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FORENSIC INVESTIGATION Of THE SAMARINDA IBU dan ANAK HOSPITAL BUILDING: STRUCTURAL SETTLEMENT ANALYSIS

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ABSTRACT

In initiatives to enhance the quality of infrastructure, especially with regard to building stability and the avoidance of structural failure, the safety and comfort of visitors has taken center stage. In order to improve infrastructure, older or decaying buildings are frequently reinforced or renovated. This may entail repairing accumulated damage without requiring total demolition. In order to guarantee the structure's dependability and safety, these remodeling initiatives require careful assessment and study. Concerns over apparent settlement of the Ibu dan Anak Hospital building in Samarinda have been brought up, highlighting the significance of assessing structural integrity to guarantee ongoing safety and functionality. The purpose of this study is to conduct a thorough structural audit of the building in order to find any possible hazards and suggest any necessary improvements.
The study assessment the building's stability and forecasts future settlement by simulating its behavior under various circumstances, including dynamic and static load scenarios, using sophisticated modeling software such as GEOSLOPE-GEOSTUDIO (Student Version). According to the aforementioned analytical results, there are signs that the hard soil layer is not reached by the pile depth, which causes settlement. Over the course of the following year, the settlement increased from 15.89 cm in the first 178 days to 17.64 cm. The analysis indicates that the settlement will stay at 31.65 cm for the next five years, therefore after 1,780 days, it is deemed stable.

1. INTRODUCTION

Ensuring visitor safety and comfort has emerged as a top priority in the endeavor to improve infrastructure quality, especially with regard to building stability and protection against structural failure. Older or decaying facilities are frequently reinforced or rebuilt as part of infrastructure quality enhancements. This can involve renovating buildings without requiring total demolition and instead concentrating on fixing damage that has accumulated over time. In order to ensure ongoing service reliability and user security, such projects require thorough study and analysis to evaluate and validate the safety and stability of building structures.
Concerns have been made about a noticeable settlement of the structure of the Ibu dan Anak Hospital building, which is a pressing issue in this regard. This settlement emphasizes how crucial structural evaluation is to guaranteeing that the building can sustain daily operations without endangering user safety. The Maternity and Children's Hospital must therefore conduct a thorough building audit in order to assess the structure's existing state, pinpoint any possible hazards, and carry out any necessary upgrades. In order to provide crucial insights into structural integrity and areas that need intervention, the behavior of the building structure under various conditions has been modeled and analyzed using GEOSLOPE-GEOSTUDIO (Student Version) software.
By emphasizing structural settlement concerns and the value of proactive maintenance and

analysis utilizing cutting-edge modeling tools, this work fills a research vacuum in the field of hospital infrastructure management. In contrast to conventional repair methods, this study highlights the use of finite element modeling and building audits as preventive measures to meet long-term safety objectives. The findings of this building audit, backed by GEOSLOPE-GEOSTUDIO (Student Version) analysis, are meant to help the building's owner make well-informed decisions that will promote the immediate safety of users and the longevity of the facility itself.

2. RESEARCH METHODOLOGY

The building inspection, which is carried out at certain intervals to guarantee the building's functional viability, entails a thorough analysis of the building's structural dependability, taking into account all of its constituent parts, materials, and supporting infrastructure. The Maternity and Children's Hospital building (previously Siloam) is subjected to a number of testing techniques. Among these techniques are soil testing, non-destructive testing (NDT), settlement measurement using a water level, pile integrity testing (PIT), and settlement analysis using Finite Element Modeling (FEM). By simulating and assessing the behavior of structural elements under stress, this software facilitates advanced modeling, offering a comprehensive understanding of the stability of the building.

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Using GEOSLOPE-GEOSTUDIO (Student Version) software, this method combines sophisticated computational modeling with field inspections to mimic structural behavior and forecast future settlement patterns. The following steps make up the structure of the research methodology:

a. Data Collection and Preliminary Investigation

The first stage entails gathering necessary information, such as load distribution parameters, historical maintenance records, and architectural and structural As-Built Drawings. To find obvious indications of settlement, including cracks, tilts, or uneven flooring, a thorough visual examination of the building is carried out. To ascertain the subsurface conditions and bearing capability, soil investigation is carried out using techniques such as the Standard Penetration Test (SPT) and cone penetration testing (CPT or Sondir).

b. Field Testing and Non-Destructive Testing (NDT)

To evaluate the structural soundness of building components without causing damage, non-destructive testing techniques are used(Avramidis et al., 2021; I. A. W. Efendi & Eng, 2022; Onyeka, 2020). Among these tests are:

- To assess the depth and state of foundation piles and find any possible flaws or discontinuities, pile integrity testing, or PIT, is used.
- Testing for Concrete Strength: The concrete's internal quality and compressive strength are evaluated using the Schmidt Rebound Hammer and Ultrasonic Pulse Velocity (UPV) tests.
- Reinforcement Assessment: The presence, diameter, and spacing of reinforcement bars in structural members are determined using a rebar scanner.

c. Elevation and Settlement Measurements

Elevation levels are measured using water levels or high-precision digital tools to detect vertical displacements or tilts. This data is essential for analyzing the settlement patterns and their possible impact on the building's structural stability. Finite Element Modeling and Analysis

Using GEOSLOPE-GEOSTUDIO (Student Version) The main objective of the analysis is to create a detailed Finite Element Model (FEM) of the hospital structure using GEOSLOPE-GEOSTUDIO (Student Version) software, which includes:

- Structural geometry, material properties, and load conditions; data from soil testing to model soil-structure interaction; PIT and NDT results to account for variations in material strength and foundation conditions; and software that simulates stress distributions, deformation patterns, and settlement under different load combinations. Dynamic and static analysis is performed to evaluate the building's behavior over time.

d. Building Settlement

As a structure moves downhill due to changes in the ground underneath it, usually as a result of different soil conditions, load distribution, or structural alterations, this is referred to as building settlement. Both uniform and uneven settlement can result in possible structural problems, including tilting, fractures, and misaligned windows and doors. Because settlement can impact a structure's stability, safety, and usefulness, it is a crucial consideration in building design and maintenance(Bouhehrian, 2021; Cheng et al., 2021; Chowdhury & Patra, 2021; A. W. Efendi, 2023, 2024; Fattah et al., 2020; Hernández-Castillo et al., 2015; Jordanova et al., 2018; Kaplun & Bronnikov, 2021; Lee et al., 2018; Muhammed et al., 2020; Nazeri et al., 2018; Sasmal & Behera, 2018; Wang & Markine, 2019). There are two primary types of settlement:

- Uniform Settlement: When the entire foundation sinks at a consistent rate, which may be caused by soil compaction or gradual changes in load distribution.
- Differential Settlement: When parts of the foundation settle at different rates, leading to uneven displacement of the building. This is often more problematic and can cause significant damage to the structure.

Settlement can occur due to several factors, including:

- Soil type and characteristics: Soft or loose soils, such as clay or sand, are more prone to settlement.
- Changes in load distribution: Inadequate foundation design or increased load can cause additional settlement.
- Water movement and moisture content: Fluctuations in groundwater levels can alter soil compaction, leading to settlement.
- Piling and foundation integrity: Poor construction or degradation of the foundation system (such as pile misalignment) can result in settlement.

e. Finite Element Method (FEM)

A numerical method for resolving complicated issues in physics and engineering, especially in the domains of structural, mechanical, and civil engineering, is the Finite Element Method (FEM). FEM breaks down a complex problem (like a building structure) into smaller, more manageable components called finite elements. These elements are joined at specific locations called nodes. Every component is a part of the physical structure, and by examining how they behave together, the system as a whole can be understood(Eduarte, 2018; A. W. Efendi, 2020; Lim, 2016; Liong, 2012; Montenegro, 2018; Pokkula & Gupta, 2021; Sibilli & Igie, 2018; Song et al., 2017). The key steps in FEM include:

- Discretization (Meshing): The structure is divided into a finite number of elements, creating a mesh. The more refined the mesh, the more accurate the results, though it requires more computational power.
- Element Selection: Different types of elements can be chosen depending on the complexity of the structure (e.g., beams, shells, solid elements).
- Material Properties Assignment: Each element is assigned specific material properties such as elasticity, density, and thermal conductivity.
- Boundary Conditions: The physical constraints or loading conditions (such as forces, temperatures, or displacements) are applied to the model.
- Solution: The FEM software solves the system of equations that govern the behavior of each element. This produces results like displacement, stress, strain, and other physical parameters.
- Post-Processing: The results are analyzed and visualized, often through color-coded maps,

to assess the performance of the structure under different conditions.

FEM is particularly useful for:

- Modeling complex geometries that are difficult to solve analytically.
- Analyzing stress distribution, deformations, and potential failure points within structures.
- Simulating how materials and structures behave under various loads (e.g., static, dynamic, thermal).

f. Geoslope-Geostudio

Developed by GeoStudio, a top supplier of engineering software for geotechnical specialists, Geoslope is a full set of software tools for geotechnical and geoenvironmental study. The main program from Geoslope, GeoStudio, is made up of several modules that are intended to address a variety of geotechnical issues, including soil stress, deformation, slope stability, and groundwater flow. GeoStudio's robust simulation features combine finite element analysis (FEA) and finite difference techniques to model intricate geotechnical behaviors and assess the stability and safety of a range of structures, including retaining walls, embankments, and foundations. For engineers working in soil mechanics, foundation design, and environmental engineering, these modules are crucial because they contain methods for evaluating seepage, stress-strain relationships, and the factor of safety for slope stability.

Researchers can effectively develop models of soil-structure interaction and mimic real-world situations thanks to Geoslope's user-friendly interface, which is one of its main advantages. The software is an effective tool for assessing the long-term behavior of geotechnical systems since it can handle big, complicated models and carry out sophisticated analysis, including seepage, consolidation, and deformation in both the steady-state and transient states. Additionally, Geoslope offers powerful post-processing capabilities that assist engineers in interpreting data and coming to well-informed conclusions, such as graphical findings and thorough reports. Because of this, Geoslope is a useful tool for geotechnical research and design optimization in earthworks, foundation engineering, and environmental impact assessment projects (Dahale et al., 2020).

3. RESULTS AND DISCUSSION

The research results of the study on the Samarinda Ibu dan Anak Hospital building's settlement behavior are shown and thoroughly examined in this section. The conclusions stem from a thorough investigation that incorporates advanced simulation with GEOSLOPE-GEOSTUDIO (Student Version) software, non-destructive assessment (NDT), and field testing. This section's goals are to study the structural response, interpret the data gathered from various tests, and comprehend the elements that contribute to building settling.

In order to find any urgent indications of settlement or structural distress, the data from visual inspections and field testing—including soil research and pile integrity tests (PIT)—were first collated. Non-destructive testing of the concrete and reinforcing elements came next, guaranteeing that the structural integrity of important parts was within reasonable bounds. These first experiments provided the basis for additional computational modeling and assisted in identifying the most impacted regions.

The conclusions of the GEOSLOPE-GEOSTUDIO (Student Version) simulations offer a more thorough comprehension of the building's settling behavior over time. Using the data gathered, the FEM model was developed to predict how the building would react to different loads and stresses, including both dynamic forces from outside sources like wind and seismic activity and static loads from the structure itself. The sections where the foundation or structural elements are most susceptible to excessive displacement were highlighted by the simulation results, which showed zones of differential settlement.

The interpretation of these results in light of the building's long-term stability and safety is the next topic of discussion. The causes of the observed settling are investigated in detail, including load distribution, foundation design, and soil conditions. In-depth analysis is also done on the possible effects of the settlement on the building's overall structural integrity, taking into account the dangers of uneven settlement. Remedial measures, such reinforcing or strengthening the foundation, are suggested in light of these findings in order to guarantee the building's continuous safety and functionality.

Along with assessing how well the GEOSLOPE-GEOSTUDIO (Student Version) simulates the settlement process, this part offers insights into how these cutting-edge computational techniques might improve our comprehension of structural behavior, resulting in more precise assessments and prompt actions in building maintenance.
Based on the results of the Visual Analysis and Initial Investigation, and considering the building's movement behavior, vertical and horizontal settlement measurements were taken. A model was created to match the field conditions, with the following data obtained:

1. **Pile Integrity Test (PIT):** The test indicated a depth of 6 meters, with 9 pile points identified based on the pile integrity test results.
2. **Horizontal Movement:** The building has tilted approximately 7-8.9 cm in the direction of the building's x-axis.
3. **Soil Investigation:** The soil investigation revealed that at depths up to 35 meters, the NSPT values range from 18 to 20, indicating that the soil is classified as soft soil. However, data from Sondir tests S-01 and S-02 show that at a depth of 25 meters, the cone resistance reached 150 kg/cm², equivalent to an NSPT value of 25. This data will be used as input for the geotechnical analysis of the behavior after the building load is applied.

A manual analysis was carried out using a back analysis approach, determining the condition of the piles used based on the Pile Integrity Test (PIT) results. The piles were dimensioned at 20 x 20 cm with a depth of 6 meters, and the foundation consists of 9 pile points.

Color	Name	Model	Young's Modulus (E) (kPa)	Unit Weight (kN/m³)	Poisson's Ratio
(grey)	Beton fc30 MPa	Linear Elastic (Total)	2,524,522	24	0.2
(yellow)	Layer Tanah NSPT 0-5	Linear Elastic (Total)	8,500	16	0.35
(green)	Layer Tanah NSPT 10-14	Linear Elastic (Total)	30,000	16	0.25
(cyan)	Layer Tanah NSPT 14.5-20	Linear Elastic (Total)	40,000	21	0.2
(light green)	Layer Tanah NSPT 5-10	Linear Elastic (Total)	15,000	16	0.25

Figure 1. NSPT Result Parameters (Geostudio)

a. Modeling soil conditions with FEA

Modeling of building loads with FEA 2D segmental loading is taken with the largest load data, foundation position and pile depth according to field implementation as shown in Figure 3, and a review is taken according to the dotted red box mark..

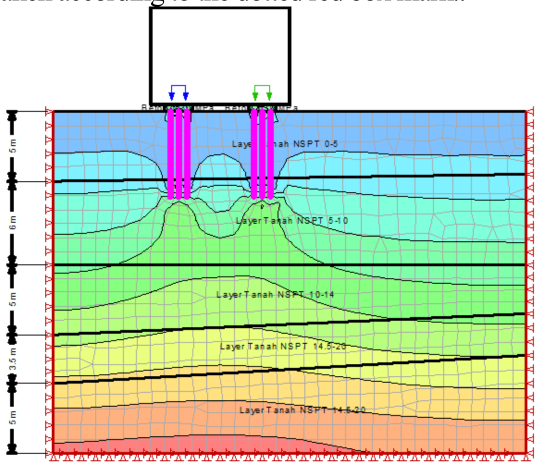

Figure 2: Post-construction existing soil statifigraphy

Figure 3. Plan of the point and depth of the implementation foundation piles

b. Modeling with foundation and 20 x 20 cm Ulin piles

A foundation with 20 x 20 cm steel piles (ulin piles) serving as the main support system is used in the modeling. Based on the results from the Pile Integrity Test (PIT), which offers important information on the integrity and condition of the piles, this model includes an embedded foundation design. By taking into consideration any potential flaws or discontinuities revealed in the pile integrity test, the PIT results are used to precisely depict how the piles behave within the soil and guarantee that the foundation system is built to sustain the structure. This method guarantees that the foundation system can withstand the anticipated loads and stresses and aids in simulating actual soil-pile interaction, shown in the figure 4.

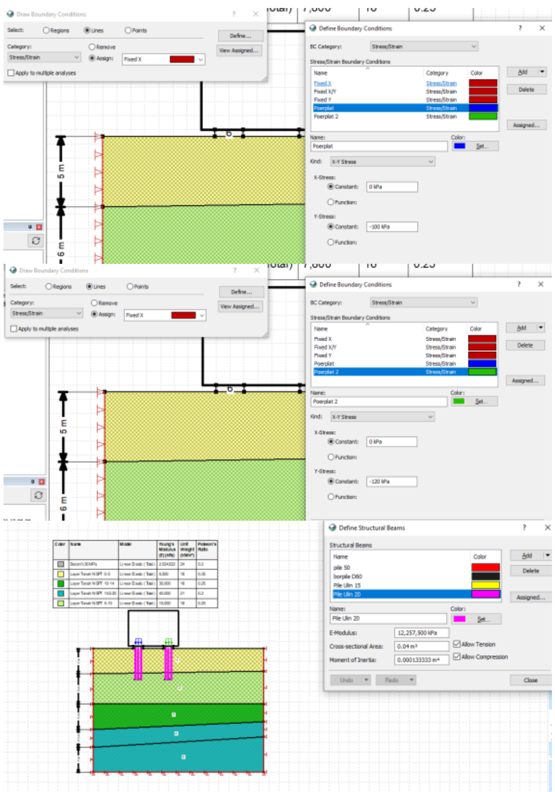

Figure 4. Modeling with embedded foundation and corresponding PIT result information.

From the results of the building deformation analysis that occurs per pile is:

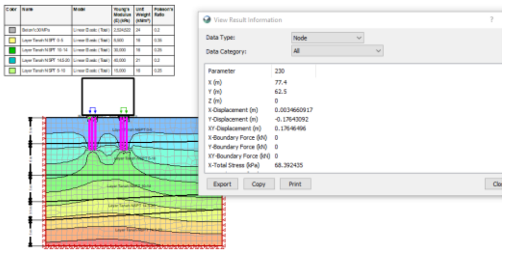

Figure 5. The hue that occurs due to the applied load

The building's deformation study results revealed a particular pattern in the settlement at each pile over time. The settlement reached -0.176 meters in the first 35 days, demonstrating a discernible downward descent of the construction. After 365 days, this original colony had grown to -0.3165 meters. Further study indicates that no major further settlement will occur over the next five years, suggesting that the settlement trend has stabilized at its current level. The settlement will stay at -0.53 meters after five years, according to the deformation analysis, indicating that the structure and foundation have stabilized..

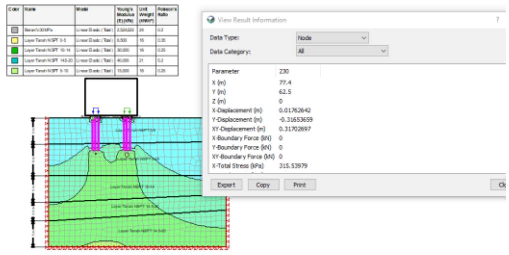

Figure 6. The hue that occurs due to the applied load

This stability is important since it indicates that the settlement issue won't require any additional corrective action in the near future. The Indonesian National Standard (SNI) 8460:2017 states that buildings may settle no more than 15 cm, or 0.15 meters. The building's settlement is well within acceptable bounds because this is far less than the observed settlement values. The findings imply that the structure is not in immediate risk of failing or becoming unstable, even though the settlement has surpassed the usual limit for allowable building movement. It seems that the settlement is a gradual process that has stabilized.

These results stress the value of ongoing observation, but they also imply that the structure is not yet at a critical stage where structural safety or usefulness might be jeopardized. According to the analysis, the building's settlement won't cause additional deformation over the coming years, and the structure should hold up over time despite the settlement that has been noticed. This conclusion demonstrates that the structure has survived the settling process and is not anticipated to move dangerously soon.

Table 1. Settlement Analysis Result

No.	Review Location	Settlement that occurred (cm)	Allowable Limit Condition (cm)	Status
1	P1 (178 Day)	15.89	15	Not Ok
2	P1 (1 Tahun)	17.64	15	Not Ok
3	P1 (5 Tahun)	31.65	15	Not Ok

(Source: SNI 8460.2017)

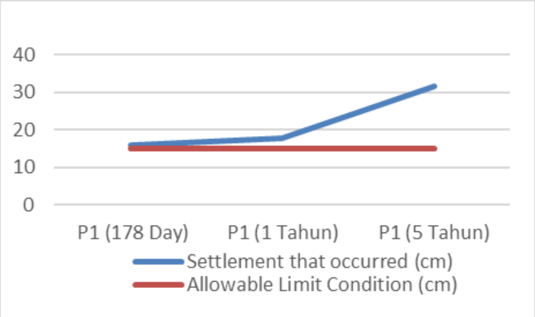

Figure 7. Settlement Analysis Chart

4. CONCLUSION

According to the aforementioned analytical results, there are signs that the hard soil layer is not reached by the pile depth, which causes settlement. Over the course of the following year, the settlement increased from 15.89 cm in the first 178 days to 17.64 cm. The analysis indicates that the settlement will stay at 31.65 cm for the next five years, therefore after 1,780 days, it is deemed stable.

This computation is predicated on six-meter-deep piles made of 20 × 20 steel piles, with nine piles at each column site. Different settlement results would arise from any changes in the number of piles or the dimensions of the piles.

The impacts of nearby earthquakes or vibrations that could affect the building's construction are not included in the settlement estimates. For instance, the vibrations acting on the structure may be affected if large capacity generators are used.

To avoid excessive settlement above the permitted limitations, which could have unintended effects for the building, the foundation must be reinforced. Additionally, strengthening the foundation will lower the cost of repairs, which would increase if the settlement damaged every structural component.

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