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A Comprehensive Literature Review on Geotechnical Stabilization Techniques for Soft Soil in Swampy Areas of South Kalimantan.

Zelby Rahayu[1*], Laili Norfajriati[2], Diah Octarinie[3]

[123]Universitas Sapta Mandiri, Balangan, Kalimantan Selatan, Indonesia

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*)Koresponden email:
raninszalma.univsm.ac.id*)

Abstract

South Kalimantan is a province in Indonesia with unique geographical characteristics dominated by extensive swamplands. According to data from the Central Statistics Agency (2023), the area of swampland in South Kalimantan reaches approximately 2.5 million hectares or approximately 66% of the total area of the province. This condition also presents its own challenges in planning and implementation of construction. Kalimantan has peat characteristics that are prone to land subsidence and have very low bearing capacity, indicating that the NSPT and sondir values on the ground surface are relatively small, with an average value of 5. This study analyzes geotechnical engineering techniques in swamplands in South Kalimantan through a systematic literature review of 22 selected publications from various databases. Qualitative analysis focused on soil improvement techniques, soil stabilization, and improvement methods. The results of the analysis indicate that preloading technology with Prefabricated Vertical Drain (PVD) and Vacuum Preloading can reduce land subsidence and accelerate consolidation. The geotechnical characteristics of swamplands show high complexity. The preloading method with PVD proved to be the most effective (67% adoption), capable of reducing settlement by 60% and accelerating consolidation by 4.2 times. Based on the literature review obtained regarding geotechnical engineering techniques, the analysis results show that suitable improvements to swampy soil are using Preloading Vertical Drain (PVD) and vacuum preloading to accelerate soil consolidation.

PENDAHULUAN

South Kalimantan is a province in Indonesia with unique geographic characteristics, dominated by extensive swamplands. According to data from the Central Statistics Agency (2023), the area of swampland in South Kalimantan reaches approximately 2.5 million hectares, or approximately 66% of the province's total area. These swamplands consist of tidal swamps, lowland swamps, and non-tidal swamps spread across various districts (Noor et al., 2019). The significant dominance of swampland makes South Kalimantan the province with the greatest wetland development potential in Indonesia. This condition also presents unique challenges in regional planning and development, particularly in aspects of land use, environmental sustainability, and socio-economic adaptation of local communities. (Balitbangda Kalimantan Selatan, 2023; Sugiartanti & Sarah, 2020; Muhammad, Arif, & Lili, 2007).

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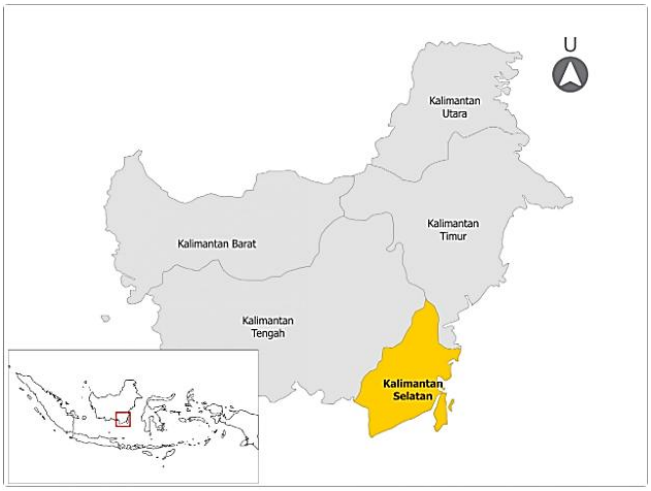

Figure 1. Location Map of South Kalimantan
Source: South Kalimantan BPS Data (2023)

Geographically, South Kalimantan is located between 114°19'33" – 116°33'28" East Longitude and 1°21'49" – 1°10"14" South Latitude. Geographically, it is located in the southern part of Kalimantan Island with boundaries: to the west with Central Kalimantan Province. to the east with the Makassar Strait. to the south with the Java Sea and to the north with East Kalimantan Province. Its area is approximately 38,744.23 km2 or 6.98 percent of the area of Kalimantan Island and 1.96 percent of the area of Indonesia. Topographically, the area of South Kalimantan Province consists of 4 parts. namely alluvial plains. swamp plains. hills and mountains. Land slope with 4 classification classes shows that 43.31% of the area of South Kalimantan Province has a land slope of 0-2%. (www.kalselprov.go.id). Geographical map images and geological maps can be seen in **figures 2.3.**

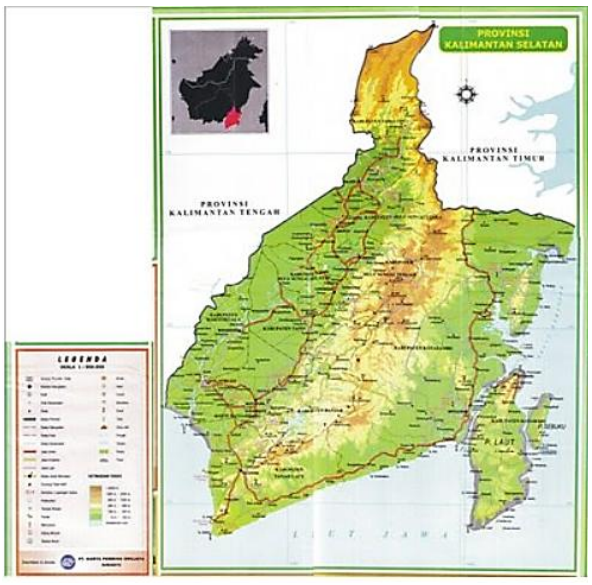

Figure 2. Geographic Map of South Kalimantan
Source: Meratusgeopark.org

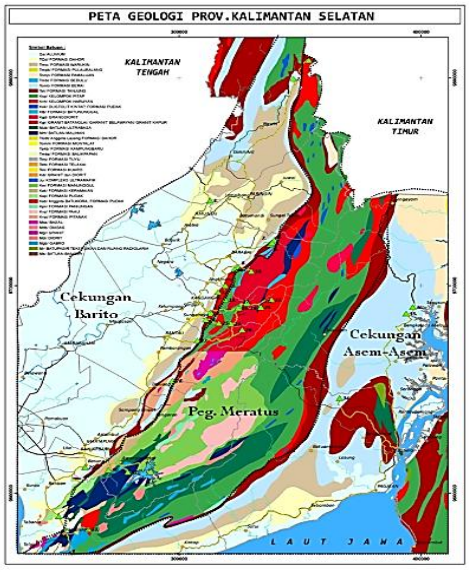

Figure 3. Geological Map of South Kalimantan
Source: Meratusgeopark.org

The swamplands of South Kalimantan were formed through thousands of years of sedimentation, resulting in ecosystems with high biodiversity but also complex management. The tidal swamps that dominate coastal areas are influenced by tidal dynamics, while the lowland swamps scattered along major rivers experience water level fluctuations according to the seasonal cycle of rain and dry seasons. These hydrological dynamics pose challenges in the

planning and implementation of sustainable infrastructure development, particularly related to water control, accessibility, and environmental conservation. The characteristics of swamp soil, characterized by low bearing capacity, high water content, and high compressibility, pose significant technical challenges in construction. This soil generally contains high levels of organic matter and has very low Standard Penetration Test (N-SPT) values, ranging from 0 to 5, reflecting very soft and easily deformed soil conditions. In addition, high soil water content can reach 200-400% of dry weight, indicating dominant plastic properties and making the soil very susceptible to significant settlement when given structural loads (Muhammad, Arif, & Lili, 2007; Sugiartanti & Sarah, 2020; Balitbangda South Kalimantan, 2023).

Based on the test results on soil samples from Tumbang Nusa, it indicates that the soil along the Trans Kalimantan Highway has peat characteristics that are easily subsided and have very low bearing capacity (Handali, S, 2014). The results of the study (Maa'ruf, 2021), show that the NSPT and sondir values on the soil surface in Banjarmasin City are relatively small, namely an average value of 5 with the dominant soil layers in the surface layer in Banjarmasin City being organic clay and silty clay, which are included in the soft soil category.

Based on the urgency of this background, appropriate and effective geotechnical engineering construction for geotechnical reinforcement and stabilization in swamplands in South Kalimantan has become a strategic imperative. The increasing acceleration of infrastructure development and the pressure to achieve land optimization have driven this urgency. Therefore, a "Comprehensive Literature Review on Geotechnical Stabilization Techniques for Soft Soil in Swampy Areas in South Kalimantan" was conducted to produce appropriate and efficient geotechnical engineering solutions.

Literature Review

The swamplands of South Kalimantan are dominated by soft soils consisting of organic clay and very soft clay. Geotechnically, these soils have very low bearing capacity and high water content. Their main characteristic is high compressibility (with an extreme compressibility index of 2–8, compared to typical mineral soils of only 0.1–0.5), which causes significant and uneven settlement of the overlying structures. Hydrologically, the majority (72%) are tidal swamps, and the permanently saturated conditions limit oxygen, triggering the formation of pyrite and acid sulfate soils (Adam, 2025). According to Geotechnical Guidelines 1 (2001), soft clay soils are soils containing clay minerals and have a high water content, which results in low shear strength.

Clay Soil

Clay is defined as having particles measuring 0.002 mm (= 2 microns). However, in some cases, particles measuring between 0.002 mm and 0.005 mm are also classified as clay (ASTM D-653).

Physical and Mechanical Properties

Tidal swamp soils exhibit high variability in physical properties, including low permeability and high sensitivity to load changes, necessitating technologies such as preloading with Prefabricated Vertical Drains (PVDs) to accelerate consolidation and reduce settlement by 45–67%. The stratigraphy of the layers is dominated by organic clay at shallow depths, with minimal slope gradients (0–2%) and low elevations (1–3 m). This creates unique challenges for road and building construction, where geotextiles or geocells with local infill can improve stability and reduce pavement thickness by up to 30% (Marzuki, 2024).

Soil Stabilization

Terzaghi, 1987, defines clay as an aggregate of microscopic and submicroscopic particles derived from the weathering of chemical elements that make up rocks and is plastic in a moderate to wide range of water contents. When dry, it is very hard and not easily peeled off with just the fingers. Clay permeability is very low. The term "gumbo" is used, especially in

western America, for clay whose plastic state is characterized by its soapy or waxy appearance, and is very hard. At higher water levels, clay will be sticky (cohesive) and very soft.

Soil stabilization is an effort to increase the stabilization and bearing capacity of the soil. According to Bowles (1984), if the soil in the field is very loose or very easily compressed, or if it has an inappropriate consistency index, a permeability that is too high, or other undesirable properties that make it unsuitable for a development project, then the soil must be stabilized.

Geotextiles

Geotextiles are sheet materials made from polymeric textiles with water permeability. They are divided into non-woven and woven geotextiles. They are commonly used when in contact with soil, rock, or other geotechnical materials.

Research Methods

This study was conducted using a Systematic Literature Review (SLR) to present an objective analysis. Using a qualitative approach, this study seeks to provide a comprehensive analysis of the developments and technologies used in geotechnical engineering construction on swampy land.

The reference search process in this study was conducted through Google Scholar, Sciencedirect and Publish or Perish Therefore, the keywords used in the search: "swamp land", "geotechnical engineering", "soil improvement" and "soil construction". The use of double quotation marks in the search so that the search results display the keywords in full and not separated. This aims to get search results that are not separated.

Results and Discussion

Based on the search results of the articles/journals obtained, there were 22 (twenty-two) references whose titles matched the keyword criteria entered in the search. Of the twenty-two articles/journals, there was 1 article that used English, Then there were 9 (nine) articles/journals that were excluded because they did not meet the journal article criteria, Thus, 13 (thirteen) articles/journals were obtained that could be used that met the criteria from 2009 – 2025.

Table 1. Results of Articles/Journals That Meet the Criteria

No.	Author	Years	Title	Journal
1.	Adam et al	2025	Construction Technology in Swamp Lands in South Kalimantan: A Systematic Literature Review	Journal of Construction Engineering (JRK) Vol. 4 No. 1 June 2025 ; Pp. 52 - 64
2	Gymnastiar et al	2024	Study on the Planning of Cliff Reinforcement Structures as an Effort to Control Landslides in the Kusan River, Tanah Bumbu Regency, South Kalimantan	Journal of Water Resources Technology and Engineering Vol. 04 No. 01 (2024) 1-14
3	Agusniansyah, Sarbini	2024	House Foundation Reinforcement Efforts for Swampy Land in Banjarmasin	G-Tech: Journal of Applied Technology Vol. 8, No. 2, April 2024, pp. 1320-1327
4	Wahyu P. Kuswanda	2015	Problems of Infrastructure	Proceedings of the National Seminar on Civil

			Development on Soft Clay Soil and Alternative Methods for Handling Them	Engineering, Unlam "Sustainable Development in Wetlands" 16-17 October 2015
5	Martini	2015	Study of Peat Soil Bearing Capacity with Geotextile Reinforcement and Changes in Groundwater Level	Infrastructure Vol. 5 No. June 1, 2015:51-59
6	Ishmah et al	2019	The Effect of CBR Value and Shear Strength of Peat Soil Stabilized Using Petrasoil with Portland Cement	Pillar Journal of Civil Engineering Vol.14 No. 01, March 2019
7	Ahsan et al	2021	Land Subsidence Analysis Using the Vacuum Consolidation Method with Variations in PVD Installation Distance	Konstruksia Journal | Volume 13 Number 1 | [Annur-Gusneli-Yanti December] 2021
8	Ma'ruf et al	2021	Digital Mapping of Soil Layer Types in 9 Settlements in Banjarmasin City	Agregat Vol. 6, No. 1, Mei 2021
9	Tjitradi, at al	2020	Modeling of Building Damage Due to Foundation Subsidence in Wetlands in Banjarmasin City	Kacapuri Journal Civil Engineering Scientific Journal Volume 3 Number 2 December 2020 Edition
10	Rachman A, Nugroho S.A	2009	The Effect of Geotextiles on the Bearing Strength of Footing Foundations on Peat Soil	Civil Engineering Communication Media Year 17, No. 2 June 2009
11	Agista Tri Kurniawan et al	2025	Land Improvement Planning Using PVD (Prefabricated Vertical Drain) and Embankment (Preloading) in the Construction of the ITS Tower 3 Building	Global Research And Innovation Journal (GREAT) Volume 1, Nomor 3, 2025, Hal. 833-845 ISSN : 3090-3289
12	Oktarini, Triyadi	2014	Criteria for Development of Riparian Wetlands Using an Ecosystem Approach	Proceedings of the 2014 IPLBI Scientific Meeting
13	Shaygan et al		Characterizing Soil Physical Properties Of Selected Temperate Highland Peat Swamps On Sandstone In The Sydney Basin Bioregion	Journal Of Hydrology: Regional Studies

Source: Processed by the author (2025)

Conclusion

Infrastructure development on soft clay soil faces serious geotechnical constraints in the form of minimal bearing capacity and high compressibility levels that trigger long-term consolidation. Inadequate handling of these soil conditions can result in differential land settlement and structural failure. Therefore, this study focuses on the evaluation of two soil stabilization methods (soil improvement): preloading with PVD assistance and its alternative, the vacuum consolidation method. The geotechnical characteristics of swamp land show high complexity. Preloading technology with PVD has proven to be the most effective (67% adoption), capable of reducing settlement by 60% and accelerating consolidation by 4.2 times (Adam, 2025). Based on the literature review obtained on geotechnical engineering stabilization techniques in swamp areas, the author recommends improvements to swamp land using Preloading Vertical Drain (PVD) and vacuum preloading to accelerate soil consolidation.

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