forms between the tire and road surface, causing the driver to lose control of the vehicle. However, it is important to note that open graded materials may not be suitable for all road construction applications and that factors such as traffic volume and the type of vehicles using the road must be taken into consideration when selecting materials for road construction [8, 9].

The base layer primarily consists of aggregates, lacking tensile strength, which can cause the base layer to segregate once loads are applied to the pavement surface. Continuous crushing by the vehicle's weight can cause aggregates to slide against one another, resulting in fatigue. Bitumen, with its tensile strength, shear strength, and cohesive strength capacity, can act as a binder to hold aggregates in place [10, 11]. The binder's cohesive qualities can extend the base layer's lifespan. The study aims to investigate the enhancement of road base materials' permeability by removing particles and restoring strength loss by stabilizing with bitumen. The project involves quantitative research and experimentation, focusing primarily on the permeability of road base and the evaluation of the layer's strength with general gradation and open graded base materials.

2. Materials and Methods

2.1. Materials selection.

In regards to the base course layer of the pavement structure, it is primarily composed of aggregates. In an open graded base course structure, the ratio of coarse aggregates is higher in comparison to the fine particles [12]. In open graded aggregates, the fine aggregates in the mixture, which are aggregates that pass through a 4.75mm sieve during testing, are removed. Conversely, open graded aggregates include a smaller amount of filler, resulting in a higher void ratio once compacted. It is crucial to grade the aggregates according to the specifications provided. The maximum density standard should be close to $n = 0.45$ to ensure optimal functionality of the pavement base course structure. It is mandatory to follow the state authority's requirements, not just for open graded materials pavement but also for regular granular pavement structure [13]. However, practical considerations have resulted in the exclusion of only fine aggregates with particle sizes below 2.0 mm in this Malaysian study. Literature evaluations have revealed that removing fines aggregates from base course materials could decrease their mechanical strength. To achieve the optimal design mix, only a fraction of the fines aggregates were removed.

2.2. Aggregates and bitumen composition.

Prior to preparing the sample batches, the aggregate proportions were established. Three separate mixtures were created, with varying proportions of fine particles removed to alter the mechanical strength of the samples, based on earlier research. Consequently, three distinct aggregate mixtures were formed for this project: fines removed up to 1.18mm and 2.0mm, and a control sample with no removal of fine particles. Each mixture had a unique aggregate composition and was stabilized with a variable percentage of bitumen relative to the aggregate mass. The composition of the bitumen used for each sample was as depicted in the table below. Each mixture was stabilized with 2%, 2.5%, and 3% bitumen, respectively, while a non-stabilized mixture was used as the control sample [14].

2.3. Sieve analysis and bitumen stabilisation.

To attain the desired particle size distribution of the aggregates, unwanted aggregate sizes were eliminated through sieve analysis following the standards of ASTM C136 and C136M-14. Verification of material selection was documented by conducting an initial sieve analysis, and a grading curve was generated by weighing each aggregate mass retained on the sieve. In preparation of the material, the fine particles described in the preceding chapter were removed by sieving the aggregates using a shaker and sieve that comply with ASTM C 136 [12, 15], as shown in the diagram below. The molds were preheated to 120°C for at least ten minutes to stabilize them. The binder used was Bitumen Grade 60/70 supplied by Borneo Hot Mix Sdn. Bhd., heated in a hot air oven to 170°C to achieve the recommended mixing temperature. To ensure thorough mixing, the bitumen was heated until fully liquefied and continuously heated with a Bunsen burner during the stabilization process to prevent a sudden drop in temperature. The proportion of bitumen stabilization was determined by comparing the aggregate weight to the binder weight. After heating and mixing the bitumen with the aggregates, the mixture was poured into preheated molds for compaction.

2.4. California bearing ratio test (CBR).

The mechanical strength of the samples prepared was evaluated using the CBR. Without stabilization, the CBR index of the general aggregates would decline on average by 80. The CBR test involved determining the force required to penetrate a sample to a depth of 2.5mm and 5mm. For the test, the sample was cast in a 100mm-diameter by 62.5mm-tall CBR mold. The CBR difference was determined by evaluating the CBR of soaked and unsoaked samples. The samples were kept in the CBR curing tank for four days or 96 hours, with the water level being maintained [16]. The CBR index due to a 2.5mm penetration was calculated using the equation provided in the ASTM standards mentioned above. The CBR index due to a 5.0mm penetration was also determined using the same equation but with a different constant for the unit standard load, as CBR 2.5 and CBR 5.0 have different constants.

Calculation of the CBR test in terms of standard pressure load is possible [12]. An Excel sheet was used to simplify the computation of pressure, and it is attached in the appendix. The standard load in kgf and kg/cm2 units is displayed in the table below. If CBR 5.0 was greater than CBR 2.5, the test was repeated as per ASTM guidelines. If the test yielded a similar outcome, CBR 5.0 was utilized. During the experiment, any CBR 5.0 sample that generated a higher value than CBR 2.5 was retested using a fresh sample, as shown in the following equation:

$$CBR\ (\%) = \frac{Corrected\ Load\ Value}{Standard\ Load}\ x\ 100 \qquad (1)$$

2.5. Constant head method test.

In addition to particle size and void ratio, other factors such as the degree of compaction, the presence of fines, and the type of binder used can also affect the permeability of the sample. For example, poorly compacted samples may have higher permeability due to the presence of larger voids. Similarly, the presence of fines can clog up the voids and reduce permeability, while the use of an effective binder can help to improve the sample's overall stability and reduce permeability. It is important to consider all of these factors when designing and evaluating open graded base materials for use in construction projects [17, 18].

The sample was examined in a permeability cell, and water was made to flow through it from a constant level tank or a constant flow rate water supply. A steady hydraulic pressure was applied to the sample to attain a saturation rate [15]. The sample was allowed to achieve complete saturation, and the time it took for 1000 ml of fluid to pass through the sample cell was recorded. This process was repeated multiple times, and the best results were used to improve the consistency of the findings. High permeability functionality is recommended for pavement foundation courses to allow water to drain quickly from the structure. The mechanical properties of the base course structure can be affected by the amount of water absorbed by the structure, as demonstrated by prior studies. It was found that the soaking CBR index decreases by around 10 CBR units, indicating a decrease in mechanical strength as water penetrates a structure, leading to eventual failure [19].

The diagrams show the equipment used for the Constant Head Method test. The sample height was set between 7 and 12 mm due to the height restriction of the permeability cell. According to ASTM regulations, the sample height should be greater than twice its diameter; hence, samples were cast with a minimum height of 7mm. As there were no steel molds available for the bituminous sample, a 63.5mm-diameter steel cylindrical pipe was used to cast the sample [13]. After 24 hours, the sample was extracted from the steel mold using a piston.

$$K = \frac{QL}{tHA} \qquad (2)$$

Where, K is coefficient of permeability (cm/sec), L is length of specimen (cm), t is elapsed Ttime (sec), Q is volume of discharge (cm^3), A is cross sectional area of specimen, H is hydraulic head difference across length (L in cm of water)

3. Results and Discussion

3.1. Sieve analysis.

This study utilized aggregates obtained from Borneo Hot Mix Sdn Bhd, a company located in Kuala Baram, Miri, Sarawak, Malaysia, known for supplying good quality aggregates suitable for pavement construction in Malaysia. Sieve testing was conducted on all aggregates to ensure their optimal appropriateness as pavement base course. The n value for grading curves should be between 0.3 and 0.5, with any value less than 0.3 indicating less stability in wet conditions and any value greater than 0.5 indicating poor stability due to excessive porosity and stoniness. The ASTM requirements for sieve analysis were followed, with 15 kg of aggregates taken for testing. The trial findings showed that both the 37.5mm and 19mm sieve sizes had a passing rate of 100%, while the sieve with a mesh size of 4.75mm had a cumulative percentage of approximately 53%, indicating a positive outcome [21, 22]. The results indicate that as sieve sizes become smaller, the grading curve approaches the upper limit (n=0.5) of the grading envelope. In the final sieve pan, less than 1% of particles were present, and the grading curve fit nicely within the maximum density envelope. Deviation from the maximum density curve's upper limit was deemed inconsequential [23, 24]. However, the focus of this study was on batches of fines smaller than 2.0mm and 1.18mm. The CBR test was utilized to evaluate the impact of these fines on the material's mechanical strength, and the Constant Head Method Test was performed to determine the material's permeability coefficient.

3.2. CBR test.

Multiple CBR tests were conducted on each batch of base course samples, and the top five results were tabulated to obtain an average CBR value. The CBR values were then used to determine the suitability of the base course material for various engineering applications, including road construction, airfield pavements, and other heavy-duty applications. The results of the CBR tests provided valuable insights into the strength and stability of the base course material under different loading conditions and helped optimize the design and construction of the road network. Table 1 displays the CBR values required for different types of roads according to Austroads specifications for road base materials. For the first batch of samples, a complete mixture of fine and coarse aggregates without stabilization was cast into cylinders of the appropriate CBR size. After settling for 24 hours, the mechanical properties of all unsoaked samples were evaluated (Figure 1).

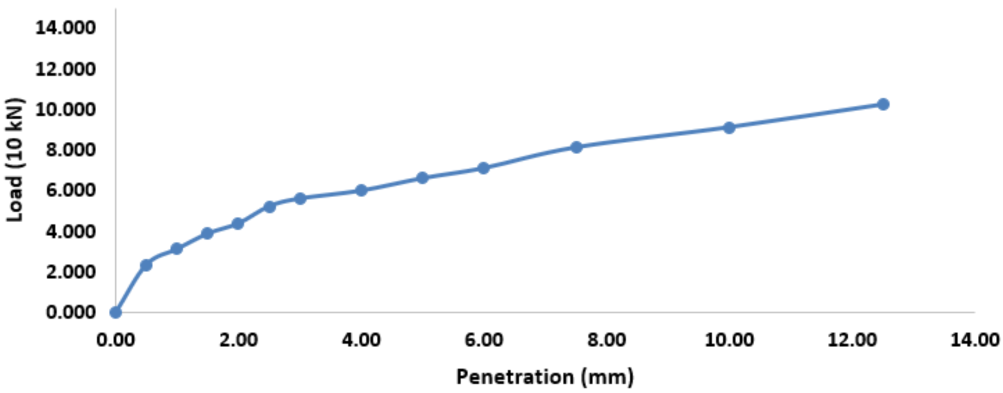

Figure 1. Load Vs penetration graph for control sample (soaked CBR).

Table 1. CBR value – control sample.

Penetration (mm)	Load (kN)	CBR (%)
2.5mm	52.2	96.38
5.0mm	64.5	81.65

The results presented in Table 1 illustrate the outcomes based on the control sample, which was characterized as an unstabilized mixture. In this section, samples with equivalent quantities of bitumen stabilization but differing aggregate mixtures were compared to the control sample, and the comparison graphs were tabulated to enhance readability. It was observed that as the proportion of aggregate mix changed, the load required to penetrate the samples at different depths decreased. Furthermore, a greater reduction in load was observed in soaked samples than in unsoaked samples. The force required to penetrate the sample at various depths increased with a larger quantity of bitumen stabilization added to the sample. CBR values were computed using the CBR equation and are presented in Table 2. Upon further examination of the CBR values, it is evident that the values exhibit an upward trend as the proportion of bitumen stabilization increases. Meanwhile, the percentage of aggregates in each sample did influence the CBR values. A decrease was observed in the CBR value proportionate to the percentage of fine aggregates removed, as compared to control samples [25, 26].

Table 2. Summary of average CBR values.

Treatment	Soaked CBR (%)	Unsoaked CBR (%)
Full Mix without Stabilisation (Control Sample)	94.62	N/A
Fines with < 1.18mm Removed without Bitumen Stabilisation	66.24	N/A
Fines with < 2mm Removed without Bitumen Stabilisation	61.73	N/A
Fines with < 1.18mm Removed – 2.0% Bitumen Stabilisation	69.97	75.92
Fines with < 1.18mm Removed – 2.5% Bitumen Stabilisation	76.11	82.13
Fines with < 1.18mm Removed – 3.0% Bitumen Stabilisation	82.17	90.52
Fines with < 2mm Removed – 2.0% Bitumen Stabilisation	66.05	70.93
Fines with < 2mm Removed – 2.5% Bitumen Stabilisation	71.22	76.44
Fines with < 2mm Removed – 3.0% Bitumen Stabilisation	76.44	83.28

3.3. Permeability test – constant head method test.

The permeability tests were conducted using the constant head method, and the permeability coefficient (K) was measured and tabulated for each sample. Multiple tests were performed, and the five closest results were used for calculating purposes with Equation 2. The data showed that the coefficient of permeability of the samples increased as the finer particles were removed. Without bitumen stabilization, the increase was as high as 17%. However, samples with varying amounts of bitumen stabilization showed a modest decrease. Figure 2 presents a graph comparing the proportion of aggregate mixing and the percentage of bitumen stabilization in terms of weight. The gradient of coarse aggregates was steeper, and the ratio of coarse aggregates to fine aggregates was substantially larger. As seen, the curve fit nicely within the maximum density envelope, and the value of the exponent, n, based on the curve was found to fall within the range specified in earlier literature. According to Hamid, a well-designed particle size distribution for a road base course material should have a curve within the range of 0.3 to 0.5 since any curve with an n value less than 0.3 is considered to contain too many fines, while any curve with an n value greater than 0.5 contains too many coarse aggregates. Based on the findings, the aggregates used in this study can be considered well-designed. The optimal grading curve obtained in the preceding chapter indicated a well-designed particle size distribution for a road base course material. This allows the particles to fill the voids created by the interparticle interaction of aggregates of larger sizes, resulting in a close packing ratio [25, 26].

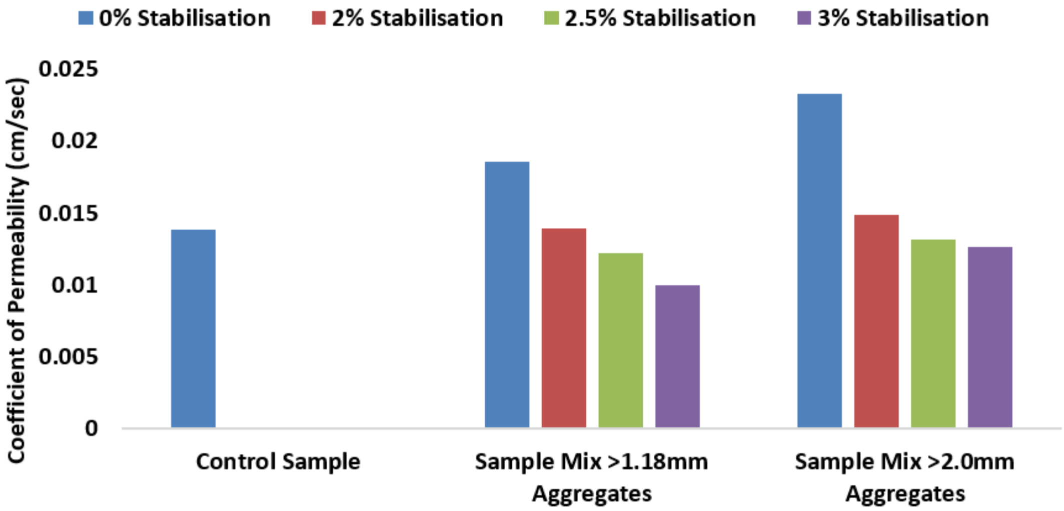

Figure 2. Permeability coefficient comparison graph with varying aggregates mixture proportion & stabilisation.

In contrast, the open-graded base course material used in this research study had to be free of aggregates with particle sizes between 1.18 and 2.0 millimeters to achieve a higher void ratio. As more fine aggregates were extracted, the void ratio increased, thereby enhancing the material's permeability. Throughout the research project, the fraction of fines removed from the base course material significantly affected the CBR values, which represent the mechanical strength of the road base material. The CBR values decreased as a higher proportion of road base material was removed as fines. The comparison graph shows that the CBR test load required to pierce the sample decreased as the amount of fines removed increased, indicating a decrease in the packing ratio and maximum density friction, as mentioned in the previous section of the research review. Reducing the packing ratio enhances permeability [25–27].

The experiment demonstrated that stabilization using bitumen as a binder could increase the mechanical strength of the road base material. Bitumen grade 60/70 was chosen for stabilization due to government regulations for the asphaltic surface friction course layer. For future construction convenience, bitumen with the same grading could be used to stabilize the road base course. Bitumen stabilization was able to mitigate the decline in CBR values as more particles were eliminated. A smaller decline in the CBR values was observed when a greater proportion of bitumen was used to stabilize the material. In terms of soaking CBR values, bitumen stabilization at 2%, 2.5%, and 3% resulted in 71.82%, 78.09%, and 83.26%, respectively, for the batch of samples where particles smaller than 1.18mm had been removed. For the batch of samples where particles smaller than 2mm had been eliminated, wet CBR values of 67.39%, 73.66%, and 78.09% were obtained for 2%, 2.5%, and 3% bitumen stabilization, respectively. The control sample, which was a complete mixture of aggregates supplied by the supplier, had a wet CBR value of 96.37% compared to the samples subjected to various amounts of bitumen stabilization [21, 24, 25].

Based on the experimental findings of this research project, it was concluded that the removal of fines smaller than 1.18mm in particle size led to a 25% decrease in soaked CBR values. However, increasing the bitumen stabilization by 0.5% resulted in an 8.7% increase in CBR values, indicating that bitumen was effective in countering the negative impact of fines removal. In the stabilization process, bitumen acted as a binder and coated the surface of aggregates, enhancing the cohesive strength between particles, preventing them from sliding against each other, and increasing the road base material's mechanical strength and durability. This experiment highlighted the effectiveness of bitumen stabilization in road construction [18, 20].

Wet CBR samples were used as standards for road base materials and for comparison purposes, owing to the characteristics of road base materials. When water permeates the pavement due to surface runoff, it causes a decrease in the mechanical strength of the road base, resulting in lower wet CBR values. Although the soaking CBR value of the materials was found to be less than the minimum value of 80 prescribed by the Austroads Standards, this design can still be used as a road base design combination in Malaysia. According to the structural design approach for Malaysian pavements, increasing the thickness of the road base layer can enhance the mechanical strength and load-bearing capacity of the road base.

Permeability is considered one of the advantages of using open-graded road base materials [26, 27]. Finer aggregates can pass through the voids between larger aggregates, reducing the sample's void ratio and resulting in a higher packing ratio. The study found that materials with a higher packing and lower void ratio had lower permeability compared to those with a higher void ratio. Samples with no particles had the lowest permeability coefficients, while the coefficient of permeability increased as the proportion of removed particles increased. The coefficient of permeability was the highest for samples that had not undergone any stabilization process and had particles smaller than 2mm removed. Samples with particles smaller than 1.18mm removed had a slightly lower coefficient of permeability but were still higher than the control mix containing all fines. Permeability improved by 8.7% for samples with 1.18mm particles removed and 17.2% for samples with 2.0mm fines removed compared to the control mix with a coefficient of permeability of 0.00814 cm/sec. Figure 2 shows an upward trend in the blue comparison graph. As mentioned earlier, the removal of particles affected the CBR values, which represents the mechanical strength of the materials. To restore the material's reduced mechanical strength, bitumen was used as a binder during the stabilization process. According to the experimental results, the stabilization had a minimal impact on the coefficient of permeability of the samples. With an increase in bitumen content, the permeability coefficient of the treated bitumen stabilization sample decreased slightly [26, 28]. The least reduction in the coefficient of permeability was 8.6%. The experimental results showed that the permeability decreased with an increasing bitumen stabilizing fraction. The primary goal of bitumen stabilization in this research project was to increase mechanical strength. This binder filled the voids between the particles, resulting in a low permeability coefficient [29–31]. However, this slight loss in permeability due to binder filling the voids had little effect, resulting in a coefficient of permeability within the acceptable range.

4. Conclusions

The removal of fines smaller than 1.18 mm particle size was observed to lead to a decrease in the California Bearing Ratio of open-graded road base materials. However, this decline was mitigated by incorporating a binder into the materials, and for this study, the bitumen stabilization technique was chosen to facilitate future construction projects. The optimal proportion of bitumen stabilization was found to be 3%, resulting in a 13.74% increase in mechanical strength for materials with fines smaller than 1.18 mm eliminated. However, samples stabilized with 3% bitumen did not exhibit the same level of improvement after removing fines with particle sizes smaller than 2mm. Consequently, the removal of fines smaller than 1.18 mm particle size, when combined with the appropriate amount of bitumen stabilization, led to the least decline in mechanical strength, yielding positive results. The permeability test revealed that the maximum permeability coefficient was observed for materials with fines smaller than 2 mm eliminated. The trend showed that as a greater proportion of fines were removed, the coefficient of permeability increased. The most significant improvement in permeability for the road base materials was a 17.2% increase for those with fines smaller than 2 mm eliminated. The use of bitumen as a binder in the stabilization process did not significantly contribute to the reduction in the material's coefficient of permeability, indicating that bitumen has the potential to serve as an effective binder in stabilizing open-graded road base materials.

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Conflicts of Interest

The authors declare no conflict of interest.

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