



Available online at
<https://jurnalteknik.unisla.ac.id/index.php/CVL>
<https://doi.org/10.30736/cvl.v2i2>



Stabilization of Coastal Embankments with Geotextile and Gabion Structures: Insights from a Tidal Zone Road Project

Dian Kharisma Dewi ^{1*}, Ferly Oktavia ²

^{1,2*}Dosen Program Studi SI Teknik Sipil, Universitas Maritim Raja Ali Haji
Email : ^{1*}diankharisma@umrah.ac.id. ^{2*}ferlyoktavia@umrah.ac.id

ARTICLE INFO

Article History :

Article entry : 07-07-2025
Article revised : 19-07-2025
Article received : 01-09-2025

Keywords :

Coastal Road; Soft Soil;
Geotextile; Gabion; Tidal zone.

IEEE Style in citing this article:

Dian Kharisma Dewi and Ferly Oktavia, "Stabilization of Coastal Embankments with Geotextile and Gabion Structures: Insights from a Tidal Zone Road Project", *CVL*, vol. 10, no. 2, pp. 141–150.

ABSTRACT

This study presents a technical overview of a coastal road embankment constructed in a tidal zone of a small island in Indonesia. The objective is to document the integrated application of non-woven geotextile and multi-level gabions as a stabilization system on moderately strong subgrade soils affected by tidal dynamics. The research method involved descriptive analysis based on as-built documentation and field data, including California Bearing Ratio (CBR) tests at three locations. The results showed CBR values ranging from 41.11% to 60.84%, which classify the subgrade as moderately strong. Despite this, the use of geotextile was essential to prevent mixing of soft subgrade and fill material, provide load distribution, and ensure drainage, while the gabion structures acted as lateral confinement and toe protection against erosion caused by tidal infiltration. The findings suggest that soil strength alone is insufficient for coastal infrastructure design, and integrated stabilization measures should account for environmental forces such as saturation cycles and hydraulic pressure. This case offers a practical insight into adaptive geotechnical strategies for road construction in tidal zones, serving as a reference for similar projects in archipelagic and low-lying coastal regions.

1. Introduction

Road infrastructure functions as the vital foundation of the transportation system and is essential for supporting socio-economic activities, thus requiring regular maintenance to ensure optimal performance[1]. The development of road infrastructure in coastal areas is vital for regional growth in archipelagic regions. Accessibility and connectivity support population mobility, logistics distribution, and socio-economic activities. In the Riau Archipelago, activity centers are typically located near shorelines, a pattern rooted in historical maritime trade routes, where coastal proximity facilitated boat access and cargo operations[2]. The coastal site lies within a tidal zone that experiences mixed tide patterns, with high fluctuation amplitudes. Tanjungpinang waters have an average MHWL of approximately 98.2 cm and an MLWL of 8.8 cm [3], contributing to cyclic saturation effects and posing challenges for embankment durability.



Copyright © 2025 Dian Kharisma Dewi, et al. This work is licensed under a [Creative Commons Attribution-ShareAlike 4.0 International License](https://creativecommons.org/licenses/by-sa/4.0/). Allows readers to read, download, copy, distribute, print, search, or link to the full texts of its articles and allow readers to use them for any other lawful purpose.

However, developing infrastructure in intertidal zones presents distinct geotechnical challenges due to tidal fluctuations and soil saturation. Although the subgrade in some areas may exhibit moderate bearing capacity, the dynamic influence of seawater levels and seasonal saturation demands additional protective measures[4]. Geotechnical, soils in tidal zones often clayey or silty can retain high moisture and remain sensitive to tidal variation. Furthermore, clay hardens when it dries and becomes plastic when combined with water [5]. Even with moderate to strong CBR values, fluctuation in pore water pressure and loss of confinement near the shoreline can compromise slope integrity. Thus, stabilization systems must not only address vertical loading, but also lateral pressure and erosion due to cyclic wetting, drying, and tidal currents.[6]. A widely adopted solution is the use of non-woven geotextiles, which act as separation, filtration, and reinforcement layers preventing subgrade-fill mixing and enhancing load distribution[7]. Geotextiles, geocells, and geo-composite blankets are widely used to control erosion on embankment slopes, particularly in railways, highways, and landfills. These slopes are highly susceptible to erosion caused by rainfall and wind, which can dislodge soil particles from the exposed surface, thus weakening its stability [8]. However, the strength of the embankment soil is primarily determined by its mechanical properties, particularly the internal friction angle and cohesion, which are fundamental parameter in governing slope stability and resistance to potential failure [9]. Nevertheless, an effective alternative to preserve slope stability in this situation is to implement sustainable and eco-friendly protective measures. Geotextile increases the bearing capacity of soil and the improvement of soil strata beneath the highway pavement so that undulations can be avoided and the life span of road increases[10]. Multi-level gabion structures provide effective lateral protection; they control toe erosion and resist earth pressure, while offering installation flexibility[11]. In modern coastal embankment design, the integration of non-woven geotextiles with multi-level gabion structures has been recognized as an effective hybrid approach. Geotextiles act not only as separators and filters but also contribute to reinforcement by distributing load and minimizing differential settlement[12]

Concurrently, gabion structures enhance embankment resilience by dissipating wave energy and providing structural support at vulnerable zones such as the embankment toe (hydrodynamic performance studies)[13]. Studies demonstrate that geotextile reinforcement improves subgrade capacity even in regions with soft, saturated soils. For example, the stabilization of soft subgrades through geotextiles enhanced the modulus of subgrade reaction and substantially reduced settlement rates [14]. In tidal environments, where hydrodynamic loads fluctuate daily, the structural integrity of gabion systems both individually and in combination with geotextiles has been validated through experimental and field-scale testing. Despite extensive research on geotextiles and gabions in general contexts, their combined application for coastal road embankments specifically within tidal zones remains underrepresented in literature. Most studies focus on separate applications either embankment reinforcement or erosion control while integrated field-based examinations are scarce[15]. This gap highlights the need for focused technical evaluations on hybrid stabilization systems under the dual stresses of soil and tidal dynamics in real-world projects.

Prior research has confirmed geotextile effectiveness in soft-soil embankment improvement and gabions in shoreline protection, yet combined application for coastal road embankments is underexplored, especially in field-based technological perspectives[16] multi-level gabions as lateral support structures. Subgrade strength was assessed through field-based California Bearing Ratio (CBR) tests conducted at three points along the alignment, yielding values ranging from 41.11% to 60.84%. The CBR and shear parameters are determined for different combinations of subgrade thickness[17]. These results indicate moderately strong subgrade conditions, yet given the tidal zone location and embankment height (4–6 meters), the use of integrated stabilization systems remained essential to enhance safety and durability. Accordingly, this study aims to document the applied stabilization system from an engineering

perspective, highlighting the rationale, configuration, and functional role of each structural component. By presenting technical insights and contextual considerations, this article seeks to contribute to the limited body of knowledge on integrated geotextile–gabion applications for coastal embankment development in tidal environments.

2. Research Method

This study adopts a qualitative case study approach to examine the engineering system applied in the construction of a coastal road embankment within a tidal zone. Rather than performing new laboratory tests or numerical simulations, this research relies on the analysis of field data and technical documentation derived from an actual infrastructure project. The methodology focuses on understanding the technical rationale and implementation of a stabilization system involving non-woven geotextile and multi-level gabions, as applied in a real-world setting. By examining California Bearing Ratio (CBR) data and as-built drawings, the study aims to describe how engineering design decisions were made in response to geotechnical and environmental conditions. The analytical process is descriptive, comparing the actual configuration of the embankment system with established engineering standards and references. This approach is intended to generate practical insights and highlight context-specific strategies for road construction in soft soil coastal environments. Further details regarding technical data, project conditions, and structural configuration are presented in the following section.

3. Description and Technical

To provide a clearer understanding of the applied stabilization system, this section presents a detailed description of the project characteristics, data sources, and technical elements used in the analysis. The information is structured to reflect the real-world implementation of coastal road construction within a tidal zone, emphasizing both geotechnical conditions and engineering configurations that influenced design decisions.

3.1 Population and Samples.

The population of this study includes road embankment systems constructed in soft-soil coastal or tidal areas where ground improvement measures are essential. The selected sample is a newly constructed road segment located within the intertidal zone of a university campus in, Riau Archipelago Province. This road was built using a combination of non-woven geotextile and multi-level gabion structures. The site was selected based on its relevance to coastal engineering challenges and the availability of technical construction data.

3.2 Sampling Techniques.

This research applies purposive sampling, selecting a specific road infrastructure project with the following criteria:

- a. Located in a coastal tidal zone;
- b. Constructed over saturated soft soil with low to moderate bearing capacity;
- c. Utilized geotextile and gabions as core stabilization components;
- d. Supported by available technical documentation, including CBR field test results and as-built drawings.

This approach allows for in-depth examination of real-world engineering practices under site-specific conditions.

3.3 Definition of Variable Operations.

Several variables were analysed to describe the stabilization system and site conditions:

- Subgrade Strength: assessed through California Bearing Ratio (CBR) field tests at three points along the road alignment, yielding values from 41.11% to 60.84%. These indicate moderate to good subgrade conditions.
- Stabilization Elements: consisting of a non-woven geotextile layer placed at the base of the embankment and multi-level gabions installed along the embankment slopes to provide lateral support and erosion control.
- Embankment Geometry: based on as-built drawings, with fill height ranging from 4 to 6 meters, and side slopes stabilized with stacked gabions.
- Environmental Setting: the site is situated within the intertidal zone, subject to daily sea level fluctuations and seasonal inundation risks.

3.4 Instrument Analysis Tool.

The instruments and data sources used in this study include:

- CBR Field Test Data: obtained from three test locations (STA 0+260 L, STA 0+335 L, STA 0+460 R) using standard penetration procedures (ASTM D1883).
- As-Built Drawings: providing detailed dimensions and layout of the embankment layers, geotextile placement, and gabion configuration.
- Design Standards and References: such as *SNI 17428-2:2019* for geotechnical design, and international literature on geosynthetics and coastal slope protection systems.

3.5 Data Analysis Techniques.

The analysis is conducted through a descriptive and engineering-reflective approach, involving:

- Interpretation of CBR values to assess the adequacy of subgrade support for the embankment load.
- Evaluation of stabilization configuration from the as-built drawings to understand structural layout and material placement.
- Comparison with best practices and standards in coastal road stabilization.
- Identification of contextual challenges related to the tidal environment, and the functional role of each component in mitigating geotechnical and hydraulic risks.

To complement the technical description above, a cross-sectional diagram of the constructed embankment is shown below on Figure 1. This illustration reflects the actual configuration based on as-built documentation, showing the layered structure of fill material, placement of non-woven geotextile, and multi-level gabion reinforcement along the slope.

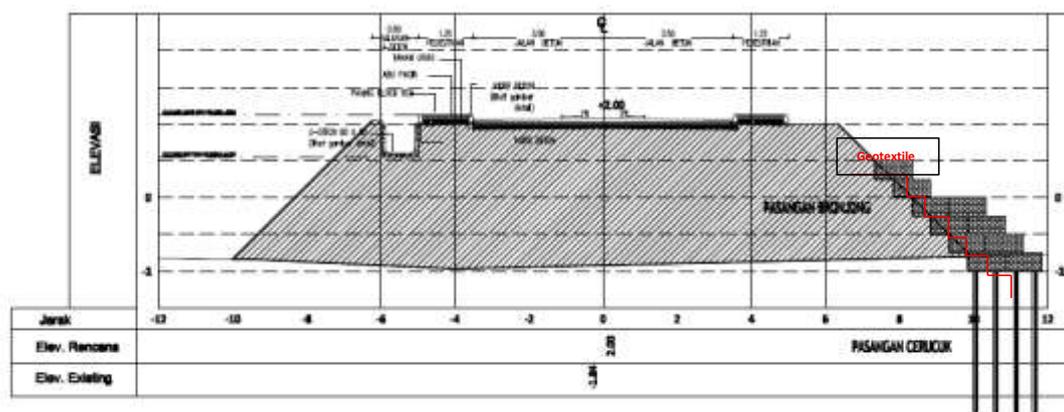


Figure 1. Cross-Section of the Coastal Embankment Showing Geotextile and Gabion Integration

Figure 1 illustrates the embankment configuration constructed in a tidal zone setting, with a base layer of non-woven geotextile placed directly above the natural subgrade, followed by a compacted fill up to 4–6 meters in height. The side slopes are reinforced using stacked gabion tiers (5–6 levels) to provide lateral support and erosion resistance. This integrated system addresses both vertical load distribution and horizontal hydraulic forces common in intertidal environments.

4. Results and Discussions

4.1 Subgrade Strength and CBR Analysis

To assess the foundational strength of the subgrade, California Bearing Ratio (CBR) tests were conducted at three locations along the embankment alignment. The tests were performed at two standard penetration depths: 2.54 mm and 5.08 mm. The results were then compared to a commonly used minimum standard value of 30% [18], which serves as a general threshold for acceptable subgrade performance in road construction. The chart below illustrates the CBR values at each location and their relation to the standard benchmark.

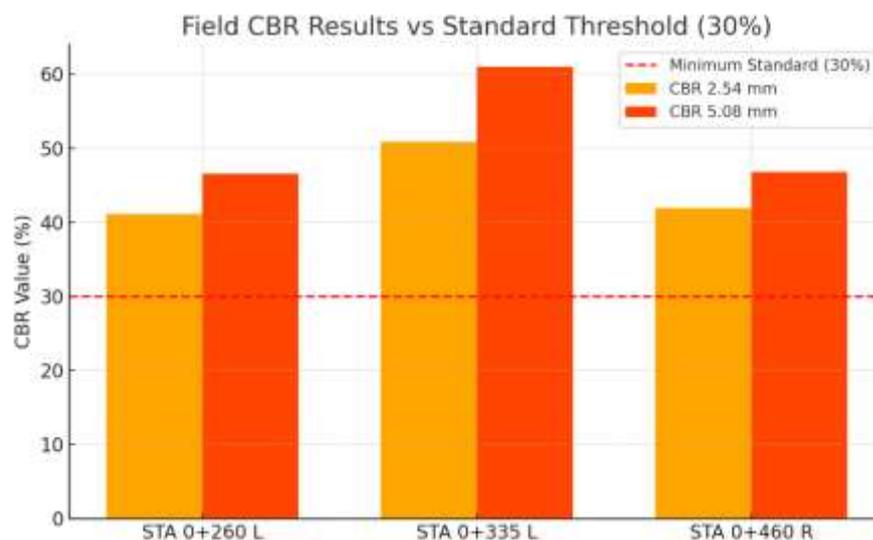


Figure 2. Comparison of Field CBR Test Results with Minimum Subgrade Strength Standard (30%)

The bar chart presents the California Bearing Ratio (CBR) values at three test points (STA 0+260 L, STA 0+335 L, and STA 0+460 R), measured at both 2.54 mm and 5.08 mm penetration depths. All recorded values significantly exceed the general minimum standard of 30% typically required for subgrade support in low to medium-load roads. Despite these satisfactory strength levels, additional stabilization using geotextile and gabion structures was implemented due to the site's location within a tidal zone and the associated hydraulic and lateral risks.

4.2 Functional Role of Geotextile and Gabion

Although the CBR values suggest that the soil was capable of supporting fill loads, the environmental context of tidal saturation justified the use of reinforcement measures. The non-woven geotextile layer served multiple functions:

- As a separator, preventing intrusion of soft subgrade into the granular fill;
- As a drainage layer, facilitating dissipation of pore water;
- As a reinforcement, distribute loads more evenly across the subgrade.

Simultaneously, the use of multi-tier gabions along the embankment slopes provided lateral support, protected against toe erosion, and accommodated hydraulic pressures due to tides. The modular and permeable nature of gabions made them well-suited for dynamic shoreline environments where rigid structures might suffer from differential settlement or hydraulic uplift (model-scale flume tests demonstrated that geo-tube embankments shielded with gabion boxes dissipated wave energy effectively and resisted scour better than geo-tube alone[19]).

4.3 Engineering Adaptation in Tidal Zone

The embankment height varied between 4 to 6 meters, with slopes stabilized using up to six stacked gabion tiers. In a tidal environment, such embankment systems must resist both vertical loads and horizontal forces from hydraulic action[20]. The combination of geotextile and gabion allows the system to respond flexibly to these stresses[21]. Importantly, this case demonstrates that subgrade strength alone is insufficient to capture the full risk profile of a coastal project[22]. Coastal environments exhibit rapid shifts in pore water pressure and moisture content that influence slope stability especially in tidal zones while geotechnical confinement methods such as gabions and geotextiles address these phenomena beyond the limitations of static strength tests.

4.4 Practical Insights

Although both geotextile and gabion systems are well-established in geotechnical and hydraulic engineering, their integrated use specifically for road embankment stabilization in tropical intertidal zones remains relatively undocumented. Much of the existing literature tends to examine these materials in isolation with geotextiles primarily analysed in the context of soil separation and reinforcement, and gabions discussed in applications such as slope protection or channel lining. However, few studies have explored the synergistic application of both systems as a unified solution in environments characterized by fluctuating tides, high moisture content, and soft cohesive soils.

This study does not attempt to present a new technology, but rather to highlight the contextual value of combining existing solutions in a setting where environmental dynamics pose challenges beyond what conventional strength tests like CBR can capture. The geotextile layer, while commonly applied over weak soils, proved beneficial even when CBR values were above minimum thresholds by ensuring load distribution, filtration, and preventing soil–fill intermixing. Similarly, the modular gabion structures demonstrated practical advantages not only in resisting lateral soil movement but also in providing flexibility, permeability, and ease of installation in remote coastal settings.

The decision to implement both components was influenced not solely by soil strength parameters, but by an appreciation of the environmental forces at play, such as tidal infiltration, cyclic saturation, and potential toe erosion. Such considerations underscore the importance of adaptive design thinking an approach, where engineers balance laboratory indicators with field conditions and construction constraints. In that sense, this study offers a reflective engineering case that may serve as a modest reference for infrastructure development in other archipelagic or low-lying coastal areas. By sharing lessons learned from actual field experience, the intent is to support a growing body of applied knowledge that prioritizes context-responsive and resilient infrastructure solutions rather than purely theoretical or idealized models.

5. Conclusion and Suggestion

5.1 Conclusion

This study presents a contextual technical overview of a coastal road embankment constructed within a tropical tidal zone, utilizing non-woven geotextile and multi-level gabions as an integrated stabilization system. Field-based CBR values ranging from 41.11% to 60.84% confirmed that the subgrade exhibited moderately strong bearing capacity. However,

considering the site's intertidal location, such static strength indicators alone were insufficient to address environmental and hydraulic challenges. The geotextile layer served not only as a separator but also contributed to load distribution and moisture control, while the gabion system functioned as a permeable and adaptable solution for slope reinforcement and toe protection. Together, these components offered a practical, modular response to complex site conditions, particularly those involving tidal saturation, cyclic hydraulic pressure, and erosion potential.

Although this study does not introduce novel materials or technologies, it highlights the value of design integration and environmental adaptation using conventional systems. The findings underscore that infrastructure design in coastal areas must consider both geotechnical properties and dynamic environmental forces in tandem, rather than relying solely on conventional strength metrics such as bearing capacity.

5.2 Suggestion

For future infrastructure projects in similar archipelagic or low-lying coastal regions, it is recommended that:

- a. Design decisions incorporate environmental dynamics, such as tidal fluctuations and groundwater behavior, during the early planning stages even when subgrade test results appear favorable.
- b. Combined use of geosynthetics and modular erosion-control structures (e.g., gabions) should be considered as a standard approach for embankments in saturated soft-soil environments.
- c. Post-construction monitoring and long-term performance evaluation will be conducted to better understand the behavior of such systems under real-time hydraulic and load conditions.
- d. Additional studies should be encouraged to explore cost-efficiency, constructability, and material optimization for similar systems in remote or resource-limited settings.

This case contributes a practical reference for engineers and planners working in coastal infrastructure development, emphasizing that context-responsive and site-specific strategies are key to achieving resilient and sustainable outcomes.

References

- [1] E. H. Manurung, K. Sawito, A. Satoto, and N. Tuanany, "Analysis of the Causes of Road Damage," *Civilla : Jurnal Teknik Sipil Universitas Islam Lamongan*, vol. 7, no. 1, p. 87, Apr. 2022, doi: 10.30736/cvl.v7i1.793.
- [2] A. Grydehøj and M. Casagrande, "Islands of connectivity: Archipelago relationality and transport infrastructure in Venice Lagoon," *Area*, vol. 52, no. 1, pp. 56–64, Mar. 2020, doi: 10.1111/area.12529.
- [3] M. H. S. Alajuri, H. A. Kusuma, T. Suhendra, and D. E. D. Setyono, "Comparation Tidal Harmonic Based on IoT Instrument Using Admiralty Method in Tanjungpinang Waters," *Journal of Applied Geospatial Information*, vol. 8, no. 2, pp. 140–145, Jan. 2025, doi: 10.30871/jagi.v8i2.9042.
- [4] J. Chu, Dennis. T. Bergado, E. C. Shin, and J. Chai, "Embankments on Soft Ground and Ground Improvement," in *5th Asian Regional Conference on Geosynthetic, GEOSYNTHETICS ASIA 2012*, Bangkok: International Geosynthetics Society, Dec. 2012, pp. 1–6.

- [5] F. Nursandah, F. N. Y. Puteri, A. I. Candra, Y. C. S. Poernomo, and M. H. Nastotok, "The Effect of Addition of Stone Ash to Shear Strength of Clay Soil in Suruh Trenggalek," *Jurnal CIVILA*, vol. 6, no. 1, pp. 1–12, Mar. 2021.
- [6] B. O. Oyegbile and B. A. Oyegbile, "Applications of geosynthetic membranes in soil stabilization and coastal defence structures," *International Journal of Sustainable Built Environment*, vol. 6, no. 2, pp. 636–662, Dec. 2017, doi: 10.1016/j.ijsbe.2017.04.001.
- [7] B. Kermani, M. Xiao, S. M. Stoffels, and T. Qiu, "Reduction of subgrade fines migration into subbase of flexible pavement using geotextile," *Geotextiles and Geomembranes*, vol. 46, no. 4, pp. 377–383, Aug. 2018, doi: 10.1016/j.geotexmem.2018.03.006.
- [8] S. Kumar, "Study of Geosynthetics and use of Non – Woven Green Geocomposite Blanket for Erosion Control and Slope Protection for Embankment," *International Research Journal of Engineering and Technology (IRJET)*, vol. 10, no. 4, Apr. 2023.
- [9] I. Ardiansah, Zainuri, and M. Anggraini, "Experimental Study of Addition of Plastic Waste (PET) to the Shear Strength of Clay Soil," *Jurnal Civilla*, vol. 7, no. 2, pp. 161–170, Aug. 2022.
- [10] V. Singh and S. Bano, "Feasibility of Geo-textile in Transportation Engineering- An Overview," in *7th Indian Young Geotechnical Engineers Conference (7IYGEC)*, Assam: Indian Young Geotechnical Engineers, 2019.
- [11] Raimondas Šadzevičius *et al.*, "An application of gabions for design of coastal protection structures in lakes," *Acta Scientiarum Polonorum. Architectura*, vol. 22, pp. 192–204, Jan. 2024, doi: 10.22630/ASPA.2023.22.19.
- [12] Raja. R. Thirumalai and A. Ranganathan, "Gabion armoured embankment and geo-tube stability from a hydrodynamic and geotechnical perspective," *Dogo Rangsang Research Journal*, vol. 9, no. 3, pp. 1988–2000, Sep. 2019.
- [13] S. Sherlin Prem Nishold, R. Sundravadivelu, and N. Saha, "Hydrodynamic Performance of Coastal Geotube Embankment with and Without Gabion Boxes," 2018, pp. 220–238. doi: 10.1007/978-3-319-61648-3_15.
- [14] N. Zhang, S.-L. Shen, H.-N. Wu, J.-C. Chai, Y.-S. Xu, and Z.-Y. Yin, "Evaluation of effect of basal geotextile reinforcement under embankment loading on soft marine deposits," *Geotextiles and Geomembranes*, vol. 43, no. 6, pp. 506–514, Nov. 2015, doi: 10.1016/j.geotexmem.2015.05.005.
- [15] M. Haritha and N. R. Krishnamurthy, "Case study: Ground Improvement technique with Geosynthetics as reinforcement on soft ground for buildings in coastal Andhra Pradesh," *IOP Conf Ser Earth Environ Sci*, vol. 1130, no. 1, p. 012001, Jan. 2023, doi: 10.1088/1755-1315/1130/1/012001.
- [16] B. O. Oyegbile and B. A. Oyegbile, "Applications of geosynthetic membranes in soil stabilization and coastal defence structures," *International Journal of Sustainable Built Environment*, vol. 6, no. 2, pp. 636–662, Dec. 2017, doi: 10.1016/j.ijsbe.2017.04.001.
- [17] . M. R. K., "EVALUATION OF CBR USING GEOSYNTHETICS IN SOIL LAYERS," *Int J Res Eng Technol*, vol. 04, no. 05, pp. 423–427, May 2015, doi: 10.15623/ijret.2015.0405079.

- [18] Kementerian Pekerjaan Umum dan Perumahan Rakyat, *Manual Desain Perkerasan Jalan*. Jakarta: Kementerian Pekerjaan Umum dan Perumahan Rakyat, 2024.
- [19] S. Sherlin Prem Nishold, R. Sundravadivelu, and N. Saha, “Hydrodynamic Performance of Coastal Geotube Embankment with and Without Gabion Boxes,” 2018, pp. 220–238. doi: 10.1007/978-3-319-61648-3_15.
- [20] J. Zhu, C. Chen, and H. Zhao, “An Approach to Assess the Stability of Unsaturated Multilayered Coastal-Embankment Slope during Rainfall Infiltration,” *J Mar Sci Eng*, vol. 7, no. 6, p. 165, May 2019, doi: 10.3390/jmse7060165.
- [21] S. S. P. Nishold, R. Sundaravadivelu, and N. Saha, “Physical model study on geo-tube with gabion boxes for the application of coastal protection,” *Arabian Journal of Geosciences*, vol. 12, no. 5, p. 164, Mar. 2019, doi: 10.1007/s12517-019-4312-5.
- [22] Y. Jia, S. Luan, M. S. Asheghabadi, D. Xing, H. Yuan, and J. Liu, “Slope stability analysis of coastal geotechnical structures under combined effects of earthquake and rainfall,” *Front Earth Sci (Lausanne)*, vol. 11, Jan. 2024, doi: 10.3389/feart.2023.1335756.

This page is intentionally left blank