Effect of Moisture Variation on the Compaction Result of Soft Clay

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Abstract. Soil moisture strongly affects compaction results, varying between rainy and dry seasons. In the rainy season, high rainfall saturates the soil, increasing pore pressure and reducing stability. Conversely, in the dry season, very low moisture inhibits particle bonding during compaction. This study examines the effect of moisture variation on soft clay compaction by comparing soil strength at equal dry unit weight (γd) in dry and wet zones. The experimental method includes testing soil physical properties and compressive strength, following Indonesian National Standard (SNI). Findings are expected to identify optimum moisture content and its implications for soil strength.

Keywords: Compaction, Dry volume weight, Optimum moisture content, Soil moisture, Soft clay.

1 Introduction

Soil is one of the main elements in infrastructure construction, especially in road and building construction. The quality of subgrade compaction greatly determines the bearing capacity, stability, and service life of the construction. Compaction is carried out with the aim of increasing the dry weight of the soil so that optimal strength and density are achieved. However, the effectiveness of the compaction process is greatly influenced by the moisture content of the soil [1]. In practice, seasonal conditions greatly affect soil moisture content. During the rainy season, the soil tends to be saturated with water (wet zone). Excess water fills the soil pores, causing high pore pressure and reducing the bonds between particles, making it difficult to achieve maximum density. Conversely, during the dry season, the soil is in a dry condition (dry zone) with low moisture content. Soil particles become rigid and difficult to move, causing compaction to be in effective [2] [3]. These two extreme conditions show that both excessively high and excessively low moisture content reduce compaction results.

This phenomenon becomes even more complex in soft clay (soft loam), which has high plasticity, is sensitive to water, and has the potential for volume expansion [4]. High plasticity allows soil particles to easily return to their original position after being subjected to pressure.

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Sensitivity to water causes soil strength to decrease dramatically when saturated, while the potential for volume expansion causes the soil to expand again after compaction if the water content increases. These conditions make soft clay one of the most challenging types of soil to compact.

Laboratory tests, such as the Proctor test, show a direct relationship between moisture content and dry bulk weight of soil. The compaction curve shows that at optimum moisture content, the soil will reach maximum density. However, when the moisture content is below (dry zone) or above the optimum point (wet zone), the density value decreases even though the compaction energy applied is the same [4]. This means that the compaction of soft clay soil is highly dependent on controlling the moisture content to be around the optimum value.

Problems in the field often arise because soil moisture conditions are unstable due to tropical climate change, especially in Indonesia. Roads and structures built on soft clay with suboptimal compaction are prone to settlement, cracking, and even structural failure. In fact, data shows that 750 km of provincial roads in North Sumatra have suffered severe damage due to poor subgrade compaction and uncontrolled moisture content [5].

Based on this phenomenon, research on the effect of water content variation on the compaction of soft clay is important. This study is expected to determine the optimal moisture content in dry and wet zones with the same dry weight, while analyzing the differences in soil compressive strength. The results of this study are not only academically useful, but also provide a real contribution to construction practices, particularly in improving the quality and durability of infrastructure in areas with soft clay soil conditions.

2 Method

2.1 Sampling areas and Laboratory materials

Soil samples in this study were taken from Sari Nembah Village, Karo Regency, North Sumatra Province, which is known to have soft clay soil characteristics with high plasticity, low bearing capacity, and high sensitivity to changes in water content. These conditions make this location relevant as a representation of subgrade soil in road and building construction in tropical climates.

The type of sample used was a disturbed sample, which is soil that was taken without maintaining its original structure, but whose physical properties were preserved. The sampling process was carried out at a certain depth and the samples were stored in closed containers to avoid changes in moisture content. In the laboratory, the samples were air-dried and tested for their physical properties, including natural moisture content, specific gravity, liquid and plastic limits, and particle size distribution.

2.2 Sampling procedure

Sampling is carried out by digging the soil at a certain depth using a hoe or simple soil drill. The soil samples are placed in thick plastic bags or sealed containers to prevent changes in moisture content due to evaporation or contamination during transportation. Each sample is labeled with the location, depth, and time of collection for easy identification.

Upon arrival at the laboratory, the samples are first air-dried before undergoing physical property testing, such as natural moisture content, specific gravity, Atterberg limits, and grain size analysis. The next stage is to determine the optimum moisture content through a standard Proctor test and evaluate the soil strength with an unconfined compressive strength (UCS) test.

2.3 Testing procedure

To determine the characteristics of landslide is done by testing soil physical properties first before, which consists of: (1) testing Water Content in accordance with sni 03-1965-1990 [6]; (2) testing Sieve Analysis in accordance with sni 3423:2008 [7]; (3) testing soil Specific Gravity in accordance with sni 1964:2008 [8]; (4) testing Liquid Limit in accordance with sni 1967:2008 [9]; (5) testing Plastic Limit in accordance with sni 1964:2008 [10]; (6) testing Shrinkage Limit in accordance with sni 3422:2008 [11]; (7) testing soil Density in accordance with SNI 1742:2008 [12].

3 Research and discussion

3.1 Results

Laboratory research results on soft clay samples from Sari Nembah Village, Karo Regency, North Sumatra, show the physical characteristics of the soil with a natural moisture content of 36.60%, specific gravity (Gs) of 2.62 g/cm³, liquid limit (LL) of 54.99%, plastic limit (PL) of 27.38%, shrinkage limit (SL) of 15.53%, and plasticity index (PI) of 27.61%.
After conducting physical testing, the next step is to conduct proctor test. The results of the proctor test show a relationship between water content (w) and dry weight (γd) of the soil, with the aim of obtaining the optimum moisture content (OMC) and maximum dry weight (γdmax). The graph of the standard compaction test results for soil from Sari Nembah Village is shown in Figure 1 below.

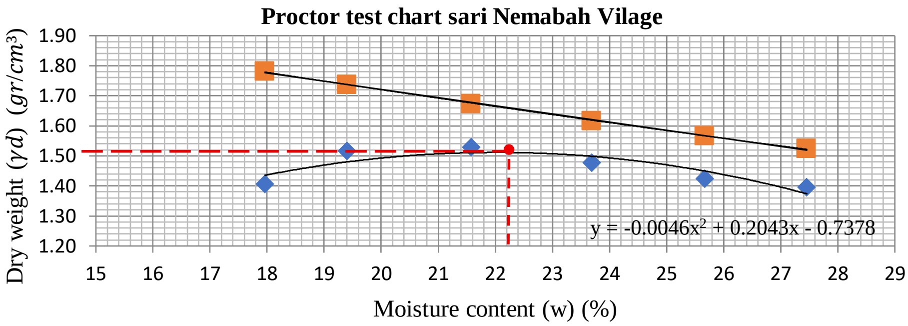

Fig. 1. Proctor test chart.

Based on Figure 1 above, the analysis results show that the maximum dry weight of 1.51 g/cm³ is achieved at an optimum moisture content of 22.2%. The parabolic curve pattern reflects the general behavior of soil during the compaction process. The Proctor graph displays the relationship between moisture content w (%) on the horizontal axis and dry unit weight γd (g/cm³) on the vertical axis for the "Sari Nemabah Village" sample, with two sets of test points plotted as different symbols and each fitted by a polynomial curve that decreases as w increases. The ZAV points lie within w ≈ 18–27% with γd around 1.55–1.78 g/cm³, while the compaction points lie within w ≈ 18–27% with γd around 1.38–1.52 g/cm³, indicating differing compaction responses between two conditions or specimen treatments. The trend equation shown in the lower-right area represents a quadratic regression for one dataset, indicating a peak γd at a certain water content before decreasing at higher w, consistent with typical Proctor curve behavior.

Interpretively, the trend shows that at low water contents (around 18–20%) γd increases toward a peak, then gradually decreases when w exceeds about 22–23%, consistent with the behavior of cohesive soils that are sensitive to changes in water content. The elevation difference between the orange and blue curves at the same w range suggests differentiating factors such as compaction energy, degree of reworking, or variations in index properties that yield different maximum γd between the datasets. As a continuation of this analysis, soil moisture content in two zones, namely the dry zone and the wet zone, is presented in the following section."

Dry zone. The moisture content value in the dry zone based on dry weight (γd) is as shown in the Table 1 below.

Table 1. Dry zone based on dry weight.

Dry weight (gr/cm³)	moisture content (%)
1,44	16,89
1,45	17,32
1,46	17,74
1,47	18,16
1,48	18,58
1,49	19,0
1,5	19,42
1,51	19,84
1,52	20,52

Wet zone. The moisture content value in the wet zone based on dry weight (γd) is as shown in the Table 2 below.

Table 2. Wet zone based on dry weight.

Dry weight (gr/cm³)	moisture content (%)
1,44	27,15
1,45	26,67
1,46	26,18
1,47	25,75
1,48	25,27
1,49	24,78
1,5	24,53
1,51	23,87
1,52	23,38

3.2 Discussion

The findings of this study validate that moisture variation significantly influences the compaction behavior of soft clay. The Proctor test found that the best moisture content (OMC) was 22.2% and the highest dry density was 1.51 g/cm³. This is in line with the general principle of compaction, which Hardiyatmo [4] points out: adding water to soil increases its density until the OMC is reached, after which adding more water lowers density because pore water pressure builds up.

A comparative analysis of dry and wet zones offers enhanced understanding. The dry zone reached this value at a moisture content of 19.84%, while the wet zone needed 23.87%. The dry density was the same in both cases (γd = 1.51 g/cm³). This difference is due to the fact that soils in the wet zone have more pore water, which makes particle interlocking less strong and lowers effective stress. The soils in the dry zone, on the other hand, have stronger contact between particles but less lubrication, which may also make it harder for grains to move around. This duality corroborates the conclusions of Utami and Caroline [2] who highlighted that variations in water content markedly affect the shear strength parameters of clay soils.

The results are also in line with what Wulandari and Tjandra [3] found: that the plasticity index has a big effect on how much soil strength decreases when the water content changes. The tested soil in this study has a plasticity index of 27.61%, which puts it in the highly plastic category. This explains why it is so sensitive to changes in moisture. When it rains, high-plasticity clays tend to swell, and when it dries, they tend to shrink. If you compact them outside of the best range, they can become unstable.

From an engineering point of view, the results show how important it is to change compaction strategies based on the seasons in tropical areas. In the rainy season, too much moisture makes it hard to reach the target density, and in the dry season, not enough moisture makes it hard to compact. This is why iNews Sumut [5] says that poorly compacted subgrades in North Sumatra have caused a lot of damage to roads. The results of this study demonstrate that sustaining soil moisture levels near the OMC is not merely advantageous but crucial for the enduring functionality of infrastructure on soft clay subgrades.

Micro and geotechnical mechanisms. Performance differences at identical γd arise from changes in micro-fabric: the wet path increases pore pressure and promotes a more dispersed structure, reducing effective stress and particle interlocking; the dry path preserves more effective grain-to-grain contact, albeit with less lubrication. In soils with PI ≈ 27.61% (high plasticity), small changes in water content around the OMC trigger shifts in the orientation of platy minerals and pore distribution, so sensitivity to deviations of ±2–3% from OMC becomes significant for γd and strength. Thus, “optimum compaction” is the outcome of a combination of compactive energy, water content, and the pathway by which the microstructure is formed.

The field implications of this research are especially pertinent for infrastructure development in tropical climates. First, controlling moisture should be the most important thing to do during field compaction. This can be done by drying out soils that are too wet (for example, by aerating them or treating them with lime) or by adding water to soils that are too dry before compaction. Second, compaction should be done when the soil is between rainy and dry seasons, when the moisture levels are closer to what is best for it. Third, construction specifications should not only require reaching the target dry density, but they should also require keeping the moisture level within ±2% of OMC, as many geotechnical standards suggest. Using these strategies, engineers can lower the chances of settlement, cracking, and early pavement failure on roads and buildings built on soft clay subgrades.

To sum up, this study adds to the theoretical framework that soil compaction is a balance between pore water resistance and particle lubrication. The innovation consists in showing, through controlled laboratory tests, that the same dry densities in dry and wet zones can lead to different soil strengths because of structural differences caused by moisture. The combination of lab results with real-world effects makes this study very useful for geotechnical work, especially in Indonesia and other tropical areas where the amount of rain changes a lot from season to season.

4 Conclusion

This study shows that changes in moisture have a big effect on how well soft clay compacts. The Proctor test showed that the best moisture content (OMC) was 22.2% and the highest dry density was 1.51 g/cm³. Soils in the wet zone needed more moisture (23.87%) than soils in the dry zone (19.84%) at the same dry density. This shows that the amount of water in the soil directly affects its structure and strength. These results show that just reaching the target dry density is not enough; controlling the moisture around the OMC is necessary to make sure the strength and stability last. For field applications, compaction should be conducted with careful regulation of soil moisture, either by drying wet soils or adding water to dry soils, and ensuring that construction practices maintain water content within an effective range. This approach will enhance the quality and longevity of infrastructures built on soft clay in tropical regions.

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