

Effect of Saline Water on the Performance of Road Base Layer with Reclaimed Asphalt Pavement and Recycled Concrete Aggregate

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Road construction; Reclaimed Asphalt Pavement (RAP); Recycled Concrete Aggregate (RCA); California Bearing Ratio (CBR); aggregate base layer; saline water.

Abstract

Road construction requires large amounts of natural aggregates while generating considerable waste materials such as reclaimed asphalt pavement (RAP) and recycled concrete aggregate (RCA). This study investigated the potential of using RAP, RCA, and a RAP-RCA mixture as alternatives to natural aggregates in base layers exposed to saline conditions. Local aggregates were prepared according to SNI standards. RAP was obtained from a local road construction contractor, and RCA came from concrete waste produced during laboratory testing. The Proctor and CBR tests (SNI 1743:2008 and SNI 1744:2012) were carried out using artificial seawater containing 3.5% NaCl for immersion periods of 4, 14, 28, and 56 days. Results showed that exposure to saline water reduced CBR values, particularly for RAP, due to weakened particle bonding. RCA retained better strength, while the RAP-RCA mixture showed moderate performance, satisfying Class B base course requirements for short-term use in coastal areas.

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INTRODUCTION

Road infrastructure is essential for supporting economic growth and regional connectivity, particularly in developing countries such as Indonesia. However, road construction and maintenance require large amounts of natural aggregates and energy, which contribute to resource depletion and greenhouse gas emissions. These activities account for nearly 30% of the total energy use and carbon emissions within the transportation sector (Suwarto & Sudibyo, 2024). At the same time, large quantities of waste materials are produced from deteriorated asphalt and concrete pavements that have reached the end of their service life.

Reclaimed asphalt pavement (RAP) and recycled concrete aggregate (RCA) are two major waste materials from road rehabilitation projects (McNeil & Kang, 2013; Vaishnavi Devi et al., 2021; Widayanti Ari et al., 2018; Wulandari et al., 2025; Yang et al., 2021). Reusing these materials offers a sustainable alternative to reduce dependence on natural aggregates while promoting circular construction practices, essentially bringing road waste back to the road. RAP provides residual bitumen that can enhance flexibility, while RCA offers angularity and strength due to its cement mortar content. Combining both materials can potentially balance these properties and produce a stable base layer.

In coastal regions, road materials are often exposed to saline conditions caused by seawater intrusion or tidal flooding. Salinity can alter the moisture balance and inter-particle bonding of aggregates, leading to reduced strength and durability (El Sharkawy, 2019). Using saline water in testing also helps minimize competition with freshwater resources, supporting sustainable water management in construction.

This study investigates the compaction and bearing characteristics of RAP, RCA, and RAP-RCA mixture under saline exposure. The research focuses on changes in California Bearing Ratio (CBR) values after immersion in artificial saline water (3.5% NaCl) for different durations and compares them with freshwater conditions. The outcomes are expected to support the use of recycled aggregates in road base layers, particularly in coastal areas, where sustainable and resource-efficient solutions are increasingly needed.

LITERATURE REVIEW

Road pavements form an essential part of transportation infrastructure, designed to provide structural strength, riding comfort, and long-term durability under varying traffic and environmental conditions. A typical pavement consists of surface, base, and subbase layers, each serving specific mechanical and functional purposes (Fig. 1). The surface course offers skid resistance and weather protection, while the base layer distributes loads to the underlying subgrade, which serves as the primary support for the entire system. Flexible pavements, the most common type in Indonesia, rely on asphalt-bound and granular layers that gradually transfer loads to the subgrade. The stability of the base layer is a key determinant of pavement performance, influencing its resistance to rutting, cracking, and settlement (Su et al., 2017). Therefore, base materials must satisfy specific engineering requirements related to gradation, abrasion resistance, and minimum California Bearing Ratio (CBR) values, as specified in the General Specifications 2018 for Road and Bridge Construction Works – Revision 2 (2020) by the Indonesian Ministry of Public Works and Housing, Directorate General of Highways. The aggregate gradation used in this study followed the standard specification for base course materials, as shown in Table 1, while the corresponding material requirements, including the minimum CBR value, are presented in Table 2.

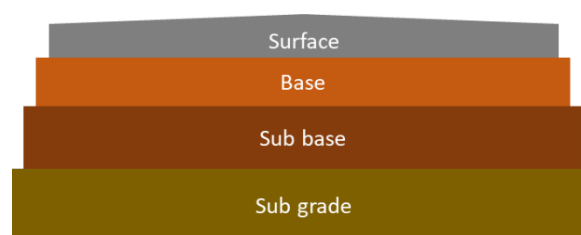


Fig. 1. Pavement Structure

The increasing scarcity of natural aggregates and the accumulation of construction waste have encouraged the adoption of recycled materials in pavement applications. Two widely studied materials are Reclaimed Asphalt Pavement (RAP) and Recycled Concrete Aggregate (RCA). RAP is produced from the milling of aged asphalt layers and contains aggregates coated with residual bitumen, which enhances flexibility and moisture resistance. Its reuse reduces dependence on virgin aggregates and minimizes waste from old pavement layers. RCA, on the

other hand, is derived from crushed concrete debris and typically exhibits higher porosity, lower density, and greater water absorption compared with natural aggregates. Despite these characteristics, RCA remains structurally suitable for base and subbase applications due to its rough texture and high angularity, which improve interparticle friction and mechanical interlock (Arshad & Ahmed, 2017; Guthrie et al., 2007; Pasandín & Pérez, 2013). The incorporation of RAP and RCA in pavement layers promotes sustainable construction by conserving natural resources, reducing landfill waste, and lowering energy consumption and carbon emissions associated with aggregate production and transportation (Jayakody et al., 2021; Morales Fournier et al., 2020). When blended, RAP contributes flexibility through its asphalt coating, while RCA enhances stiffness and load distribution, creating a balanced and stable mixture.

Mechanical characterization of unbound or stabilized base materials generally involves compaction and bearing capacity tests. The Proctor test (SNI 1743:2008) determines the optimum moisture content (OMC) and maximum dry density (MDD), which govern field compaction, while the CBR test (SNI 1744:2012) assesses the load-bearing capacity of material and is widely used as a design reference for base and subbase layers. Previous research indicates that the asphalt film in RAP can reduce interparticle friction, leading to slightly lower MDD but better water resistance. In contrast, RCA tends to absorb more water, resulting in higher OMC but increased stiffness after compaction (Arshad, 2019). The combined use of RAP and RCA can therefore compensate for these opposing characteristics, improving overall compaction and performance.

Table 1. Specification of aggregate gradation for base course

Sieve Size		Percent Passing (by weight)				Drainage Layer
		Aggregate Base Layer				
ASTM	(mm)	Class A	Class B	Class S		
2"	50		100			
1½"	37,5	100	88 – 95	100	100	
1"	25,0	79 – 85	70 – 85	77 – 89	71 – 87	
¾"	19,0				58 – 74	
½"	12,5				44 – 60	
3/8"	9,50	44 – 58	30 – 65	41 – 66	34 – 50	
No. 4	4,75	29 – 44	25 – 55	26 – 54	19 – 31	
No. 8	2,36				8 – 16	
No. 10	2,00	17 – 30	15 – 40	15 – 42		
No. 16	1,18				0 – 4	
No. 40	0,425	7 – 17	8 – 20	7 – 26		
No. 200	0,075	2 – 8	2 – 8	4 – 16		

In coastal and low-lying regions, road materials are frequently subjected to seawater intrusion or saline groundwater. Seawater, with an average salinity of 3.5%, contains sodium chloride (NaCl) as well as sulfate and magnesium ions that can affect aggregate stability through physical and chemical interactions (El Sharkawy, 2019; Netterberg, 2023a, 2023b, 2023c). Saline exposure may alter the moisture balance, increase porosity, and weaken particle bonding,

resulting in reduced compaction efficiency and lower bearing capacity (Choi et al., 2022). For recycled aggregates, RAP may offer limited protection due to its bitumen coating, while porous structure of RCA and residual mortar can promote salt ingress and microcracking. Despite these differences, studies examining the combined performance of RAP and RCA under saline exposure remain scarce. Moreover, using saline water in laboratory testing offers environmental relevance by simulating real coastal conditions while reducing dependence on freshwater resources, which aligns with sustainable construction practices.

Although extensive research has investigated RAP and RCA individually, limited attention has been given to their blended performance, particularly under saline environments. To address this limitation, the present study evaluates changes in CBR values of RAP, RCA, and a RAP–RCA mixture after immersion in saline water (3.5% NaCl) for various durations. The findings are compared with those under freshwater conditions to determine the influence of salinity on compaction and strength, contributing to the understanding of recycled aggregate performance in coastal base layer applications and supporting the development of more sustainable and resilient pavement materials.

Table 2. Specification requirements for base course materials

Properties	Aggregate Base Layer			Drainage Layer
	Class A	Class B	Class S	
Abrasion of Coarse Aggregate (SNI 2417:2008)	0 – 40%	0 – 40%	0 – 40%	0 – 40%
Crushed Particles Retained on No.4 Sieve (SNI 7619:2012)	95/90 ¹	55/50 ²	55/50 ²	80/75 ³
Liquid Limit (SNI 1967:2008)	0 – 25	0 – 35	0 – 35	-
Plasticity Index (SNI 1966:2008)	0 – 6	0 – 10	0 – 15	-
Plasticity Index x % Passing No.200 Sieve	max. 25	-	-	-
Clay Lumps and Friable Particles (SNI 4141:2015)	0 – 5%	0 – 5%	0 – 5%	0 – 5%
Soaked CBR (SNI 1744:2012)	min.	min.	min.	-
	90%	60%	50%	-
Ratio of % Passing No.200 and No.40 Sieves	max. 2/3	max. 2/3	-	-
Uniformity Coefficient: $C_v = D_{60} / D_{10}$	-	-	-	> 3.5

Note:

- 1) 95/90 indicates that 95% of the coarse aggregate has one or more broken surfaces and 90% of the coarse aggregate has two or more broken surfaces.
- 2) 55/50 indicates that 55% of the coarse aggregate has one or more broken surfaces and 50% of the coarse aggregate has two or more broken surfaces.
- 3) 80/75 indicates that 80% of the coarse aggregate has one or more broken surfaces and 75% of the coarse aggregate has two or more broken surfaces.

METHODS

This study used natural aggregates, Reclaimed Asphalt Pavement (RAP), Recycled Concrete Aggregate (RCA), tap water, and sodium chloride (NaCl). Natural aggregates were sourced from Pasuruan, East Java, and classified into three size fractions: 10–15 mm, 5–10 mm, and 0–5 mm. The materials were oven-dried, sieved according to standard sizes, and recombined to achieve the mid-point gradation of Class B base course material, as specified in Table 1. RAP was obtained from the milling of aged asphalt pavements provided by a road construction contractor specializing in pavement works, while RCA was sourced from concrete waste generated during testing activities at the Concrete Laboratory of Petra Christian University. Although the RCA was not directly obtained from demolished pavement, the laboratory source

ensured uniformity and controlled material composition, suitable for initial evaluation of recycled aggregate behavior. The waste concrete contained residual cement paste and adhered mortar, representing similar characteristics to recycled concrete from pavement demolition.

Tap water was used for the control samples, while artificial saline water was prepared by dissolving 35 g of NaCl in each liter of tap water (3.5% NaCl) to simulate seawater conditions. The aggregates underwent several basic tests, including gradation, Los Angeles abrasion, flakiness and elongation index, specific gravity, sand equivalent, and fines content passing the No. 200 sieve. For the RAP material, an asphalt extraction test was carried out to measure the remaining bitumen content. All tests followed the General Specifications 2018 for Road and Bridge Construction (2020) to ensure that the materials met the requirements for Class B base layers.

The experimental program included Proctor compaction and California Bearing Ratio (CBR) tests to evaluate the compaction and bearing characteristics of natural, recycled, and blended aggregates under freshwater and saline conditions. The Standard Proctor test was conducted in accordance with SNI 1743:2008, using both tap water and saline water for moisture conditioning. Each mixture was compacted at five different moisture contents to determine the Optimum Moisture Content (OMC) and Maximum Dry Density (MDD). CBR testing followed SNI 1744:2012. Specimens were compacted at their respective OMC and MDD, and each value represents the mean of three replicates. For control specimens, the CBR test was performed after a standard soaking period of 4 days in tap water. For saline exposure, specimens were immersed in 3.5% NaCl solution for extended periods of 14, 28, and 56 days at ambient temperature. The saline solution was replaced weekly to maintain consistent salinity. Independent sets of specimens were prepared for each soaking duration to avoid repeated handling or testing of the same sample.

RESULTS AND DISCUSSION

This section presents the results and interpretation of laboratory tests, including material characterization, compaction behavior, and bearing capacity under both tap and saline water conditions. The discussion emphasizes the influence of saline exposure on the strength and durability of natural, recycled, and blended aggregates used as base layer materials. All CBR specimens were compacted at their respective Optimum Moisture Content (OMC) and Maximum Dry Density (MDD) determined from the Proctor test. Although this study is limited to CBR testing as an initial performance indicator, the results provide valuable insights into the potential use of Reclaimed Asphalt Pavement (RAP) and Recycled Concrete Aggregate (RCA) under saline conditions typical of coastal areas.

1. Asphalt Content in RAP

The extraction test showed that the Reclaimed Asphalt Pavement (RAP) contained an average asphalt content of 4.37%, which falls within the typical range for reclaimed materials used in pavement recycling. In unbound base applications, this residual asphalt slightly enhances particle cohesion and compaction without compromising granular behavior. Excessive asphalt could lead to higher plasticity and reduced shear strength, but the measured value in this study represents a balanced condition suitable for base layer mixtures.

2. Aggregate Gradation

All aggregates in this study were proportioned to follow the mid-point gradation curve for Class B base course material, as outlined in the Table 1. Maintaining proper gradation is essential to achieve good particle interlock, compaction, and resistance to deformation under repeated loading. The gradation envelope and the target mid-curve used in this study are presented in Fig. 2. To ensure uniformity across all mixtures and minimize variability due to particle size distribution, the same mid-curve gradation was applied to every sample preparation.

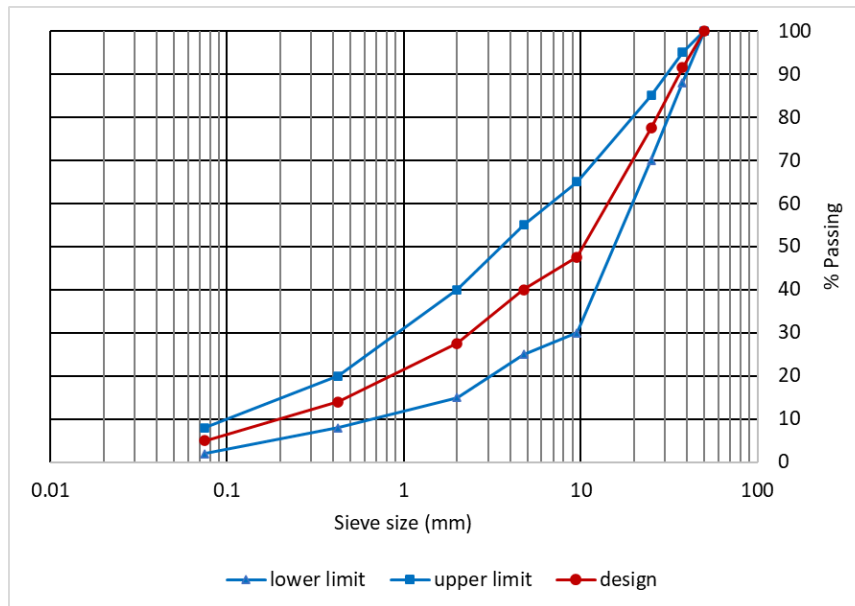


Fig. 2. Aggregate gradation curve for Class B base course material

3. Aggregate Properties

Physical characterization of the natural aggregate was conducted to ensure its suitability for base course applications. Key parameters evaluated included Los Angeles abrasion, specific gravity, and water absorption, following the relevant SNI standards. The Los Angeles abrasion value was 25.17%, which is well within the allowable limit of 40%, indicating that the aggregate possesses good resistance to wear and mechanical degradation under traffic loading. This result suggests that the material can maintain its integrity and contribute to long-term stability of the base layer.

The specific gravity of 2.67 and water absorption of 2.56% fall within the typical range for natural aggregates used in pavement construction. These values reflect a relatively dense and durable material, with moderate porosity that remains acceptable for use in base course layers. Overall, the natural aggregate used in this study satisfies the essential physical requirements specified for Class B base course materials. The results confirm that, despite the natural variability of locally sourced aggregates, their performance characteristics remain adequate for road construction purposes, supporting the use of regional materials to promote sustainability and practicality in infrastructure development.

4. Proctor Compaction Results under Saline Water Exposure

Compaction is one of the most important factors controlling the performance of an unbound base layer. A well-compacted material provides better interlock between particles, leading to higher strength and greater resistance to deformation under traffic loads. However, when saline water is used for compaction, such as in coastal construction areas, the presence of dissolved salts can influence how water interacts with the aggregate surface. These chemical interactions may change the water demand and affect how tightly the particles can pack together. Therefore, understanding how saline water influences the optimum moisture content (OMC) and maximum dry density (MDD) is essential, particularly when comparing natural and recycled aggregates. The compaction characteristics of all aggregate types were evaluated using the Modified Proctor method under both tap and saline water conditions. The relationship between dry density and water content for each material are presented in Figure 3 to Figure 6.

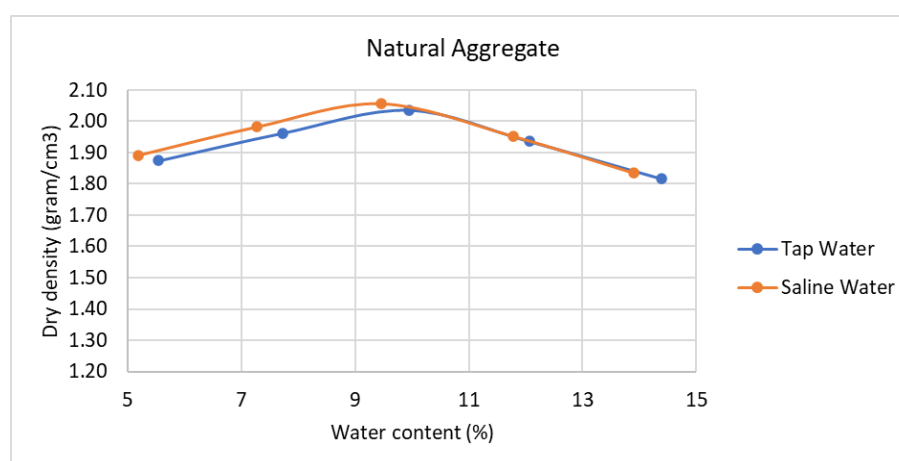


Fig. 3. Relationship between dry density and water content for 100% Natural Aggregate under tap and saline water conditions.

For natural aggregates (Fig. 3), the compaction curve followed a typical parabolic trend, with dry density increasing as water content rose until reaching the Optimum Moisture Content (OMC), then decreasing with further moisture addition. The Maximum Dry Density (MDD) reached 2.04 g/cm³ at an OMC of 9.94% when compacted with tap water. Under saline conditions, the MDD slightly increased to 2.06 g/cm³, while the OMC shifted to 9.46%. This minor improvement indicates that the presence of sodium chloride enhanced particle lubrication and promoted better packing during compaction. The salt ions likely reduced surface tension and facilitated closer particle contact, a behavior consistent with previous observations that moderate salinity can improve soil and aggregate compaction.

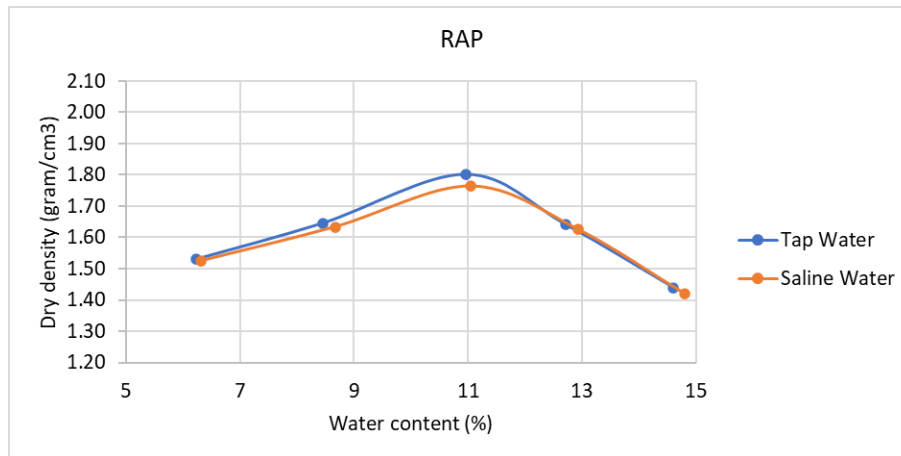


Fig. 4. Relationship between dry density and water content for 100% Reclaimed Asphalt Pavement (RAP) compacted using tap and saline water.

For the RAP material (Fig. 4), the maximum dry density was 1.80 g/cm^3 at an OMC of 10.96% with tap water, while saline water produced a slightly lower MDD of 1.76 g/cm^3 at an OMC of 11.05%. The lower density compared with natural aggregates can be attributed to the residual asphalt coating, which decreases inter-particle friction and prevents close packing. The minor decrease in density under saline water suggests that salinity had little positive influence, possibly due to the hydrophobic nature of bitumen, which limits interaction between particles and water regardless of salinity.

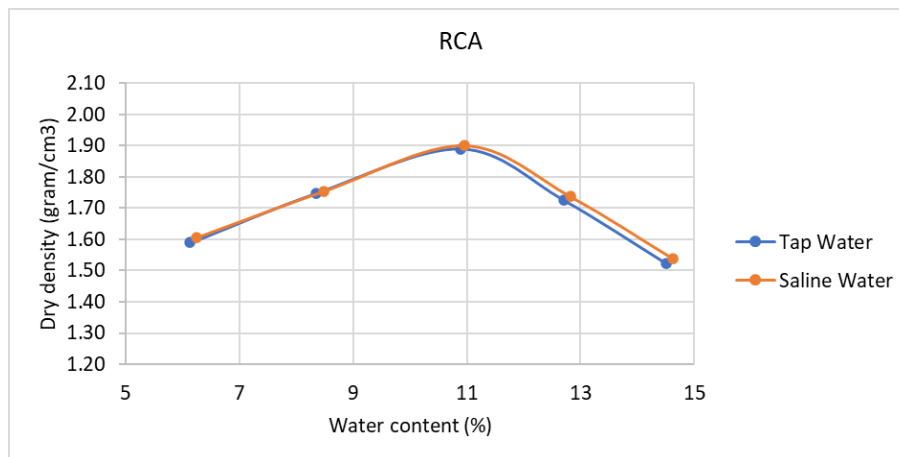


Fig. 5. Relationship between dry density and water content for 100% Recycled Concrete Aggregate (RCA) under both tap and saline water conditions.

The RCA samples showed an MDD of 1.89 g/cm^3 at an OMC of 10.89% using tap water, and 1.90 g/cm^3 at an OMC of 10.95% when compacted with saline water (Fig. 5). The nearly identical values indicate that RCA's compaction behavior was largely unaffected by salinity. A slight improvement in density with saline water may be due to the flocculation of fine particles as dissolved ions compress the electrical double layer surrounding residual cement paste, allowing tighter packing. However, the relatively high porosity of RCA limits the extent of this improvement.

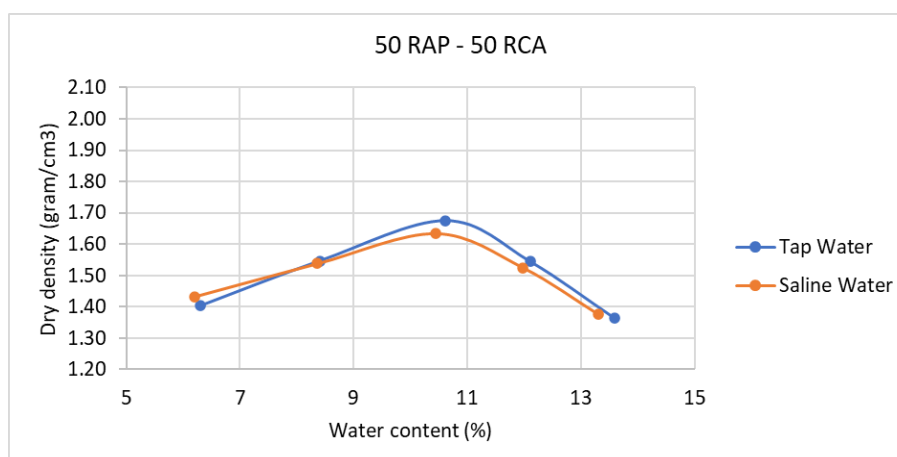


Fig. 6. Relationship between dry density and water content for the blended mixture of 50% RAP and 50% RCA compacted using tap and saline water.

For the 50% RAP – 50% RCA blend (Fig. 6), the maximum dry density was the lowest among all materials, reaching 1.67 g/cm³ at an OMC of 10.62% with tap water and 1.63 g/cm³ at an OMC of 10.45% under saline water. The combination of RAP’s coated surface and RCA’s porous texture likely hindered particle rearrangement during compaction. The slight decrease in MDD in saline water suggests that the mix’s overall response to salinity was governed by limited cohesion and reduced inter-particle contact efficiency.

In general, saline water produced only minor changes in compaction characteristics across all materials. Natural aggregate and RCA showed a small improvement in MDD, indicating a beneficial ionic effect on particle interaction, while RAP and the blended mix showed either negligible or slightly negative responses. These results imply that the use of saline water in compaction does not significantly hinder performance and may even provide minor benefits for certain aggregate types. The extent of salinity’s effect, however, depends strongly on the material’s surface condition, porosity, and the presence of bituminous coatings.

5. CBR Performance under Tap and Saline Water

The California Bearing Ratio (CBR) test is one of the most widely used indicators of base layer strength in pavement design. It reflects the combined effects of material density, particle interlock, and moisture condition on load-bearing performance. Since base layers are often exposed to varying moisture and salinity levels in coastal regions, understanding how these factors influence CBR behavior is essential for assessing long-term pavement stability.

In this study, CBR testing was carried out following the compaction tests to assess the bearing capacity of natural, recycled, and blended aggregates. All samples were compacted at their respective optimum moisture content (OMC) and maximum dry density (MDD), as determined from the Proctor tests, ensuring a consistent and realistic evaluation of strength. Since CBR performance is highly dependent on compaction quality, the small variations in OMC and MDD observed with saline water during the Proctor tests were expected to influence the bearing capacity, providing insight into how salinity affects the mechanical behavior of these base layer materials.

In accordance with the standard procedure (SNI 1744:2012), the 4-day soaking period was used as the reference condition to determine the soaked CBR value. For saline water exposure,

extended soaking durations of 7, 14, 28, and 56 days were applied to evaluate the long-term durability of the materials in aggressive environments.

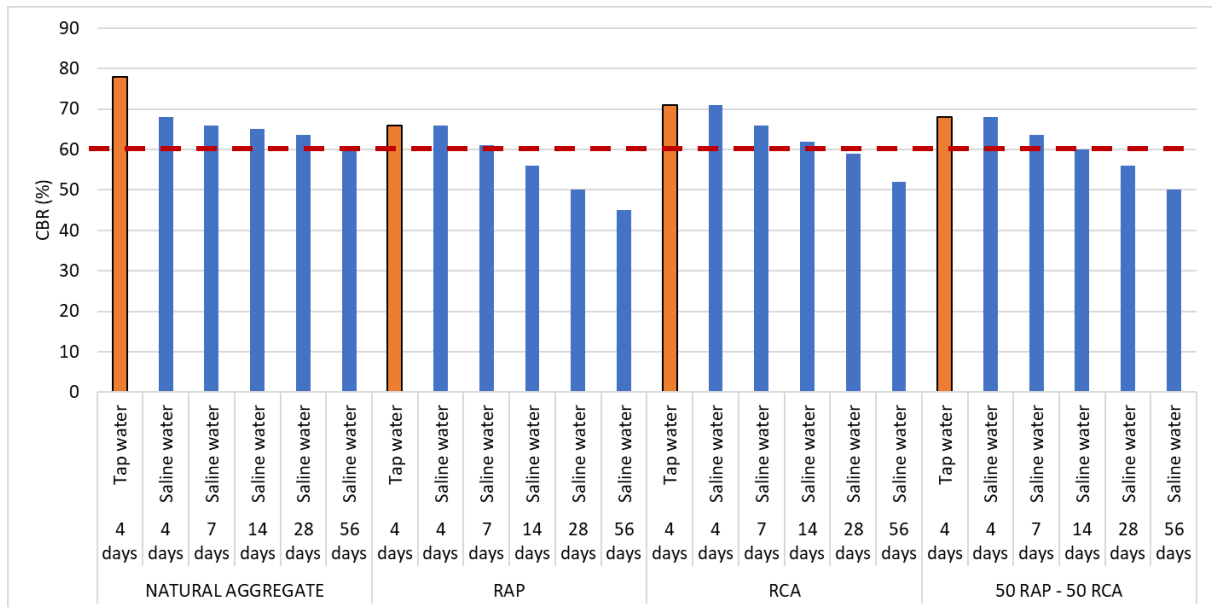


Fig. 7. Soaked CBR values of Natural aggregate, RAP, RCA, and RAP–RCA under tap and saline water at different soaking durations.

As shown in Fig. 7, all materials achieved CBR values exceeding the minimum specification of 60% under the 4 day-soaked condition, confirming their suitability for use in unbound base layers. The natural aggregate exhibited the highest CBR value of 78%, followed by RCA (71%), the 50% RAP–50% RCA blend (68%), and RAP (66%). These trends align with the Proctor results, where the natural aggregate attained the highest dry density, reinforcing the strong relationship between compaction quality and bearing capacity.

Under saline water conditions, all materials showed a gradual decline in CBR values with longer soaking durations. The natural aggregate’s CBR decreased from 68% after 4 days to 60% after 56 days. In contrast, RAP experienced the most significant reduction—from 66% to 45%—due to the softening of the aged asphalt film and reduced particle interlock under prolonged salt exposure. RCA and the blended mixture exhibited moderate declines, ending at 52% and 50%, respectively.

These results indicate that salinity has a cumulative weakening effect on aggregate strength, primarily through moisture ingress and salt crystallization within the pore structure. Nevertheless, all materials met or closely approached the minimum specification under the standard 4 day-soaked condition, suggesting that local and recycled aggregates remain feasible for base course applications when adequate drainage and compaction are maintained.

CONCLUSION

This study investigated the effects of saline water on the compaction and bearing capacity of natural aggregate, Reclaimed Asphalt Pavement (RAP), Recycled Concrete Aggregate (RCA), and a 50:50 RAP–RCA blend for Class B unbound base layers. The natural aggregate demonstrated

the highest compaction and soaked CBR values, with a 4 day-soaked CBR of 78%, followed by RCA (71%), the RAP–RCA blend (68%), and RAP (66%). Proctor tests showed that saline water caused only minor changes in Optimum Moisture Content (OMC) and Maximum Dry Density (MDD) for natural aggregate and RCA, slightly improving packing due to ionic effects, while RAP and the blended mixture were minimally affected or slightly reduced in density due to bituminous coatings and higher porosity. CBR tests confirmed that all materials met the minimum specification of 60% under the 4 day-soaked condition, but prolonged exposure to saline water caused gradual reductions, most notably for RAP, highlighting the importance of particle interlock, compaction quality, and material composition in resisting saline-induced weakening. Overall, the findings support the use of locally sourced natural and recycled aggregates for unbound base layers in coastal or saline-prone regions, provided proper compaction is achieved.

From a practical perspective, these results suggest that natural aggregates are preferable where long-term exposure to saline conditions is expected, whereas RAP and RCA can still be used effectively if proper drainage and surface protection measures are implemented. Compaction should always be carried out at the determined OMC to maximize dry density and bearing capacity, and periodic inspection or maintenance may be needed in areas exposed to prolonged salinity to ensure the structural performance of the base layer is maintained.

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