JETIR.ORG ISSN: 2349-5162 | ESTD Year : 2014 | Monthly Issue
JOURNAL OF EMERGING TECHNOLOGIES AND INNOVATIVE RESEARCH (JETIR)
An International Scholarly Open Access, Peer-reviewed, Refereed Journal

ANALYSIS ON THE STABILIZATION OF SUBGRADE SOIL USING RECLAIMED ASPHALT PAVEMENT

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Abstract:There are approximately 5.90 million kilometers of roads in India, with 300,000 kilometers comprising National Highways (NH) and State Highways (SH). As a result of an increase in traffic flow and the ageing of bituminous surfaces, the majority of these road segments are currently under resurfacing, rehabilitation, and upgradation (4/6 laning). Massive amounts of aggregates and asphalt binder are needed for all of these tasks. On the other hand, when current highways are upgraded (4/6 laning), large sections of bituminous pavement are buried to make room for new facilities such as flyovers, vehicular underpasses (VUPs), pedestrian underpasses (PUPs), and more. As bituminous pavement ages, it becomes necessary to mill or remove it before resurfacing or rehabilitation can begin. Reclaimed asphalt pavement (RAP) allows for the possible reuse of old bituminous pavement materials that are buried during up gradation (4/6laning) and milled or removed during resurfacing or rehabilitation. In addition to protecting the environment and reducing construction costs, reusing RAP in pavement construction also decreases the necessity of virgin materials, which helps preserve natural resources for future generations and eliminates waste. Subgrade, granular subbase, base course, and bituminous binder course are the four layers that make up flexible pavement. RAP can be utilized in each of these layers. Subgrade, granular subbase, and base course applications of RAP with reinforcing elements can improve the performance of flexible pavement. Because of its lower unit rates, RAP does not significantly increase the financial advantage when used in subgrade construction. In contrast, bituminous binder course manufacture requires RAP of exceptionally high quality with consistent characteristics. Therefore, the purpose of this research is to investigate the potential use of RAP in the building of Flexible Pavement's granular Subbase and Base course. Mixing RAP with Crushed Stone Aggregates (CSA) and/or stabilizing it with a small percentage of cement improved its California Bearing Capacity Ratio (CBR) and Unconfined Compressive Strength (UCS) value, making it suitable for use in the construction of granular Subbase / Base course of Flexible Pavement. However, untreated RAP was not deemed suitable for this purpose. Pavement alternatives that used stabilized RAP as subbase, consisting of 50% RAP, 50% CSA, and 4% cement, outperformed traditional flexible pavement with granular subbase in terms of predicted pavement life. iv The findings of the model experiments show that when compared to unreinforced WMM materials laid over a soft marine clay bed, the load settlement characteristics of RAP and mixtures of RAP and Wet Mix Macadam (WMM) reinforced with Polymer geogrid, Polymer geocells, Bamboo geogrid, and Bamboo geocell are superior. So, instead of using traditional WMM foundation materials for Flexible Pavement construction, you can utilize polymer- reinforced aggregate (RAP) or a blend of RAP and WMM (50:50). Bamboo geogrid and bamboo geocell are reinforcing materials that are treated with bitumen emulsion to make them more durable. In contrast, polymer reinforcements are not biodegradable. When compared to traditional flexible pavement with granular subbase, alternative pavement choices using stabilized RAP as subbase are approximately 36% more cost effective, according to market- based cost analyses. Similarly, when compared to traditional flexible pavement with granular subbase, the use of polymer/bamboo geogrid and geocell reinforced RAP as subbase had the potential to reduce costs by around 11.50%.

INTRODUCTION

1.1 Context Nearly 5.90 million miles make up India's road network. Along with 1,90,000 km of state highways, 1,10,000 km of national highways, and 56,000 km of main district roads, rural roads, and urban roads, there are a total of 56,000,000 km of roadways. Flexible pavement with bituminous surface is used for the majority of the NH, SH, and main district roads. These bituminous surfaces need repair, reinforcement, and expansion to accommodate an upgraded carriageway design as a result of ageing and heavy traffic increase. Massive amounts of aggregates and bituminous binder, two building components derived from naturally occurring resources, are needed for all of these endeavors. Reclaimed Asphalt Pavement (RAP) is an important alternative to new asphalt since road authorities and engineers are under pressure to find cheaper and more sustainable building materials due to rising prices and dwindling supplies of natural asphalt. When reinforcing, repairing, or reconstructing an asphalt pavement, the old materials are often removed. Recycled Asphalt Pavement (RAP) is the final product of processing used bituminous materials after their removal from old pavement. The asphalt binder and aggregate in RAP are excellent alternatives to the more costly virgin materials used to make hot mix asphalt (HMA). It is essential to handle RAP stock piles properly to prevent performance-affecting mix heterogeneity (Valdes et al., 2010). 2 The mixture's fatigue resistance is worsened because RAP reduces ductility while increasing HMA's stiffness (Leandri et al., 2012). The currentresearch is centered around the utilization of RAP as a granular subbase or base course in the construction of flexible pavements. The use of 100% RAP in the subbase and base course of flexible pavement is not recommended, according to the literature (Monteparra et al., 2012). For it to be appropriate for use as a subbase or base course of flexible pavement, it must be mixed with virgin aggregates (McGrrah, 2007) or stabilized with cement (Taha et al.,2002) or flyash (Saride et al., 2015). Many things affect the amount of RAP that gets recycled and used in flexible/bituminous pavement. Cost savings in road development and environmental protection are two of the most important considerations. The aggregates and bitumen in RAP can be used in different layers of asphalt pavement. Nonetheless, RAP's qualities, notably its consistency, dictate its application in pavement layers. Since RAP is a byproduct, including it in pavement layers lowers the overall cost of pavement building. Similarly, recycled aggregate pavement (RAP) helps preserve the environment by reducing the need for virgin aggregates in pavement building. On top of all that, there are less problems with debris disposal when RAP is used in pavement. The stabilization of loose soil during road building has been accomplished globally with the use of geosynthetic materials. Geosynthetics, when placed at the junction of subgrade and subbase or base, prevent the two materials from mixing by acting as a separator. Pavement performance is enhanced in this way. Geogrid can be used to reinforce subgrade, granular subbase, and base, which can improve their performance. Studies have shown that load bearing capacity is improved when polymer reinforced RAP base is placed on a weak subgrade (2% CBR) compared to unreinforced RAP (Thakur et al., 2012). Bituminous surfacing also benefits from the use of glass grid or geogrid to delay reflection cracking and improve performance (Khodai et al., 2009). Separation, filtration, drainage, reinforcing, and other roles are performed by geosynthetics in pavement. 3 Part 1.2: Goals The current investigation aims to accomplish the following: a. Research on the effects of using RAP as a base or subbase course material for flexible pavements. b. To determine if the mixture is suitable for use as a subbase course of flexible pavement by studying the effects of mixing RAP with Crushed Stone Aggregates (CSA) and stabilizing it with cement. c) To investigate how a combination of a soft marine clay substrate and RAP bases reinforced with polymer geogrid, bamboo geogrid, polymer geocells, and bamboo geocells affects their load-bearing capacities. d. Investigate the viability of utilizing RAP (reinforced asphalt pavement) instead of granular subbase or base of flexible pavement.

1.3 The Advantages of RAP for Pavement Use The following are some of the advantages of RAP (Reclaimed Asphalt Pavement): a. Financial gain: Pavement building operations necessitate virgin aggregates and bitumen. Aggregates and bitumen, which are essential components of pavement, are finite resources that are being steadily depleted as a result of rising demand. The price of materials used to build roads is going up because natural resources are becoming increasingly scarce. It is possible that in this case, money could be saved by reusing RAP. section b. Embankment or fill The subbase, base, and bituminous course of a flexible pavement are typically constructed using high-quality, homogenous RAP. On the other hand, granular RAP can also be utilized as embankment fill. c. Positive impact on the environment: Pavement construction that makes use of recycled aggregates (RAP) uses less virgin aggregates. Natural resources are conserved, and the ecosystem is protected, as a result. d. Practical advantage: research has shown that HMA made from RAP effectively minimizes rutting in flexible pavement. Use of RAP in subbase and base has the potential to reduce costs, according to numerous research. 4 e. Energy conservation: Using RAP in pavement construction can reportedly result in savings of 25–40% in energy use. A number of layers of flexible pavement can incorporate RAP, including: i. Subbase and base granular aggregate: Several studies have shown that untreated RAP is not appropriate for the subbase and base course of flexible pavement, primarily because it does not meet the CBR and graduation requirements. On the other hand, a flexible pavement's subbase or base course can be RAP mixed with virgin aggregates. ii. Base and subbase stabilization: As mentioned before, untreated RAP is not an appropriate material for the base and subbase courses of flexible pavement. But, with the appropriate cement/flyash treatment, RAP can serve as a stabilized subbase or base with an interlayer to alleviate cracks. iii) RAP holds aggregates and bitumen, which are added to asphalt cement for a more durable concrete. The manufacturing of HMA for use in the binder course (DBM layer) can thus make use of high-quality uniform RAP. Thus, in order to make HMA, bitumen and aggregates found in RAP are both used. 1.4 Pavement Geosynthetics Bituminous surfacing (wearing and binder course), base course, granular subbase, and subgrade are the four separate layers that make up a standard system for flexible pavement. For the most part, geosynthetics have improved the drainage, separation, filtration, and reinforcing capabilities of flexible pavements. In order to improve the performance of pavements, geosynthetics have been utilized as a layer separator between granular subbase and subgrade. By preventing soil particles from migrating to the subgrade and facilitating water passage to the nearby subbase material, geosynthetics can double as a filtering layer. Another application for geosynthetics is reinforcing flexible pavement. When it comes to geosynthetics, geogrid is by far the most common material used to reinforce pavement. Unreinforced flexible pavement experiences more strains over the subgrade compared to geosynthetic reinforced pavement. The most common locations for geosynthetic reinforcements in flexible pavements include the base course layer, the interface between the subbase and subgrade layer, or the base and granular subbase material. Furthermore, geosynthetics have been utilized in pavement overlays to seal the asphalt layer and reduce the spread of reflection cracking. 5 1.5 Purpose Research into the literature has shown that RAP, or Reclaimed Asphalt Pavement, might be utilized in nearly all layers of flexible pavement. It has also been noted that there are environmental and economic benefits of using RAP. The wearing and binder course of hot mix asphalt (HMA) made from recycled asphalt pavement (RAP) contains aggregate and asphalt binder instead of the

more costly virgin aggregate and bitumen.Therefore, the most cost-effective application of RAP is in bituminous courses. Nevertheless, somewhat homogeneous RAP of extremely high quality is necessary. Similarly, RAP is a cost- effective and practical tool for the subbase and base courses. With the exception of gradation, nearly all of RAP's physical qualities are suitable for usage in subbase and base course. Achieving an acceptable grading of RAP for its usage in subbase and base course requires the addition of virgin aggregates. On top of everything else, RAP is a lifesaver when it comes to subgrade, particularly weak subgrade. Mixing poor subgrade with RAP and a little quantity of cement (up to 2%), it is possible to significantly increase subgrade CBR. Pavement construction costs go down when the subgrade CBR goes up because less upper layer material, notably bituminous material, is needed to withstand the same amount of traffic. In addition, National Highway (NH) strengthening and repair operations produce massive amounts of RAP. For 4/6 laning projects, it is common practice to bury long sections of bituminous pavement in order to make way for additional amenities such as pedestrian underpasses, vehicular underpasses, and flyovers. Reusing these massive amounts of RAP for pavement construction will result in substantial cost reductions. When recycled asphalt pavement (RAP) is utilized in the building of flexible pavement, geosynthetics materials used as separation, filtering, drainage, and reinforcements can significantly improve the pavement's performance. To improve the performance of RAP base / subbase, geogrids and geocells made of either polymer or bamboo can be employed. 6 1.6 Process of the Research In order to conduct this study, we reviewed a large amount of literature on the topic of flexible pavement construction layers that combine Reclaimed Asphalt Pavement (RAP) and geosynthetics. Thorough experiments were carried out in a controlled environment on several materials, including RAP, CSA, a combination of RAP and CSA, and cement-stabilized versions of the aforementioned. This study compared the estimated lifespan of two types of pavement—conventional flexible pavement with a granular subbase and an alternate pavement option employing stabilized RAP as subbase—using IITPAVE software in accordance with IRC: 37-2012. A steel tank measuring 600 mm x 600 mm x 600 mm has been used for the model's testing. The subbase or base course was a 150 mm thick RAP layer laid over soft coastal clay that had a CBR value of less than 2% after being soaked for 4 days. A layer of nonwoven polymer geosynthetics has been employed to separate the soft coastal clay bed from the RAP base or subbase. To further investigate how reinforcement affects the RAP layer's load-bearing capacity, Polymer Geogrid, Polymer Geocell, Bamboo Geogrid, and Bamboo Geocell are subsequently added to the RAP base. In order to determine the optimal placement of reinforcement in the RAP layer for best benefit, single-layer polymer and bamboo geogrid have been utilized as reinforcements.

Literature Review

Two main categories of pavements are 2.1Pavement Types & Composition. There are two types of pavement: bituminous pavement, which is flexible, and concrete pavement, which is hard. Paver block pavement is an additional kind of pavement. Because it is so easy to maintain, it is commonly used to accommodate utility wires below it near intersections of metropolitan roads. Furthermore, there is the possibility of composite pavement, which combines elements of the aforementioned and is tailored to meet particular needs. Flexible pavement is made up of multiple layers that are both naturally flexible and can easily bend in response to traffic loads. Rigid pavements, in contrast, are made of concrete slabs that do not flex readily under the weight of traffic. Pavements that are both flexible and rigid disperse loads over the subgrade in diverse ways. Because of the concrete slab's high elastic modulus (stiffness), rigid pavement spreads the traffic load over a larger area on the subgrade. In contrast, flexible pavement uses more pliable surface courses to disperse traffic loads over smaller regions.

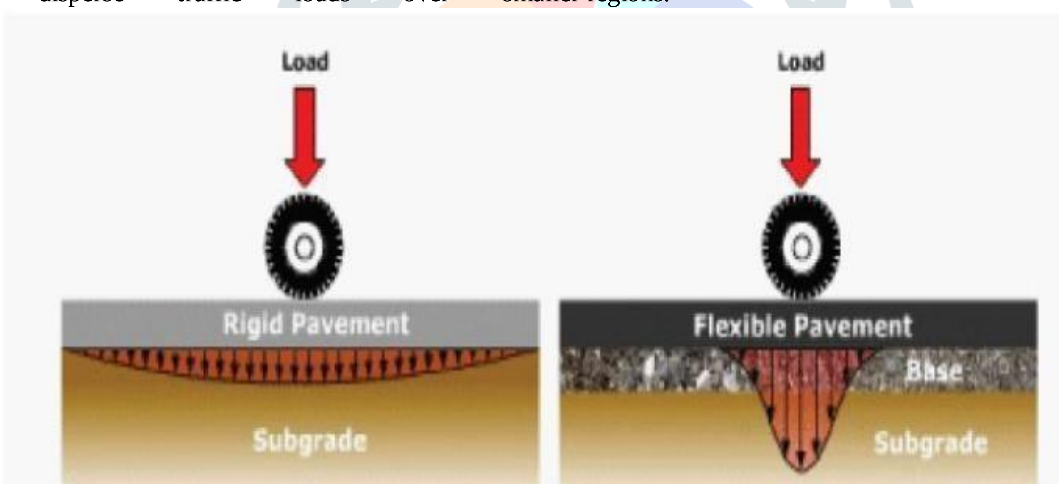


Figure 2.1 Typical stress distribution under rigid and flexible pavement (TxDOT 10/2006)

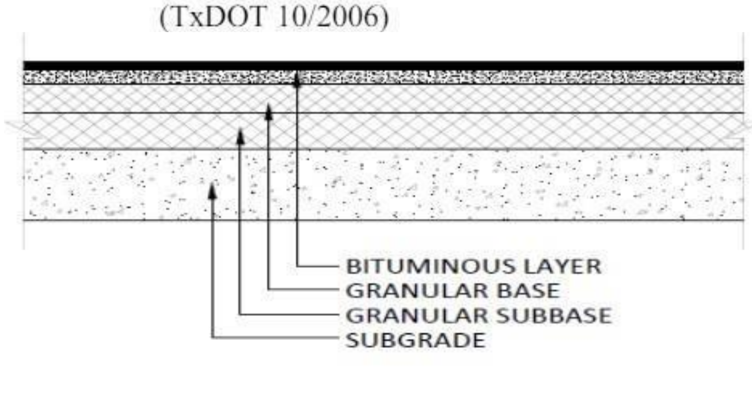


Figure 2.2 Typical composition of flexible pavement

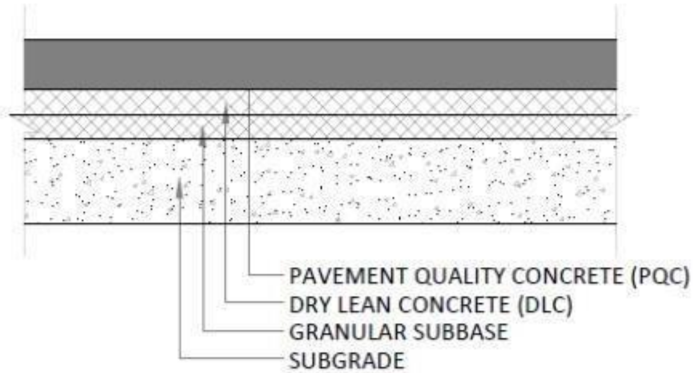


Figure 2.3 Typical composition of rigid pavement

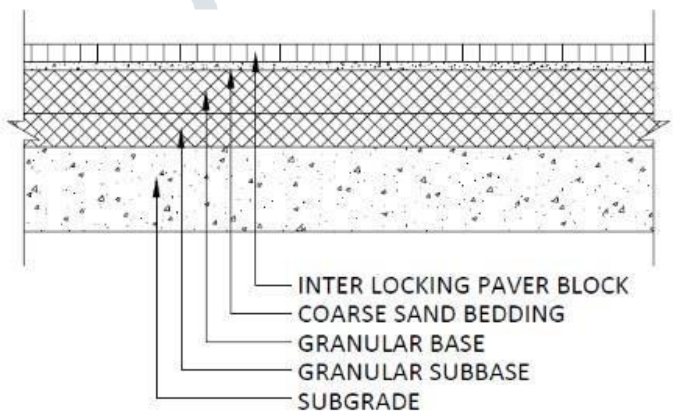


Figure 2.4 Typical composition of paver block pavement

Table 2.1 Grading for Granular Subbase materials (MORT & H, 2013)

IS Sieve Designation	Percent by weight Passing the IS Sieve					
	Grading I	Grading II	Grading III	Grading IV	Grading V	Grading VI
75.0mm	100	-	-	-	100	-
53.0mm	80-100	100	100	100	80-100	100
26.5mm	55-90	70-100	55-75	50-80	55-90	75-100
9.50mm	35-65	50-80	-	-	35-65	55-75
4.75mm	25-55	40-65	10-30	15-35	25-50	30-55
2.36mm	20-40	30-50	-	-	10-20	20-25
0.85mm	-	-	-	-	2-10	-
0.425mm	10-15	10-15	-	-	0-5	0-8
0.075mm	<5	<5	<5	<5	-	0-3

Table 2.2 Physical requirements of materials for granular subbase (MORT & H, 2013)

Aggregate Impact value (AIV)	IS:2386 (Part 4) or IS:5640	40 maximum
Liquid Limit	IS:2720 (Part 5)	Maximum 25
Plasticity Index	IS:2720 (Part 5)	Maximum 6
CBR at 98% dry density (at IS: 2720-Part8)	IS:2720 (Part 5)	Minimum 30 unless otherwise specified in the contract

Table 2.3 Physical requirements of coarse Aggregates for Subbase / Base course (MORT & H, 2013)

S. No	Test	Test Method	Requirements
1	Los Angeles Abrasion value or	IS:2386 (Part -4)	40 percent (Max.)
	Aggregate Impact value	IS:2386 (Part-4) or IS5640	30 percent (Max.)
2	Combined flakiness and Elongation	IS:2386	35 percent (Max.)

b. Grading requirement: Grading of aggregate for WMM shall be as follows:

Table 2.4 Grading requirements of aggregate for Wet Mix Macadam (MORT & H, 2013)

IS Sieve Designation	Percent by Weight passing the IS Sieve
53.00 mm	100
45.00 mm	95-100
26.50 mm	-
22.40 mm	60-80
11.20 mm	40-60
4.75 mm	25-40

Table 2.5 Physical requirement of coarse aggregate for Dense Bituminous Macadam (MORT & H, 2013)

Property	Test	Specification	Method
Cleanliness (dust)	Grain size analysis	Max 5% passing 0.075mm sieve	IS:2386 Part I
Particle shape	Combined flakiness and Elongation	Max 35%	IS:2386 Part I
Strength	Los angles Abrasion value or Aggregate Impact value	Max 35% Max 27%	IS:2386 Part IV
Durability	Soundness either: sodium sulphate or Magnesium sulphate	Max 12% Max 18%	IS:2386 Part V
Water Absorption	Water Absorption	Max 2%	I:2386 Part III
Stripping	Coating and stripping of Bitumen Aggregate	Minimum retained coating 95%	IS:6241
Water sensitivity	Retained Tensile Strength	Min. 80%	AASHTO 283

Table 2.6 Grading requirements for mineral filler (MORT & H, 2013)

IS sieve (mm)	Cumulative percent passing by Weight of Total Aggregate
0.6	100
0.3	95-100
0.075	85-100

Table 2.7 Composition of Dense Graded Bituminous Macadam (MORT & H, 2013)

Grading	1	2
Nominal Aggregate size	37.5mm	26.5mm
Layer thickness	75-100mm	50-75mm
IS Sieve (mm)	Cumulative % by weight of total aggregate passing	
45.0	100	-
37.5	95-100	100
26.5	63-93	90-100
19.0	-	71-95
13.2	55-75	56-80
9.5	-	-
4.75	38-54	38-54
2.36	28-42	28-42
1.18	-	-
0.6	-	-
0.3	7-21	7-21
0.15	-	-
0.075	2-8	2-8
Bitumen content % by mass of total mix	Min 4.0	Min 4.5

Table 2.8 Physical requirements of Coarse Aggregate for Bituminous Concrete (MORT & H, 2013)

Property	Test	Specification	Method of Test
Cleanliness (dust)	Grain size analysis	Max 5% passing 0.075 mm sieve	IS:2386 Part I
Particle shape	Combined Flakiness and Elongation indices	Max 35%	IS:2386 Part I
Strength	Los Angeles Abrasion Value or Aggregate Impact Value	Max30% Max 24%	IS:2386 Part IV
Durability	Soundness either: Sodium Sulphate or Magnesium Sulphate	Max 12% Max 18%	IS:2386 Part V
Polishing	Polished stone value	Min 55	BS:812-114
Water Absorption	Water Absorption	Max 2%	IS:2386 Part III
Stripping	Coating and Stripping of Bitumen Aggregate of Bitumen Aggregate	Minimum retained coating 95%	IS:6241
Water Sensitivity	Retained Tensile Strength	Min 80%	AASHTO 283

Table 2.9 Grading requirements for Mineral Filler (MORT & H, 2013)

IS sieve (mm)	Cumulative percent passing by weight of total aggregate
0.6	100
0.3	95-100
0.075	85-100

Table 2.10 Composition of Bituminous Concrete pavement layers (MORT & H, 2013)

Grading	1	2
Nominal aggregate size	19mm	13.2 mm
Layer thickness	50mm	30-40 mm
IS Sieve	Cumulative % by Weight of total aggregate passing	
45	-	-
37.5	-	-
26.5	100	-
19	90-100	100
13.2	59-79	90-100
9.5	52-72	70-88
4.75	35-55	53-71
2.36	28-44	42-58
1.18	20-34	34-48
0.6	15-27	26-38
0.3	10-20	18-28
0.15	5-13	12-20
0.075	2-8	4-10
Bitumen content % by mass of total mix	Min 5.2	Min 5.4

Figure 2.5 Photograph of milled RAP

Table 2.11 Grain size distribution of RAP (FHWA- RD- 97- 148)

Sieve size	% finer after processing
37.5mm(1.5 in)	100
25mm(1.0 in)	95-100
19mm(3/4 in)	84-100
12.5mm(1/2 in)	70-100
9.5mm(3/8 in)	58-95

2.3.2.4 Physical and mechanical properties of RAP

Table 2.12 Properties of RAP

Type of properties	RAP Properties	Type range of values
Physical properties	Gradation	40 mm down
	Asphalt content	3 - 4%
Mechanical properties	Compacted unit weight	1.9-2.2 gm/cm^3
	California bearing ratio (CBR)	100% RAP: CBR 20% 50% RAP + 50% CSA: CBR 28% 50% RAP + 50% CSA + 3% Cement: CBR 162%

3. Laboratory Investigations and Pavement Analysis

3.1 Introduction An alternative to Granular Subbase (GSB) in flexible pavement, Reclaimed Asphalt Pavement (RAP) is the topic of this study. Thus, some tests involving RAP and RAP combined with CSA, either alone or with cement, have been carried out in the lab. The addition of CSA and cement to RAP, in varying quantities, improves its Unconfined Compressive Strength (UCS) and California Bearing Ratio (CBR). According to IRC: 37-2012 "Tentative Guidelines for the design of flexible pavements," the pavement's fatigue and rutting life have been estimated for several alternatives through the use of IITPAVE software. Pavement life was superior to that of conventional pavement with granular subbase when stabilized RAP (50% RAP + 50% CSA + 4% Cement) was used as the subbase. Items

3.2 The following are examples of materials used in laboratory investigations: (a) RAP, or reclaimed asphalt pavement; (b) CSA, or crushed stone aggregates; and (c) OPC, or ordinary Portland cement.

3.2.1 RAP, or Reclaimed Asphalt Pavement, was sourced from a neighboring NH project that has just undergone a four-lane width expansion to a six-lane design. Reclaimed Asphalt Pavement (RAP) was created during the milling process of the old bituminous pavement before it was strengthened as part of this project's effort to broaden and strengthen the pavement. There is 3.2% bituminous component in RAP, and its compacted dry density is 19.8 kN/m3. When RAP passes a 37.5 mm sieve, its grain size is 100%. RAP typically has a CBR value of around 10% to 20%. When combined with crushed stone aggregates (CSA) and a specific ratio of cement, however, RAP's CBR value increases by more than 100%. According to the modified proctor tests, the Maximum Dry Density (MDD) was found to be 22.5 kN/m3 and the Optimal Moisture Content (OMC) to be 5.2%. Figure 3.1 shows photographs of RAP that were taken for different laboratory tests.

3.2.2 Stone Aggregates in Crushed Form (CSA) According to previous study by Taha et al. (2002) and McGrrah (2007), the strength of Reclaimed Asphalt Pavement (RAP) materials is enhanced when they are mixed with fresh aggregates, as measured by the

California Bearing Ratio (CBR). Consequently, various amounts of RAP and virgin aggregate were settled upon. For financial reasons, however, CSA have been deemed virgin aggregates rather than Wet Mix Macadam (WMM). The crushers used in a neighboring National Highway (NH) project provided the CSA for this experiment. Figure 3.2 shows photographs of CSA that were used for RAP mixing. One hundred percent of the CSA grain size passes through a 3.75 mm sieve. A granular substance that is not plastic was discovered. In accordance with the modified proctor tests, the Maximum Dry Density (MDD) was found to be 22.5 kN/m3 and the Optimal Moisture Content (OMC) to be 5.2%. The CBR, or California Bearing Ratio, is 6 percent. A value of 55 kPa is the unconfined compressive strength. Cement (3.2.3) For sale Both RAP and RAP + CSA mixes have utilized Ordinary Portland Cement (OPC) of grade 43 as their stabilizer. The cement used is shown in Figure 3 as a photograph.3.3.3 RAP and CSA laboratory tests A number of laboratory tests have been carried out on crushed stone aggregates (CSA), reclaimed asphalt pavement (RAP), and mixtures of the two, both with and without cement. What follows is a rundown of our laboratory investigations.

3.3.1 Distribution of Grain Size The RAP samples are sieved according to ASTM D4 22 (1963), "Standard test method for particle size analysis of soil," since they were collected from the project site after milling and did not undergo any additional pulverization. There was also a sieve analysis performed on the CSA samples. We did not wash the RAP or CSA samples before running them through the sieve. Sieve analysis testing schedules are as follows. a. Pure RAP with no CSA c. RAP 75%: CSA 25% half of RAP and half of CSA

c. 25% Rap + 75% Crop Shield 100% CSA plus 0% RAP Figure 3.4 shows the grain size distribution of samples with different combinations, including 100% RAP, 75% RAP + 25% CSA, 50% RAP + 50% CSA, 25% RAP + 75% CSA, and 100% CSA.

Figure 3.1 RAP Sample

Figure 3.2 Crushed Stone Aggregate (CSA) Sample

Figure 3.3 Cement Sample

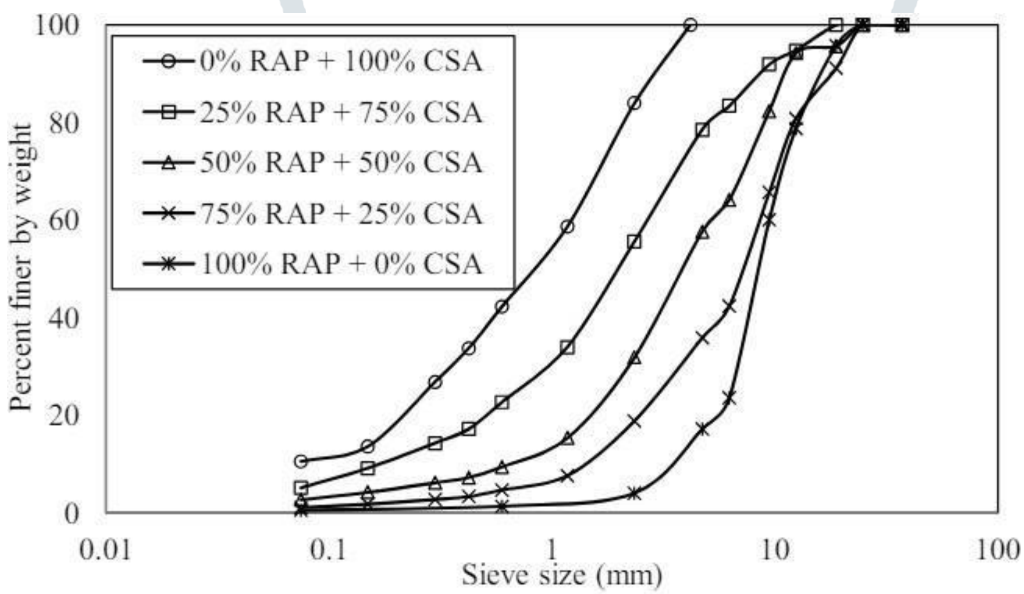


Figure 3.4 Grain size distribution of RAP + CSA

The Grain size distribution curve for 100% RAP + 0% CSA sample and its comparison with the Granular Subbase (GSB) envelope is shown in Table 3.1 and Figure 3.5.

Table 3.1 Grain size distribution of 100% RAP

Is Sieve Designation	Percent by Weight passing the IS sieve	
	GSB	100% RAP + 0% CSA
75.00 mm	-	100
53.00 mm	100	100
26.50 mm	75-100	100
9.50 mm	55-75	60
4.75 mm	30-55	17.1
2.36 mm	10-25	4.0
425 microns	0-8	1.2
75 microns	0-3	0.5

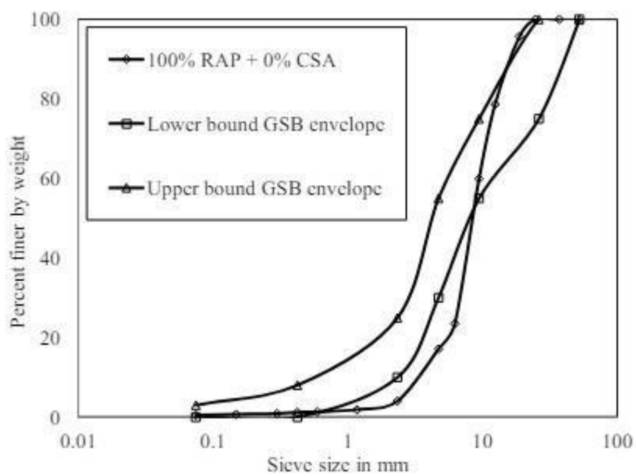


Figure 3.5 Grain size distribution of 100% RAP + 0% CSA

The Grain size distribution curve for 75% RAP + 25% CSA sample and its comparison with the Granular Subbase (GSB) envelope is shown in Table 3.2 and Figure 3.6.

Table 3.2 Grain size distribution of 75% RAP +25% CSA

Is Sieve Designation	Percent by Weight passing the IS sieve	
	GSB	75% RAP + 25% CSA
75.00 mm	-	100
53.00 mm	100	100
26.50 mm	75-100	100
9.50 mm	55-75	65.6
4.75 mm	30-55	35.8
2.36 mm	10-25	18.8
425 microns	0-8	3.3
75 microns	0-3	1.0

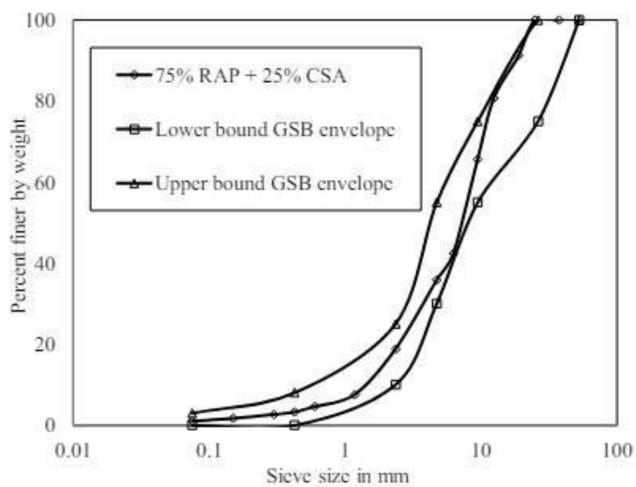


Figure 3.6 Grain size distribution of 75% RAP + 25% CSA

The Grain size distribution curve for 50% RAP + 50% CSA sample and its comparison with the Granular Subbase (GSB) envelope is shown in Table 3.3 and Figure 3.7.

Table 3.3 Grain size distribution of 50% RAP +50% CSA

Is Sieve Designation	Percent by Weight passing the IS sieve	
	GSB	50% RAP + 50% CSA
75.00 mm	-	100
53.00 mm	100	100
26.50 mm	75-100	100
9.50 mm	55-75	82.3
4.75 mm	30-55	57.6
2.36 mm	10-25	31.8
425 microns	0-8	7.2
75 microns	0-3	2.6

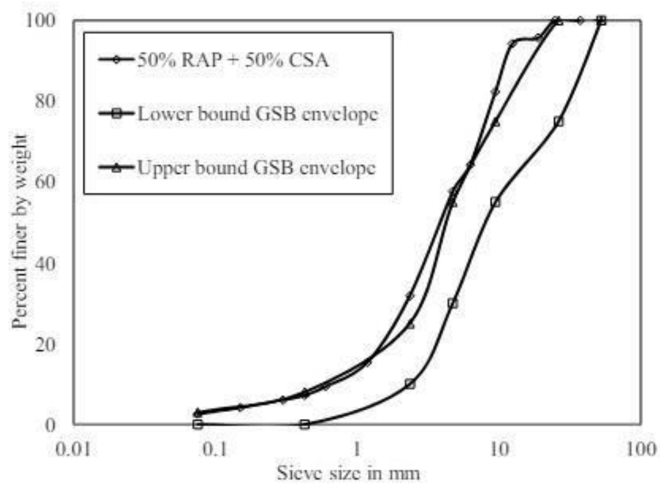


Figure 3.7 Grain size distribution of 50% RAP + 50% CSA

The Grain size distribution curve for 25% RAP + 75% CSA sample and its comparison with the Granular Subbase (GSB) envelope is shown in Table 3.4 and Figure 3.8.

Table 3.4 Grain size distribution of 25% RAP +75% CSA

Is Sieve Designation	Percent by Weight passing the IS sieve	
	GSB	25% RAP + 75% CSA
75.00 mm	-	100
53.00 mm	100	100
26.50 mm	75-100	100
9.50 mm	55-75	91.9
4.75 mm	30-55	78.5
2.36 mm	10-25	55.6
425 microns	0-8	17.1
75 microns	0-3	5.1

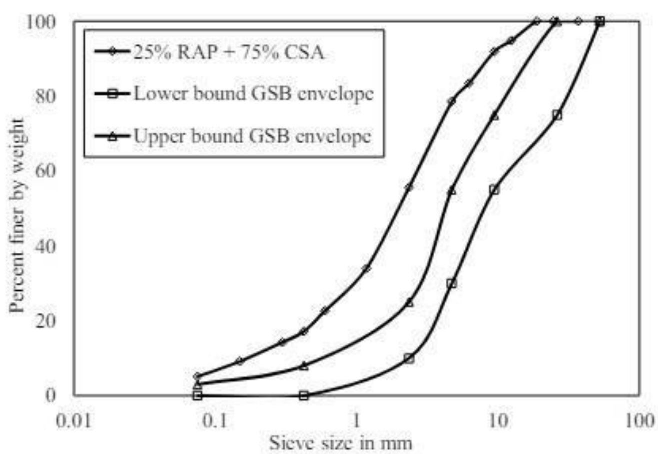


Figure 3.8 Grain size distribution of 25% RAP + 75% CSA

The Grain size distribution curve for 0% RAP + 100% CSA sample and its comparison with the Granular Subbase (GSB) envelope is shown in Table 3.5 and Figure 3.9.

Table 3.5 Grain size distribution of 0% RAP +100% CSA

Is Sieve Designation	Percent by Weight passing the IS sieve	
	GSB	0% RAP +100% CSA
75.00 mm	-	100
53.00 mm	100	100
26.50 mm	75-100	100
9.50 mm	55-75	100
4.75 mm	30-55	100
2.36 mm	10-25	83.95
425 microns	0-8	33.73
75 microns	0-3	10.48

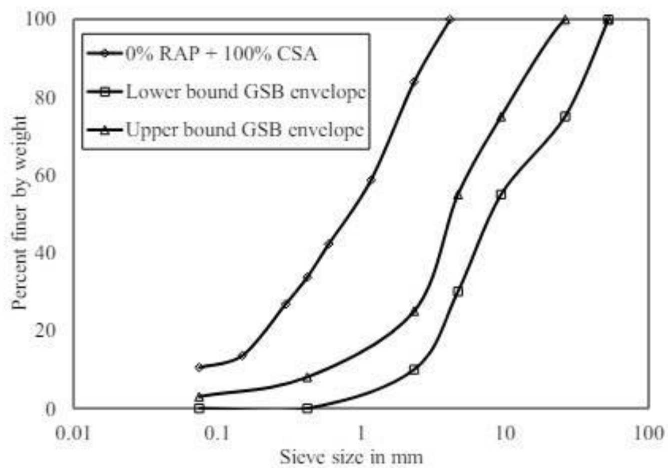


Figure 3.9 Grain size distribution of 0% RAP + 100% CSA

3.3.2 Compaction Tests

Modified Proctor compaction tests were carried out in accordance with ASTM D 1557 – 07. "Standard test method for laboratory compaction of soil using modified effort (2,700 KN-m/m^3)". Proctor compaction tests were conducted on RAP, CSA and RAP + CSA mixture in various proportions and also on above mentioned samples, stabilized with cement. The laboratory testing schedule carried out for compaction tests are as follows.

a. 100% RAP + 0% CSA
b. 75% RAP + 25% CSA
c. 50% RAP + 50% CSA
d. 25 % RAP + 75 % CSA
e. 0% RAP + 100% CSA
f. 100% RAP + 0% CSA + 2% cement Stabilizer
g. 50% RAP + 50% CSA + 2% Cement
h. 75% RAP + 25% CSA + 2% Cement
i. 25% RAP + 75% CSA + 2% Cement
j. 0% RAP + 100% CSA+ 2% Cement

The moisture density relationships based on proctor compaction tests on RAP, CSA and mixture of RAP and CSA for various proportions without and with 2% cement are shown in Figure 3.10 and Figure 3.11 respectively.

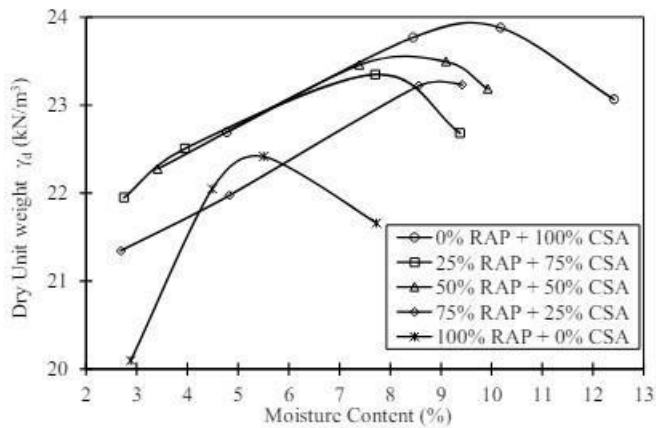


Figure 3.10 Moisture Density Relationship of RAP + CSA (without cement)

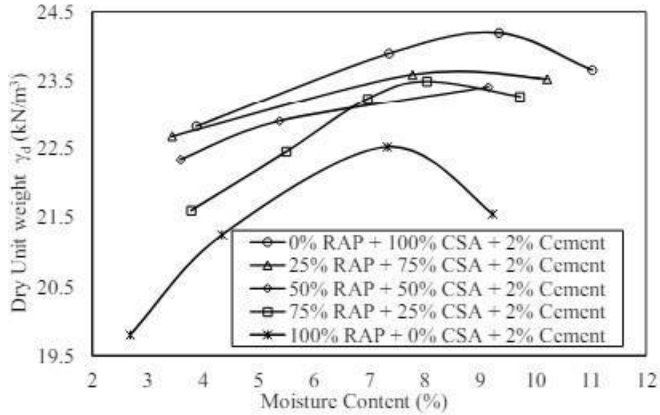


Figure 3.11 Moisture Density Relationship of RAP + CSA (with 2% cement)

The maximum dry density (MDD) of 100% RAP is 22.4 kN/m3, while the optimum moisture content (OMC) is 5.2%, as shown in Figure 3.10. Furthermore, it has been noted that the MDD and OMC values of RAP both rise when combined with CSA. From 22.4 kN/m3 to 24.0 kN/m3 is the range of MDD values for RAP + CSA mixes in different proportions. A similar range of OMC values, from 5.2% to 9.5%, is seen for RAP + CSA mixes in different proportions. Although the OMC value rises to 7.5% when 100% RAP is stabilized with 2% cement, the MDD value stays about the same at 22.4 kN/m3. Figure 3.11 shows that the MDD value ranges from

22.4 kN/m3 to 24.0 kN/m3 for RAP + CSA mixes stabilized with 2% cement and in different concentrations. Also, when RAP and CSA are mixed with 2% cement in different quantities, the OMC value can range from 7.5% to 9.5%. The two plots show that the OMC value increases significantly, while the MDD value of RAP and RAP + CSA mix does not change much as a result of cement stabilization. 20.5%, 20.5%, 21.5%, 22.5%, 23.5%, 24.5, 2, 3,

4, 5, 6, 7, 8, 9, 10, and 11 are all part of the 12. Gross density (kN/m3) of a dry unit The percentage of moisture 2% cement, 100% CSA, and zero RAP 50% Cement, 75% RAP, and 25% CSA 50% CSA plus 2% RAP Building material 100% RAP, 25% CSA, and 2% cement 2% cement, 0% CSA, and RAP

3.3.Testing for the California Bearing Ratio (CBR) The CBR tests were carried out following the guidelines laid forth by ASTM D 1883 - 07E1. "Standard test method for CBR (California Bearing Ratio) of laboratory compacted soils" on a variety of compositions, including RAP, CSA, and RAP + CSA mixtures, as well as on the aforementioned compositions. Made with cement for stability. Images of the CBR testing apparatus are shown in Figure 3.12. Figure 3.13shows a photograph of a soaked CBR sample.

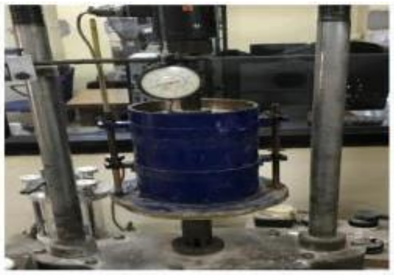
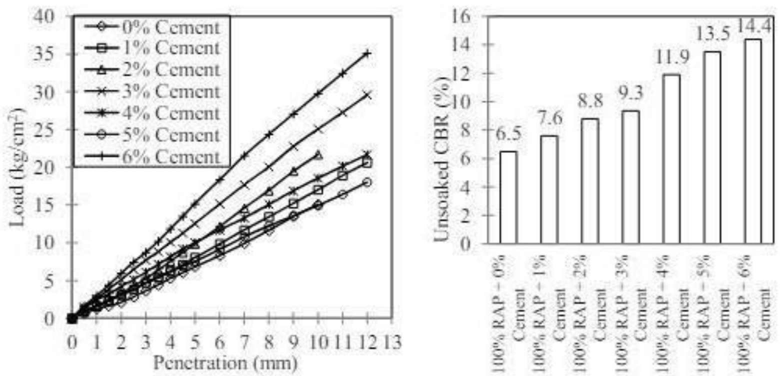


Figure 3.12 CBR testing machine

Figure 3.13 Soaked CBR samples

3.3.3.1 100% RAP

Results of Unsoaked and 4 days soaked CBR tests conducted on 100% RAP with varying percentages of cement are indicated in the Figure 3.14 and Figure 3.15.



(a) (b)

Figure 3.14 100% RAP with varying % of cement (Unsoaked) **(a)** Load – Penetration curve, **(b)** CBR Variation

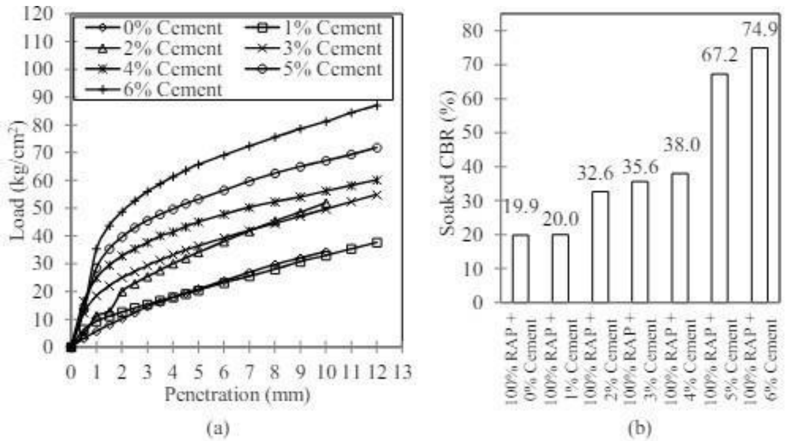
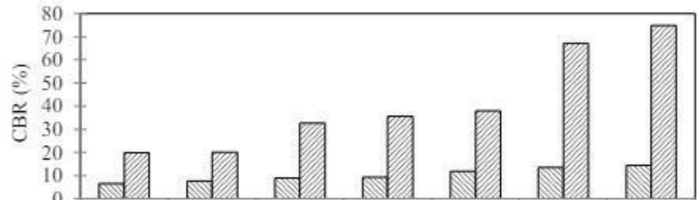


Figure 3.15 100% RAP with varying % of Cement (Soaked) **(a)** Load – Penetration curve, **(b)** CBR variation



	100% RAP + 0% Cement	100% RAP + 1% Cement	100% RAP + 2% Cement	100% RAP + 3% Cement	100% RAP + 4% Cement	100% RAP + 5% Cement	100% RAP + 6% Cement
Un Soaked	6.47	7.60	8.81	9.34	11.90	13.50	14.40
Soaked	19.85	20.00	32.60	35.62	38.00	67.20	74.90

Figure 3.16 Unsoaked and Soaked CBR value of 100% RAP with varying % of cement

From Figure 3.16, it is observed that, Unsoaked CBR value of 100% RAP varies from 6.5% to 14.5% with cement varying from 0 – 6%. Similarly, soaked CBR value varies from 20% to 75% for 100% RAP with cement varying from 0 – 6%.

3.3.3.2 75% RAP + 25% CSA

Results of Unsoaked and 4 days soaked CBR tests conducted on 75% RAP + 25% CSA with varying percentages of cement are indicated in the Figure 3.17 and Figure 3.18.

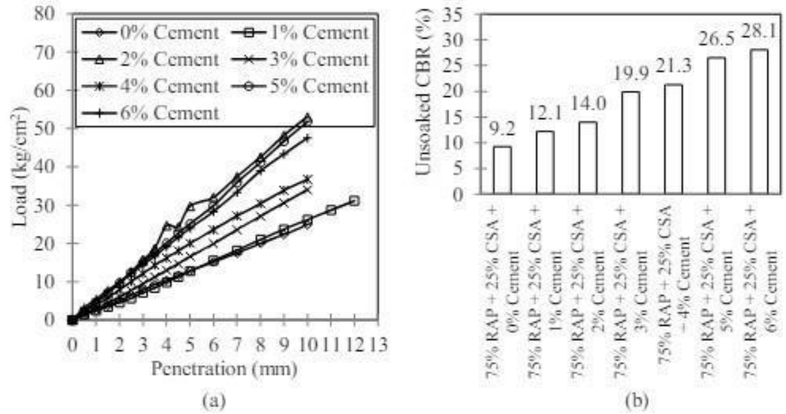


Figure 3.17 75% RAP + 25% CSA with varying % of cement (Unsoaked) **(a)** Load - Penetration curve, **(b)** CBR variation

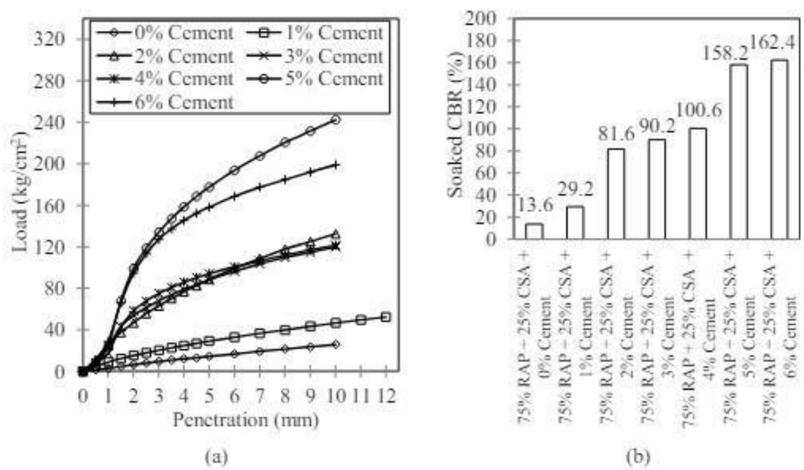
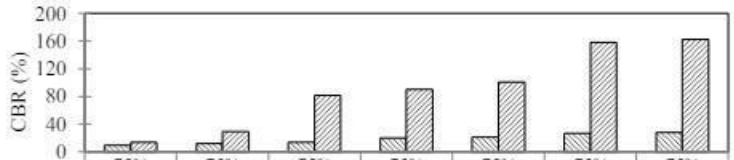


Figure 3.18 75% RAP + 25% CSA with varying % of cement (Soaked) **(a)** Load - Penetration curve, **(b)** CBR Variation



	75% RAP + 25% CSA + 0% Cement	75% RAP + 25% CSA + 1% Cement	75% RAP + 25% CSA + 2% Cement	75% RAP + 25% CSA + 3% Cement	75% RAP + 25% CSA + 4% Cement	75% RAP + 25% CSA + 5% Cement	75% RAP + 25% CSA + 6% Cement
Un Soaked	9.2	12.1	14.0	19.9	21.3	26.5	28.1
Soaked	13.6	29.2	81.6	90.2	100.6	158.2	162.4

Figure 3.19 Unsoaked and Soaked CBR value of 75% RAP + 25% CSA with varying % of cement

From Figure 3.19, it is observed that, Unsoaked CBR value of 75% RAP + 25% CSA varies from 9.0% to 28.0% with cement varying from 0 – 6%. Similarly, soaked CBR value varies from 14.0% to 162.0% for 75% RAP + 25% CSA with cement varying from 0 – 6%.

3.3.3.3 50% RAP + 50% CSA

Results of Unsoaked and 4 days soaked CBR tests conducted on 50% RAP + 50% CSA with varying percentages of cement are indicated in the Figure 3.20 and Figure 3.21.

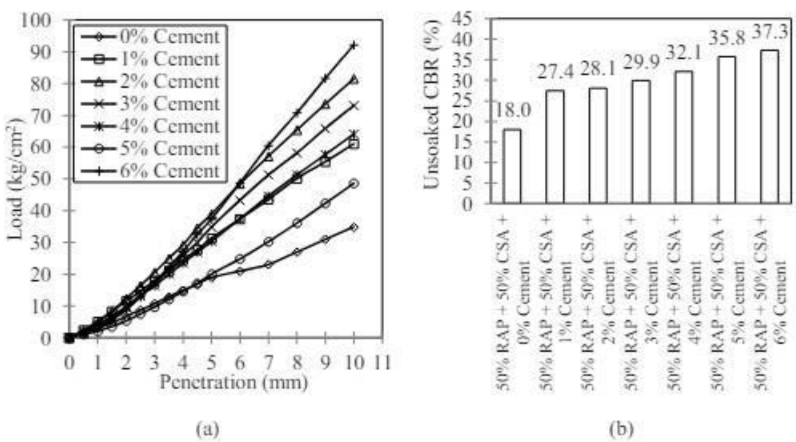


Figure 3.20 50% RAP + 50% CSA with varying % of cement (Unsoaked) **(a)** Load - Penetration curve, **(b)** CBR Variation

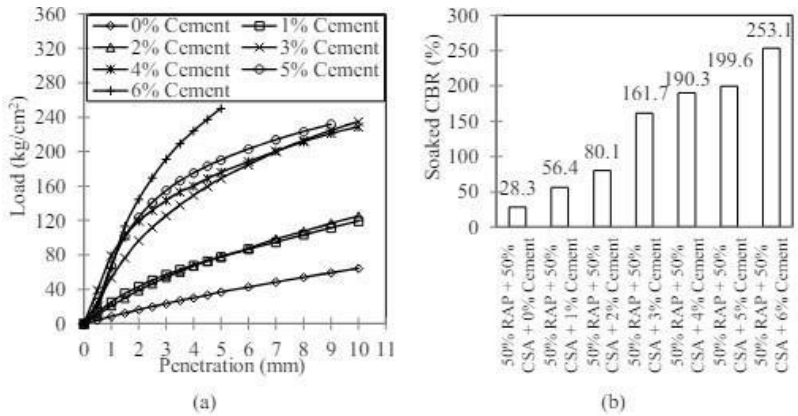
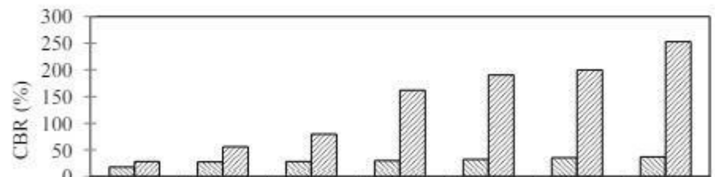


Figure 3.21 50% RAP + 50% CSA with varying % of cement (Soaked) **(a)** Load – Penetration curve, **(b)** CBR variation



	50% RAP + 50% CSA + 0% Cement	50% RAP + 50% CSA + 1% Cement	50% RAP + 50% CSA + 2% Cement	50% RAP + 50% CSA + 3% Cement	50% RAP + 50% CSA + 4% Cement	50% RAP + 50% CSA + 5% Cement	50% RAP + 50% CSA + 6% Cement
Un Soaked	18.0	27.4	28.1	29.9	32.1	35.8	37.3
Soaked	28.3	56.4	80.1	161.7	190.3	199.6	253.1

Figure 3.22 Unsoaked and Soaked CBR value of 50% RAP + 50% CSA with varying % of cement

From Figure 3.22, it is observed that, Unsoaked CBR value of 50% RAP + 50% CSA varies from 18.0% to 37.0% with cement varying from 0 – 6%. Similarly, soaked CBR value varies from 28.0% to 253.0% for 50% RAP + 50% CSA with cement varying from 0 – 6%.

3.3.3.4 25% RAP + 75% CSA

Results of Unsoaked and 4 days soaked CBR tests conducted on 25% RAP + 75% CSA with varying percentages of cement are indicated in the Figure 3.23 and Figure 3.24.

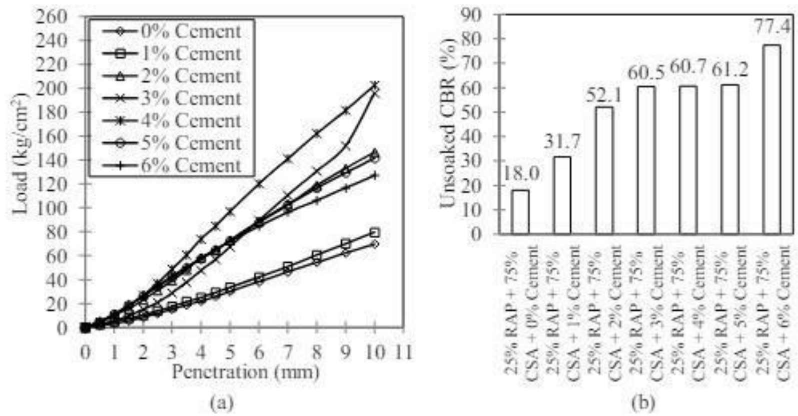


Figure 3.23 25% RAP + 75% CSA with varying % of cement (Unsoaked) **(a)** Load - Penetration curve, **(b)** CBR variation

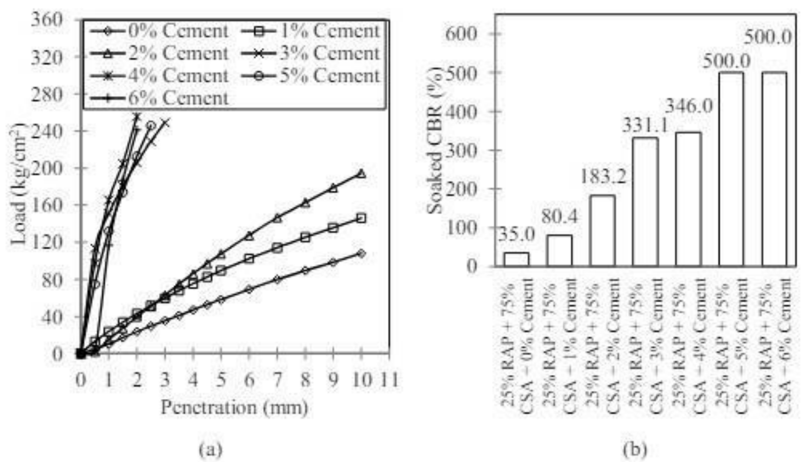


Figure 3.24 25% RAP + 75% CSA with varying % of cement (Soaked) **(a)** Load - Penetration curve, **(b)** CBR Variation

CONCLUSION

The following materials were subjected to a battery of laboratory tests: RAP, CSA, and RAP/CSA mixtures both with and without cement. The CBR value of raw RAP, which has not been processed, is 10–20%. Adding CSA and a little amount of cement to RAP, however, significantly raises the CBR value. 50% RAP, 50% CSA, and 3% cement has a CBR value of more than 160% after 4 days of soaking. There was also a significant lack of Unconfined Compressive Strength (UCS) in RAP. When RAP is combined with CSA and a small amount of cement, its UCS value goes up. The UCS value of a mixture of 50% RAP, 50% CSA, and 4% cement is greater than 1.50 MPa. Pavement alternatives using stabilized RAP as subbase have a longer expected life than traditional pavement using granular subbase.

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