ANALISA STABILITAS DAN JUSTIFIKASI TEKNIS PERKUATAN STRUKTUR PADA TANAH LUNAK (STUDI KASUS : REHABILITASI DAERAH IRIGASI GLAPAN TIMUR DAN BARAT)

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ABSTRAK

Penelitian ini bertujuan untuk menganalisis stabilitas dan menyusun justifikasi teknis perkuatan struktur pada pekerjaan rehabilitasi Daerah Irigasi Glapan Tahap II yang berada pada kondisi tanah lunak yang rentan terhadap kegagalan sliding. Metode penelitian meliputi investigasi lapangan, analisis geoteknik, evaluasi stabilitas lereng, serta kajian alternatif solusi perkuatan. Hasil analisis menunjukkan bahwa struktur lining eksisting tidak memenuhi persyaratan keamanan dengan faktor keamanan terhadap sliding sebesar 1,15, lebih rendah dari standar minimum 1,5. Oleh karena itu, sistem perkuatan menggunakan minipile dipilih sebagai solusi yang paling efektif. Minipile dengan diameter 20 cm dan kedalaman 3–4 meter mampu meningkatkan faktor keamanan menjadi 2,15, sehingga memenuhi persyaratan teknis dan meningkatkan stabilitas struktur secara signifikan. Penelitian ini menghasilkan rekomendasi teknis untuk modifikasi desain yang lebih aman dan andal pada kondisi tanah lunak, serta memberikan kontribusi dalam peningkatan kinerja infrastruktur irigasi pada kondisi geoteknik serupa.

ABSTRACT

This study presents a technical justification for structural reinforcement in the rehabilitation of the Glapan Irrigation Area Phase II, focusing on soft soil conditions prone to sliding failure. The research aims to evaluate the stability of the existing lining structure and to determine an appropriate reinforcement method. The methodology includes field investigation, geotechnical analysis, slope stability evaluation, and assessment of alternative reinforcement solutions. The results indicate that the existing structure does not meet the minimum safety requirements, with a safety factor of 1.15 against sliding, which is below the standard value of 1.5. To address this issue, a minipile system is proposed as the most effective reinforcement solution. The designed minipile, with a diameter of 20 cm and a depth of 3–4 meters, significantly improves structural performance. The analysis shows that the safety factor increases to 2.15 after reinforcement, indicating a substantial enhancement in stability. This study provides a technically justified recommendation for design modification, ensuring structural safety and long-term performance under soft soil conditions. The findings contribute to improving the reliability of irrigation infrastructure in similar geotechnical environments.

Keywords: *Irrigation area, technical justification, structural reinforcement, minipile, soil stability, rehabilitation channels*

1. INTRODUCTION

The Glapan Irrigation Area is one of the important irrigation infrastructures with an area of 18,784 ha, equipped with two intake structures: Right Intake Structure (Glapan East Irrigation Area) covering 8,671 ha and Left Intake Structure (Glapan West Irrigation Area) covering 10,113 ha [1].

Based on Minister of Public Works and Public Housing Regulation No. 14/PRT/M/2015 concerning Criteria and Status Determination for Irrigation Areas, the Central Government has authority and responsibility in managing Glapan Irrigation Area,
which in this case is managed by Balai Besar Wilayah Sungai Pemali Juana [1].

Results of monitoring evaluation andjoint inspection together in the field show there are obstacles in the lining construction of channels with very soft soil characteristics and prone to occur sliding. This condition requires a special study as input and consideration for the Irrigation and Rawa PPK to address these issues.

Soil softening issues in construction Irrigation channels are a technical challenge often faced in infrastructure projects [2, 3]. The soft soil characteristics with low bearing capacity and high compressibility can cause structural failures if not addressed with appropriate strengthening methods [4].

This study is based on key issues related to the characteristics of soft soil at the irrigation canal rehabilitation site, the capacity of the existing lining structure to withstand loads, the potential for sliding failure, and the need for appropriate structural reinforcement solutions along with their technical specifications and implementation methods. The objectives of this research are to analyze soil conditions, evaluate structural stability, and formulate optimal and applicable reinforcement recommendations. Theoretically, soft soil is characterized by low shear strength, high compressibility, and low bearing capacity, making it susceptible to settlement and stability failure, which is analyzed using the factor of safety as the ratio between resisting and driving forces.

The scope of this study covers the rehabilitation of the Glapan Timur irrigation network, including main and secondary canals, with work consisting of lining construction, excavation, and structural reinforcement. This research is expected to provide technical justification, support decision-making processes, and improve the quality of irrigation infrastructure to support national food security.

2. LITERATURE REVIEW

2.1. Irrigation System and Channel Network.

An irrigation system is a vital infrastructure to support agricultural productivity. The irrigation network consists of primary, secondary, and tertiary channels that transport water from sources to agricultural land [5]. Design and construction of irrigation channels must consider hydraulics, structural, and geotechnical aspects to ensure long-term functionality

2.2. Characteristics of Soft Soil

Soft soil is defined as cohesive soil with low shear strength (generally cu < 25 kPa) and high compressibility [3]. Characteristics of soft soil include :

1. High moisture content approaching or exceeding the limit fluid
2. Low bearing capacity
3. High compressibility
4. Low permeability
5. Potential for large consolidation settlement

Construction on soft soil requires special handling to prevent structural failure [4].

2.3. Slope stability and sliding

Slope stability analysis is a vital aspect in structure design on soft soil. Sliding failure can occur when the shear forces acting exceed the soil's shear strength. The safety factor (FK) against sliding is calculated with equation [2]:

$$FK = \frac{Resistance\ Force}{\text{Acting/Driving Force}}$$

According to SNI and international standards, the minimum safety factor for slope stability is 1.5 for normal conditions and 1.25 for extreme conditions [6].

2.4. Structural Reinforcement System

Various structural reinforcement methods can be applied to soft soil, including

2.4.1. Minipile

Minipile or mini pile is a small-diameter foundation system (10-30 cm) installed by drilling or driving methods [7]. Advantages of minipiles include.

1. Can be installed in confined spaces
2. Effective for reinforcing existing structures
3. Relatively quick installation with minimal vibration
4. Capable of penetrating soft soil layers to reach hard layers

The bearing capacity of minipiles is calculated based on end bearing and skin friction [8]

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$$Qu = Qp + Qs$$

Where :
Qu = ultimate bearing capacity
Qp = end resistance
Qs = cafering resistance

2.4.2. Soil Improvement

Soil improvement methods such as preloading, vertical drain, and chemical stabilization can enhance the characteristics of soft soil [10].

2.5. Channel Lining Construction

Lining saluran irigasi berfungsi untuk

1. Reduce water losses due to seepage
2. Increase efficiency of flow
3. Prevent canal erosion
4. Facilitate maintenance

Lining material can be concrete, stone lining, or geomembrane, with selection depending on hydraulic and geotechnical conditions [11]

3. RESEARCH METHOD

This study was conducted in the rehabilitation project of the Glapan Irrigation Area (Phase II, Package 1), covering five irrigation channels with various types of works, including lining construction, rigid concrete, channel normalization, and embankment. The research methodology was carried out systematically through several stages, namely literature review and data collection, field survey and site investigation, geotechnical analysis, and structural stability analysis. Subsequently, alternative reinforcement solutions were evaluated, followed by the design of structural reinforcement and the formulation of recommendations.

The data analysis method consists of qualitative and quantitative approaches. The qualitative analysis includes field observations and evaluation of design conformity with existing conditions, while the quantitative analysis involves slope stability calculations, bearing capacity assessment, stress and deformation analysis, and safety factor evaluation using Bishop or Fellenius methods. All analyses were supported by engineering software such as AutoCAD, GeoStudio, and Microsoft Excel.

4. RESULTS AND DISCUSSION

Field investigation results indicate that the existing site conditions are dominated by soft soil layers with depths ranging from 2 to 4 meters. The soil is characterized by N-SPT values between 2 and 8, indicating very soft to soft consistency. High water content, approaching or exceeding the liquid limit, along with low bearing capacity ($qc < 20$ kg/cm^2), leads to significant consolidation settlement potential. Geometrically, the channel has a depth of 1.5–3.0 m, a base width of 2.0–4.0 m, and slope inclinations ranging from 1:1 to 1:1.5, with several հատված experiencing erosion and slope failure. These conditions result in major engineering challenges, including difficulties in lining construction, potential structural sliding, differential settlement, and high groundwater seepage.

Stability analysis without reinforcement reveals that the safety factor against sliding is only 1.15 and against overturning is 1.20, both of which do not meet the minimum required standard ($SF \geq 1.5$). Furthermore, the applied stress (55 kPa) exceeds the soil bearing capacity (45 kPa), indicating a high risk of structural failure. Therefore, structural reinforcement is required to ensure stability and safety.

Several reinforcement alternatives were evaluated, including minipile systems, geotextile reinforcement, and geometric modification. Based on multi-criteria analysis, the minipile system was identified as the most effective solution due to its ability to significantly improve bearing capacity without altering the structural geometry. The calculated ultimate bearing capacity of the minipile is 33.92 tons, with an allowable capacity of 11.31 tons using a safety factor of 3.0.

The implementation of minipile reinforcement significantly improves structural performance. The safety factor against sliding increases from 1.15 to 2.15, while the safety factor against overturning increases from 1.20 to 2.40. Additionally, the maximum settlement is reduced to 2.5 cm, which is within acceptable limits. This demonstrates that the minipile system effectively transfers loads to deeper, more stable soil layers, thereby enhancing overall structural stability.

From an implementation perspective, this method requires an additional cost of approximately IDR 5.07 billion and an extended construction time of 2–3 months. However, the significant improvement in structural safety, reduction of failure risks, and increased service life justify the investment both technically and economically. Therefore, minipile reinforcement is recommended as an optimal solution for irrigation channel lining construction on soft soil conditions.

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Section	Aspect	Key Findings	Before Reinforcement	After Minipile Reinforcement	Remarks
Soil Condition	Soil Type	Very soft clay, high water content	-	-	N-SPT: 2–8
Soil Capacity	Bearing Capacity	Low bearing capacity	qc < 20 kg/cm²	Improved via minipile	Critical issue
Geometry	Channel Dimensions	Depth 1.5–3 m, width 2–4 m	-	-	Some erosion observed
Problems	Main Issues	Sliding risk, settlement, seepage	High risk	Reduced	Needs reinforcement
Stability	Sliding Safety Factor	Below standard (≥1.5 required)	1.15	2.15	Meets requirement
Stability	Overturning Safety Factor	Below standard	1.20	2.40	Meets requirement
Soil Stress	Applied vs Capacity	Overstressed soil	q = 55 kPa > qu = 45 kPa	Controlled	Previously unsafe
Alternative 1	Minipile	Most effective solution	Not used	Applied	Selected method
Alternative 2	Geotextile	Limited effectiveness	Not used	Not selected	Less suitable
Alternative 3	Geometry Change	Requires more land	Not used	Not selected	Reduces flow capacity
Minipile Spec	Diameter	20 cm	-	20 cm	Standard design
Minipile Spec	Depth	3–4 m	-	3–4 m	Reaches hard layer
Minipile Capacity	Allowable Capacity	-	-	11.31 ton/unit	SF = 3
Settlement	Structural Settlement	Excessive risk	High	2.5 cm	Acceptable
Cost	Project Cost	Increased	-	~Rp 5.07 billion	+10% supporting cost
Time	Duration	Extended	-	+2–3 months	Due to installation
Impact	Structural Safety	Unsafe	Unsafe	Safe	Major improvement
Conclusion	Final Decision	Reinforcement required	No	Yes	Minipile selected

5. CONCLUSION AND SUGGESTIONS

5.1 CONCLUSION

The findings indicate that the subsoil conditions at the project site are classified as very soft to soft, with N-SPT values ranging from 2 to 8 and low bearing capacity (qc < 20 kg/cm²), which differ significantly from the initial design assumptions. Stability analysis of the lining structure without reinforcement yields a sliding safety factor of 1.15, which does not satisfy the minimum requirement (FK ≥ 1.5), thereby indicating potential structural failure. Among the evaluated alternatives, the minipile reinforcement system proves to be the most effective solution for improving stability under soft soil conditions. The application of minipiles increases the sliding safety factor to 2.15, representing a significant improvement and meeting the required safety standards. The estimated implementation of 10,246 minipile units, with a total cost of approximately IDR 5.07 billion, is considered technically justified. Additionally, the success of this method depends on strict adherence to construction procedures and quality control. The design modification is also supported by contractual provisions and validated through field verification processes involving relevant stakeholders.

5.2 SUGGESTION

It is recommended that design changes and additional minipile work be approved and outlined in a contract addendum. Work implementation must be supported by strict quality control and optimal supervision. For future similar projects, more detailed soil investigations should be conducted during the planning stage to anticipate geotechnical issues and minimize design changes during construction.

6. RECOMMENDATIONS

Based on the above conclusions, several recommendations are proposed. The project owner is advised to approve the design changes and formalize them through a contract addendum, including adjustments to cost and project duration. The contractor should prepare detailed shop drawings, implement systematic construction procedures, and maintain strict quality assurance, particularly in drilling, reinforcement placement, and concreting processes. The supervising consultant is responsible for ensuring compliance with design specifications through continuous monitoring, inspection, and documentation. For future work, it is recommended to conduct additional soil investigations, perform pile load testing, and implement long-term monitoring systems to validate structural performance. Furthermore, from a broader policy perspective, it is essential to enhance the quality of geotechnical investigations during the design phase and allocate sufficient contingency budgets to accommodate unforeseen ground conditions.

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