Effect of Water Acidity and Salinity on the CBR (California Bearing Ratio) of Compacted Laterite

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Abstract. Water in soil compaction mixtures serves as a wetting agent and lubricant during the compaction process. The salinity and pH of the water influence the behavior of soil, especially clayey soil. Field conditions result in water sources near construction sites being used for mixing and compaction, with varying pH and salinity levels. Flooding and tidal fluctuations also lead to compacted soil becoming submerged, resulting in changes in soil strength. This research aims to analyze the influence of river water ($pH < 7$) and seawater on the properties of laterite soil. The laterite soil with clay content was collected from the Bungur District, Tapin Regency. The water sources used include tap water, seawater from Kusan Hilir District, and acidic water sourced from a river in Mandastana District. The soil was compacted using both standard Proctor and modified procedures. Other tests conducted include the Atterberg limits and California Bearing Ratio (CBR). The research results indicate that there is an influence on the soil properties due to the water. The liquid limit and plastic limit decrease due to the influence of seawater and increase due to the influence of river water acidity. The maximum dry density increases due to the influence of seawater, and the optimum moisture content decreases. The most significant decreases in CBR values is observed due to the influence of seawater salinity, reducing from 19.94 % to 8.54 % for CBR with modified compactions and for CBR with standard proctor compactions from 9.74 % to 4.09 %. On the other hand, the influence of river water acidity results in a decrease compared to tap water, reducing from 19.94 % to 12.02 % for CBR with modified compactions and for CBR with standard proctor compactions from 9.74 % to 9.10 %.

Keywords: Laterite Soil; Salinity; $pH < 7$; CBR

1. Introduction

High salinity and pH can lead to changes in the geotechnical properties of soil [1]. The negatively charged surface of clay will attract positive charges from salts present in the soil pores [2]. Research conducted by several researchers on *kaolinite and montmorillonite* has shown that the quantity and distribution of charges on clay minerals depend on the pH of the water. In environments with low pH, the particle ends of *kaolinite* can become positively charged, subsequently resulting in attractive forces between the ends and the surfaces of adjacent particles, leading to cohesive properties [2].

In South Kalimantan Province, there is an abundant supply of fill materials, one of which is laterite soil. Laterite soil is found in various areas and is often located in

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mountainous regions. This type of laterite soil is widely used in construction work due to its superior strength compared to other soils. The physical and mechanical properties of this laterite soil vary depending on the mineral content and particle size distribution of the soil. Red laterite soil is predominantly composed of *kaolinite* [3].

Water is one of the essential components in construction material mixtures. It serves as a binding agent between fine and coarse aggregates when reacting with cement in concrete mixtures. In compaction work, water plays a role as a wetting agent for soil and a lubricant for the soil material, facilitating soil movement during compaction [4]. Therefore, the water used in material mixtures can potentially influence the strength of the material.

The potential strength of soil materials can be determined through laboratory testing, specifically the *California Bearing Ratio* (CBR) test [5]. The CBR test in the laboratory begins with compaction testing to obtain the optimum moisture content and maximum dry density, followed by penetration tests to determine the soil's resistance under loading. Compacted soil material is soaked in water as a simulation of field conditions when saturated with water from overflowing rivers during rainfall or tidal flooding. The soaked CBR value obtained represents the minimum strength value of the soil.

In field soil compaction, the choice of water type is typically based on the construction site's location, as it can minimize costs and streamline construction activities. Compacting soil with locally available water is a common practice, often with the assumption that water does not significantly affect the strength of the compacted soil, and various water sources are available for use. In the soil classification A-4, saline water does impact soil strength by increasing the maximum dry density and reducing the optimum moisture content [6]. The pH of water's influence on clayey soil explains the decrease in soil strength in tests such as UCS (Unconfined Compressive Strength) and CBR (California Bearing Ratio) at high levels of acidity and alkalinity [7]. Therefore, the impact of water type on soil strength is an interesting area for further research.

Furthermore, an issue that arises in low-lying areas of South Kalimantan Province is flooding from river overflow and tidal floods (tidal flooding). Flooding in these areas leads to changes in soil pH and salinity content depending on the type of water inundating them. Tidal floods will affect the behavior of clayey soil, and the soil affected by tidal flooding will have a higher dry density compared to soil that is not affected by it [8]. Therefore, the type of water inundating the soil will influence its properties, and most importantly, it will affect soil strength.

In general, when conducting laboratory tests on soil materials, distilled water or tap water is commonly used. The use of water directly sourced from the field may sometimes differ from laboratory conditions. This can be problematic if there are differences in the characteristics of soil materials, which can lead to a reduction in soil strength. To understand the influence of the type of water on soil strength, it is necessary to conduct tests using various types of water.

2. Materials Used

Laterite soil from the Bungur District in Tapin Regency was used in this research. The laterite soil used belongs to the coarse-grained soil category, with a composition of gravel 14.9%, sand 46.58%, silt 17.60%, and clay 20.92%, with a density of 2.677 g/cm^3. Tap water from Banjarmasin with a pH of 7.29 and salinity of 0.24 PSU was used. Saline water used was obtained from the sea in Gusunge Village, Kusan Hilir District, Tanah Bumbu Regency, with a salinity of 24.25 PSU and pH of 8.44. Acidic water was sourced from a river in Puntik Luar Village, Mandastana District, Barito Kuala Regency with a pH of 3.30 and salinity of 0.09 PSU.

3. Method

The research method employed was experimental, conducted in a laboratory setting. The soil was naturally dried and then mixed with different types of water, namely tap water from Banjarmasin, seawater sampled from Gusunge Village, Kusan Hilir District, Tanah Bumbu Regency, and river water from a river in Puntik Luar Village, Mandastana District, Barito Kuala Regency. Physical properties of the soil, such as particle size distribution analysis, were conducted following the standards outlined in SNI 3423-2008 [9], and soil density was determined as per SNI 1964-2008 [10]. The soil was initially mixed with water and left to stand for 24-48 hours to allow it to react with the water used. Subsequently, the liquid limit was tested using the four-stroke method (2 readings below 25 strokes and 2 readings above 25 strokes), and the plastic limit was determined following the standards in SNI 1966-2008 [11] and SNI 1967-2008 [12]. After mixing with water and ensuring homogeneity, the soil was subjected to standard and modified compaction tests as per SNI 1742-2008 [13] and SNI 1743-2008 [13] to obtain the maximum dry density and optimum moisture content values. Laboratory CBR testing was performed following the standards in SNI 1744-2008 [5] using the optimum moisture content obtained from the standard and modified compaction tests. The soil's CBR value was determined based on the maximum dry density value.

4. Results and Discussion

4.1 Soil Consistency Limits (Atterberg Limit Test)

The Atterberg limits values for laterite soil mixed with tap water, seawater, and river water yield different results, as seen in Table 1. These differences are due to the influence of seawater salinity and river water acidity. Salinity affects the soil's plastic limit value [15], as can be observed from the decrease in values for both tap water and river water. The soil's liquid limit also decreases due to the influence of salinity, as shown in Figure 1, similar to research on fine-grained soils that also experience a decrease in soil liquid limit values [15]. In clayey soil, the impact of seawater salt content reduces the soil's double layer, leading to a decrease in soil moisture content.

The comparison of soil liquid limit values can be seen in Figure 1. The liquid limit due the influence of salinity in sea water with 24.25 PSU will decrease compared to tap water with 0.24 PSU and river water of 0.09 PSU accordance with research on clayey soil, sandy clay and base course which decreases due to the influence of salt water [16], while due to the acidity of River water with a pH of 3.30 will experience an increase. Salinity greatly influences the properties of laterite soil by reducing the water content and the acidity of the water will increase the water content at the under the conditions of the soil's plastic limit.

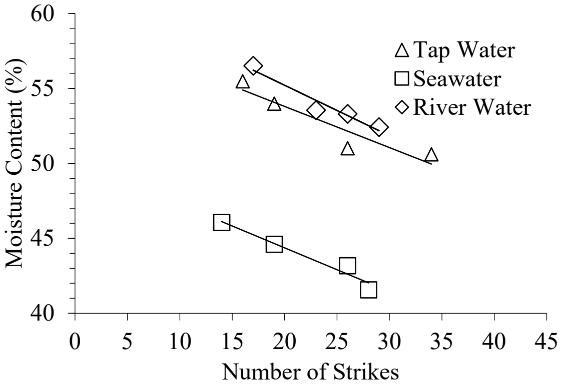

Fig. 1. Soil Liquid Limit

The Atterberg limits values experience a relatively small increase due to the influence of river water acidity compared to tap water, as shown in Table 1. The acidity with pH 3.30 gives minor impact on atterberg limit of the soil compared to tap water with pH 7.29. The decreasing water with pH 7.29 to water with pH 3.30 did not significantly affect changes in the properties of laterite soil with a clay content of 20.92%. The acidity with pH 3.30 gives minor impact on atterberg limit of the soil compared to tap water with pH 7.29. The decreasing water with pH 7.29 to water with pH 3.30 did not significantly affect changes in the properties of laterite soil with a clay content of 20.92%, as observed in Atterberg limit testing, as indicated in Table 1. However, there is a decrease in the plasticity index (PI) of the soil compared to tap water due to the influence of water pH. The pH value of water affects the PI, with a pH below 6 reducing the PI [17]. This aligns with the decrease in PI from 23.89% at pH 7.29 to 23.21 at pH 3.30.

Table 1. Results of Atterberg Limits Testing for Laterite Soil

Type of water	Liquid Limit (LL) %	Plastic Limit (PL) %	Plasticity Index (PI) %
Tap Water	52.42	28.54	23.89
Seawater	42.91	21.13	21.78
River Water	53.52	30.31	23.21

4.2 Dry Density and Optimum Moisture Content of Standard Proctor Compaction Testing

The graph of standard Proctor compaction results in Figure 2 indicates that the dry density values with the use of river water are the lowest among the use of tap water and seawater. This affects the maximum dry density value of the laterite soil, as shown in Table 2. The river water's acidity with a pH of 3.30 reduces the dry density value to 1.636 g/cm³.

Seawater salinity has a minor influence on coarse-grained laterite soil, similar to fine-grained soil [15]. The graph of standard Proctor compaction results in Figure 2 shows no significant difference in the use of tap water. However, when considering the maximum dry density, compaction with seawater results in a noticeable increase. This increase is attributed to the pore size distribution of the compacted sample being dependent on salinity [18], in line with other research showing an increase in maximum dry density [15][19]. Other studies [4] have also indicated an increase in maximum dry density due to the influence of salt.

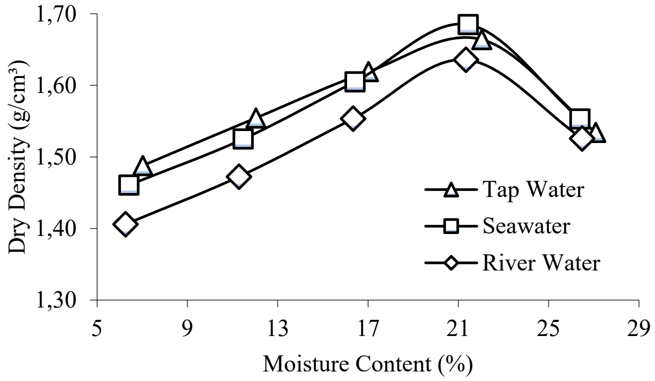

Fig. 2. Graph depicting the relationship between dry density and moisture content in standard Proctor compaction results

The values of maximum dry density and optimum moisture content can be seen in Table 2. The highest maximum dry density is achieved when seawater is used in standard Proctor compaction testing, while the lowest is obtained with river water. Salinity has an impact on increasing the maximum dry density value and decreasing the optimum moisture content, as observed in other studies [15][19][20]. The acidity of river water also has a relatively small influence, as seen from the relatively close difference in values.

Table 2. Values of Maximum Dry Density and Optimum Moisture Content from Standard Proctor Density Testing

Type of water	Maximum Dry Density gr/cm^3	Optimum Moisture Content %
Tap Water	1.66	22.0
Seawater	1.69	21.4
River Water	1.64	21.3

4.3 Dry Density and Optimum Moisture Content of Soil from Modified Compaction Testing

Figure 3 illustrates the values of dry density as a function of moisture content in the modified compaction results. The salinity of seawater and the acidity of river water have relatively insignificant effects on this laterite soil. The differences in results are only relatively small among the three modified compaction tests. However, the use of seawater yields a dry density value that is relatively higher compared to the others, indicating the influence of seawater salinity, as observed in other studies on standard Proctor compaction [15][19].

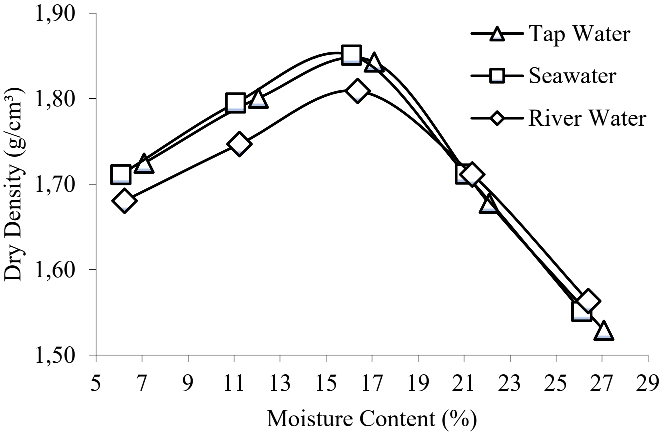

Fig. 3. Graph showing the relationship between dry density and moisture content in modified compaction results.

Table 3 presents the values of maximum dry density and optimum moisture content for the use of three types of water in modified compaction. The highest maximum dry density value is achieved when using seawater, in accordance with other studies [15][19], and the lowest is obtained with river water. Compaction results with seawater and tap water show relatively small differences in values. The significant differences in values are evident when river water is used compared to other types of water.

Table 3. Maximum Dry Density and Optimum Moisture Content Values from Modified Compaction Density Testing

Type of water	Maximum Dry Density gr/cm^3	Optimum Moisture Content %
Tap Water	1.84	17.1
Seawater	1.85	16.1
River Water	1.81	16.4

The lowest optimum moisture content is obtained when using seawater, as shown in Table 3, similar to standard Proctor compaction, which also experiences a decrease compared to tap water, as seen in other studies [15][19]. The difference in optimum moisture content values between tap water and seawater approaches 1%, indicating the influence of salinity on the optimum moisture content in modified compaction tests. The effect of river water acidity is also evident in the optimum moisture content of these laterite soil samples.

4.4 CBR Soaked for Laterite Soil

The CBR values with modified compaction and standard proctor compaction, soaked in each type of water, yield significantly different results, as depicted in Figure 5 and Table 4. The best results are obtained with compaction and soaking in tap water. Seawater salinity has a substantial impact on the CBR value of laterite soil, leading to a decrease from 19.94 % to 8.54 % for CBR with modified compactions and for CBR with standard proctor compactions from 9.74 % to 4.09 %. Additionally, river water acidity also influences the CBR value, as observed in other studies a decrease in pH below 7 can reduce the CBR value [7], although its effect is not as pronounced as that of seawater salinity. The effect of river water acidity results in a decrease compared to tap water, reducing from 19.94 % to 12.02 % for CBR with modified compactions and for CBR with standard proctor compactions from 49.74 % to 9.10 %.

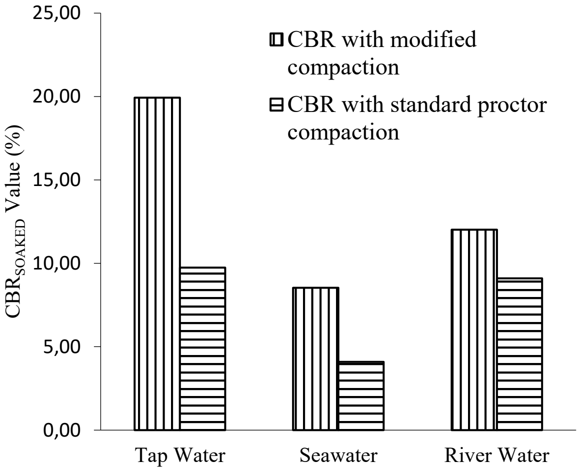

Figure 5. Laboratory CBR$_{\text{Soaked}}$ Values

Table 4. Laboratory $\mathrm{CBR}_{\mathrm{Soaked}}$ Values

Type of Water	CBR with modified compaction %	CBR with standard proctor compaction %
Tap Water	19.94	9.74
Seawater	8.54	4.09
River Water	12.02	9.10

5 Conclusion

The laterite soil from the Bungur District in Tapin Regency, with a clay composition of 20.92%, experiences a decrease in both liquid limit and plastic limit values due to the influence of seawater salinity and an increase due to river water acidity when compared to tap water. In general, the maximum dry unit weight of the laterite soil is higher when using seawater compared to other types of water, whether subjected to standard Proctor compaction or modified compaction, with values of 1.69 g/cm^3 and 1.85 g/cm^3, respectively. The impact of seawater salinity and river water acidity is clearly evident in the CBR (California Bearing Ratio) values, which experience a relatively high decrease when compared to the use of tap water. The salinity influence of seawater and also acidity influences of river water is obviously see on CBR soaked value which had decrease from tap water. The decrease in the CBR (California Bearing Ratio) values is evident when using modified compaction methods. The most significant reduction in CBR values is observed due to the influence of seawater salinity, reducing from 19.94 % to 8.54 % for CBR with modified compactions and for CBR with standard proctor compactions from 9.74 % to 4.09 %. Meanwhile, the effect of river water acidity results in a decrease compared to tap water, reducing from 19.94 % to 12.02 % for CBR with modified compactions and for CBR with standard proctor compactions from 9.74 % to 9.10 %.

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