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Structural Performance and Stress Contour Analysis of Multi Utility Tunnels Using LISA V.8 Finite Element Analysis

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Abstract

The growing complexity of urban infrastructure necessitates efficient management of utilities like electricity, water, and telecommunications. Multi Utility Tunnels (MUTs) provide a consolidated approach to housing these utilities, reducing surface disruption and enhancing maintenance efficiency. This study assesses the structural performance and stress distribution within MUTs using Finite Element Analysis (FEA) through LISA FEA V.8 software. The analysis involved detailed geometric modeling of the MUT, considering initial conditions and potential subsidence. Material properties for steel, concrete, wood, backfill soil, and the top surface layer were defined, focusing on their Young's modulus, density, and Poisson's ratio. The MUT was subjected to a uniform line pressure of 86.49 kN/m, representing vehicular traffic and pedestrian loads. Results showed that the applied stresses and observed deflections were within safe limits, with a tensile strength of 3.4 MPa and current stress at 3046 kN/m², indicating no risk of cracking. The observed deflection of 3.9 mm was significantly below the allowable limit of 10 mm, affirming structural stability. The reinforcing steel also exhibited stress levels well within its allowable limit, demonstrating the design's adequacy and ensuring the structure's safety and efficiency under the specified load conditions.

Keywords: *Deformation, FEM, LISA, MUT, Stress.*

Abstrak

Infrastruktur perkotaan yang semakin kompleks membutuhkan pengelolaan utilitas yang efisien seperti listrik, air, dan telekomunikasi. Terowongan Multi Utilitas (MUT) menyediakan pendekatan terkonsolidasi untuk menampung utilitas ini, mengurangi gangguan permukaan dan meningkatkan efisiensi pemeliharaan. Studi ini menilai kinerja struktur dan distribusi tegangan dalam MUT menggunakan Finite Element Analysis (FEA) melalui perangkat lunak LISA FEA V.8. Analisis ini melibatkan pemodelan geometris MUT secara rinci, dengan mempertimbangkan kondisi awal dan potensi penurunan tanah. Sifat-sifat material untuk baja, beton, kayu, tanah timbunan, dan lapisan permukaan atas ditentukan, dengan fokus pada modulus Young, kepadatan, dan rasio Poisson. MUT diberi tekanan garis seragam sebesar 86,49 kN/m, yang mewakili lalu lintas kendaraan dan beban pejalan kaki. Hasil penelitian menunjukkan bahwa tekanan yang diberikan dan lendutan yang diamati berada dalam batas aman, dengan kekuatan tarik 3,4 MPa dan tekanan saat ini sebesar 3046 kN/m², yang mengindikasikan tidak adanya risiko retak. Lendutan yang teramati sebesar 3,9 mm jauh di bawah batas yang diijinkan yaitu 10 mm, yang menegaskan stabilitas struktural. Baja tulangan juga menunjukkan tingkat tegangan yang berada di dalam batas yang diijinkan, yang menunjukkan kecukupan desain dan memastikan keamanan dan efisiensi struktur dalam kondisi beban yang ditentukan.

Kata kunci: Deformasi, FEM, LISA, MUT, Stres.

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1. Introduction

The growing complexity of urban infrastructure necessitates efficient management of utilities such as electricity, water, and telecommunications. Multi Utility Tunnels (MUTs) provide a consolidated approach to housing these utilities, which aids in reducing surface disruption and enhancing maintenance efficiency [1] . This study focuses on assessing the structural performance and stress distribution within MUTs using Finite Element Analysis (FEA), specifically through LISA FEA V.8 software [2].

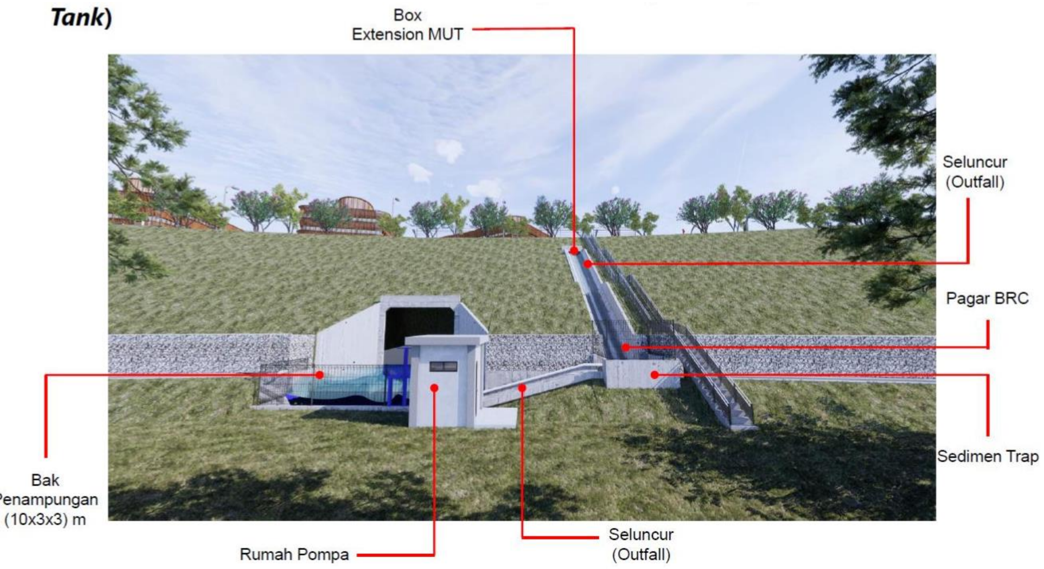


Figure 1. 3D plan view of MUT cross section

This research was conducted to get a description of the behavior that occurs in the selected embankment replacement material into mortar foam material, in the modeling using finite element method software LISA FEA V.8, the use of this software is so that researchers can develop several possibilities that can be seen when each parameter of the model is made different according to with applicable standards.

2. Research Method

The design and analysis of Multi Utility Tunnels (MUTs) have garnered significant attention in the field of civil engineering due to their critical role in urban infrastructure management. The use of Multi Utility Tunnels, which house various utility services such as electricity, water, sewage, and telecommunications within a single underground conduit, is a solution to the increasing complexity of urban utility systems. This literature review aims to provide a comprehensive understanding of the evolution of MUT design, the role of Finite Element Analysis (FEA) in their structural evaluation, and the current state of knowledge in this domain.

2.1. Evolution of Multi Utility Tunnels

The concept of housing multiple utilities within a single tunnel has evolved significantly over the past few decades. Early implementations of utility tunnels were primarily focused on the management of steam and heating systems in industrialized cities [3]. As urban areas expanded and diversified, the scope of utility tunnels broadened to include water, sewage, and electrical systems. The growing complexity of urban infrastructure has necessitated more sophisticated design and analysis methods to ensure the reliability and safety of these tunnels.

One of the key benefits of MUTs is their ability to centralize and streamline utility management. According to Bathe (2006), MUTs reduce the need for repeated excavation and surface disruption, which can be costly and disruptive to urban environments. The integration of various utilities within a single tunnel simplifies maintenance and repairs, as all services are accessible from a centralized location. This approach not only enhances operational efficiency but also contributes to the overall sustainability of urban infrastructure [2].

2.2. Design Considerations for Multi Utility Tunnels

The design of MUTs involves several critical considerations, including structural capacity, load distribution, and environmental impact. The structural capacity of MUTs must accommodate the combined weight of the utilities they house, as well as external loads such as soil pressure and traffic loads. Xie and Shi (2019) highlight that the design of MUTs requires a thorough understanding of load distribution and the potential interactions between different utility systems.

A comprehensive design approach involves the use of advanced modeling techniques to predict the behavior of MUTs under various loading conditions. According to Chen and Zhang (2018), Finite Element Analysis (FEA) has become an essential tool in the design process, allowing engineers to simulate the structural performance of MUTs and identify potential areas of weakness. FEA enables the detailed examination of stress distribution, deformation, and load-bearing capacity, which is crucial for optimizing the design and ensuring the structural integrity of MUTs.

2.3. Role of Finite Element Analysis (FEA) in MUT Design

Finite Element Analysis (FEA) has revolutionized the way engineers approach the design and analysis of complex structures, including MUTs. FEA is a numerical method that divides a complex structure into smaller, manageable elements, allowing for detailed analysis of stress, strain, and deformation. This method provides valuable insights into the behavior of MUTs under various loading conditions, enabling engineers to make informed design decisions [3].

In the context of MUT design, FEA is used to simulate the interaction between different utility systems and the surrounding environment. Li and Guo (2016) emphasize that FEA allows for the examination of how external loads, such as soil pressure and traffic loads, affect the structural performance of MUTs. The ability to model various load scenarios and environmental conditions helps engineers identify critical stress zones and optimize the design to enhance safety and performance.

A mathematical strategy for handling complex examination concerns is the finite element method (FEM). The restricted component approach combines a few numerical concepts to establish the parameters of a linear or nonlinear framework. The number of conditions generated is often very high, exceeding 20,000 conditions. Therefore, unless a good PC is used, this method is of little practical value.
The finite element method uses a utilizes a component discretization way to deal with tackle the issue of tracking down relocations of vertices/associations/grids and primary powers. The lattice approach for primary examination is linked to discrete component circumstances, and the results obtained are identical to those of conventional structural study. With one-layered components (line components), two-layered components (plane components), or three-layered components (volume/continuum components), discretization ought to be achievable. This method makes use of a continuum component to select a more accurate result [4] [5] [6].

2.4. Current State of Knowledge and Research Gaps

Despite the advancements in MUT design and analysis, several research gaps and challenges remain. One of the key areas of concern is the integration of new materials and technologies into MUT design. Gao and Liu (2020) suggest that the use of advanced materials, such as high-strength concrete and fiber-reinforced polymers, can improve the durability and performance of MUTs. However, there is a need for further research to understand the long-term behavior of these materials in underground environments.

Another important area of research is the impact of environmental factors on MUT performance. Yang and Xu (2019) highlight the need for more detailed studies on the effects of seismic activity, groundwater conditions, and temperature variations on the structural integrity of MUTs. Understanding how these environmental factors influence MUT performance is crucial for designing resilient and reliable infrastructure.

Furthermore, the integration of smart technologies and sensors into MUTs is an emerging area of interest. According to Ding and Zhao (2017), the use of monitoring systems and real-time data analysis can enhance the management and maintenance of MUTs. However, there is a need for research on the implementation of these technologies and their impact on the overall performance of MUTs.

2.5. Case Studies and Practical Applications

Several case studies provide valuable insights into the design and performance of MUTs in different urban contexts. For example, the implementation of MUTs in cities like Tokyo and London has demonstrated the benefits of centralized utility management and reduced surface disruption [7]. These case studies highlight the importance of considering local conditions and requirements when designing MUTs.

In addition to urban case studies, research on MUTs in various geological settings provides valuable information on how different soil and rock conditions affect tunnel design. According to Xie and Shi (2019), the performance of MUTs can vary significantly depending on factors such as soil type, groundwater conditions, and seismic activity. These findings underscore the need for site-specific analysis and design adjustments to ensure the structural integrity of MUTs.Finite Element Method.

2.6. LISA FEA V.8

Three different types of intensity exchangers were each subjected to a temperature rise measurement using finite element method software LISA FEA V.8, a well-known restricted component assessment program. The line component model, the shell model, and the strong model are the three different types of models, in order of how basic and easy they are to construct [8] [9] [10] [11] [12] [13].

Since we cannot prevent convection from accumulating the baseplate surface with the face determination device, the convection coefficient of the baseplate surface is not fixed as a percentage of the value used elsewhere for line component models alone. It's only a matter of being mindful.

By avoiding that area, we can easily prevent convection on the mounting surface for the other two models. For each case, an internal intensity generator is used, and the volume of the entire floor piece is considered the intensity source. Applying limit conditions to a line component model should be done with caution[iii].

3. Results and Discussion

This analysis delves into the material composition and finite element modeling of a Multi-Utility Tunnel (MUT) structure in the Nusantara Capital City, utilizing LISA v.8 FEA software. The MUT's walls and slabs are constructed with concrete possessing a compressive strength (fc) of 30 MPa. Reinforcement steel is categorized based on diameter: bars larger than or equal to 10mm are deformed, grade BJTS-420B, with a yield strength (Fy) of 420 MPa; while bars smaller than or equal to 12mm are plain, grade U-24, with a yield strength of 240 MPa. These specific material properties were incorporated into the FEA model to accurately simulate the structural behavior of the MUT under various loading conditions.

The LISA v.8 FEA software was employed to create a detailed 3D model of the MUT. The concrete elements were modeled using solid elements, and the reinforcement steel was represented by beam elements. Boundary conditions, such as fixed supports at the base and roller supports at the sides, were applied to replicate the actual support conditions of the tunnel. A combination of dead loads, live loads, and soil pressures were applied to the model to assess the structure's response. The FEA results provided valuable insights into the stress and strain distribution within the MUT, enabling the evaluation of the adequacy of the reinforcement and the overall structural integrity of the tunnel..

3.1. Material Properties

In this study, researchers compared the stresses that arise when reinforcing oprit using granular material with foam mortar material. with material parameters as in table 1.

Table 1. Material Properties

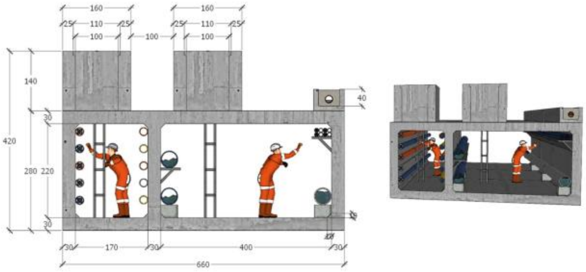
No.	Material	Young Modulus (kN/m^2)	Density (kN/m3)	Poison Ratio
1	Steel	210,000,000	78.50	0.30
2	Concrete fc' 30 MPa	25,742,960,2	24	0.20
3	Rigid Pavement	25,742,960,2	24	0.20
4	Embakment	30,000	18	0.3

Source: Research 2024.

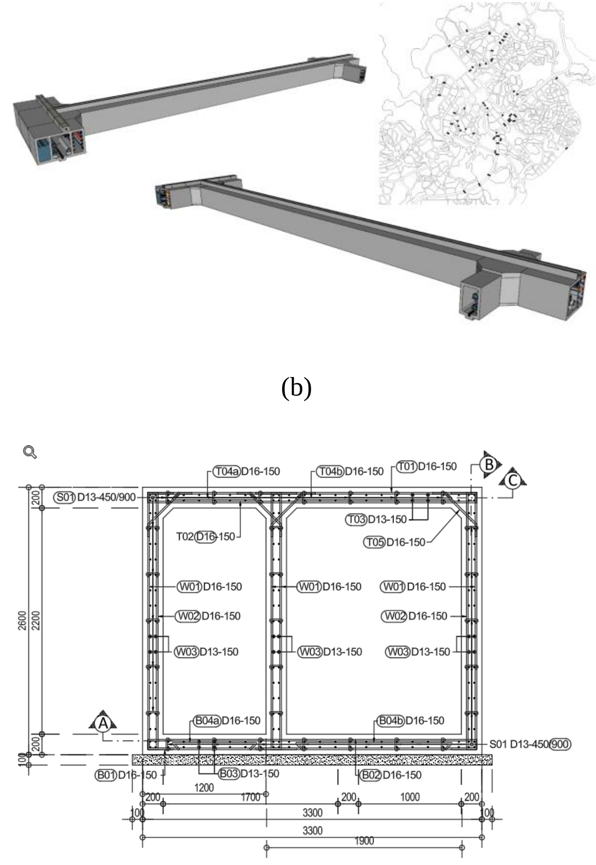
3.2. Research locations

This research is focused on the KIPP area within the Nusantara Capital City, specifically investigating the utility access infrastructure in this region. The KIPP area, situated in the heart of the new capital, is a critical development zone that requires efficient and reliable utility services to support its growing population and economic activities. This study aims to assess the existing utility infrastructure, identify potential gaps or challenges, and propose solutions to ensure optimal utility access within the KIPP area, contributing to the overall sustainability and functionality of the Nusantara Capital City..

Figure 6. Location distribution of MUT building points



(a)



(b)

(c)

Figure 7. (a) plan condition (b) 3-dimensional drawing of the MUT (c) MUT detailing plan.

Shown in Figure 7(a) is the plan condition of the MUT geometry, while Figure 7(b) is a 3-dimensional drawing of the MUT construction plan and Figure 7(c) is the MUT detailing plan.

3.2. Analisys

3.2.1. Modeling

In this study, the modeling of the results of collecting the parameters of several materials and identified by using the finite element method software LISA FEA V.8. MUT modeling adjusts the results of the MUT plan drawing, shown in Figure 8.

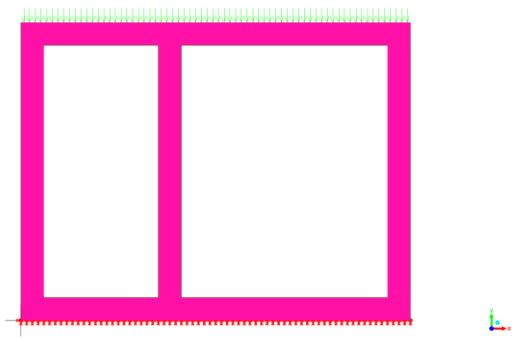


Figure 8. MUT Modeling with LISA

3.2.2. Material and Loads

The material parameters used in this study is, for walls and slabs, the concrete strength (fc) is 30 MPa. The reinforcement steel used varies based on the bar diameter. For bars with a diameter greater than or equal to 10 mm and with deformed bars, the steel grade is BJTS-420B with a yield strength (Fy) of 4200 kg/cm². For bars with a diameter less than or equal to 12 mm and with plain bars, the steel grade is U-24 with a yield strength (Fy) of 2400 kg/cm².

The table presents the mechanical properties of various materials commonly used in construction. It lists the Young's modulus, density, and Poisson's ratio for steel, concrete (with a compressive strength of 30 MPa), wood, backfill soil, and a top surface layer. Young's modulus indicates the material's stiffness, density its mass per unit volume, and Poisson's ratio describes its tendency to expand or contract perpendicular to an applied force. These properties are crucial for engineers to select appropriate materials for different structural applications, considering factors such as load-bearing capacity, weight, and deformation under stress.

3.2.3. Crossing types of MUT

The structure is subjected to a line pressure of 86.49 kN/m acting uniformly across the upper surface of the MUT. This load represents the equivalent force exerted by vehicular traffic passing over the structure. In engineering terms, a line load is distributed along a linear element, such as a beam or a slab, and is often used to simplify the analysis of continuous loads, like the weight of a vehicle or a row of closely spaced point loads. The magnitude of the line load, 86.49 kN/m, indicates the intensity of the distributed force per unit length of the structure.

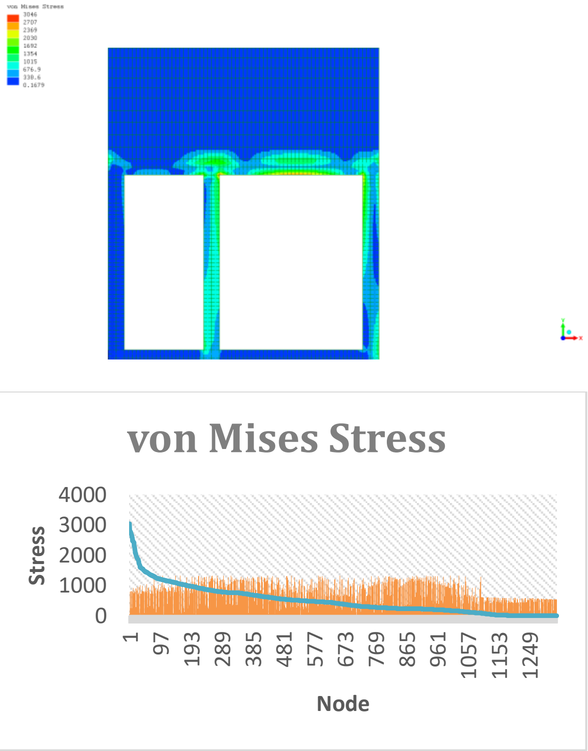


Figure 9. Stress of MUT

The material's tensile strength, the maximum stress it can withstand before fracturing, is 3.4 MPa or equivalently 3400 kN/m². The stress currently acting on the material is 3046 kN/m². Since the applied stress of 3046 kN/m² is less than the material's tensile strength of 3400 kN/m², no cracking has occurred. The material is operating well within its safe stress limits and is not at risk of failure due to tensile stress, shown in Figure 9.

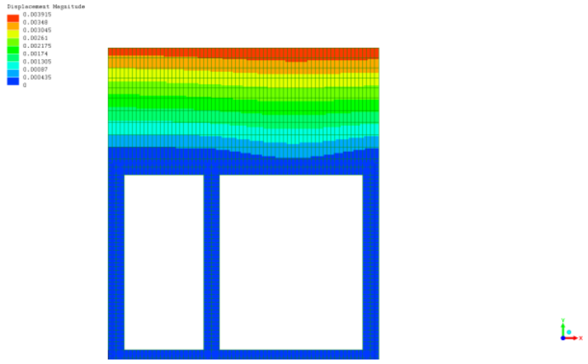


Figure 10. MUT deflection

The observed deflection of the structure is 0.0039 m or 3.9 mm, which is significantly less than the allowable deflection of 10 mm. The allowable deflection is calculated using the formula Δ Allowable = L * 1000 / 240, where L is the span of the member. In this case, the calculated allowable deflection is 10 mm. Since the actual deflection is well below the allowable limit, the structure is considered to be structurally sound and is not experiencing excessive deformation, shown in Figure 10.

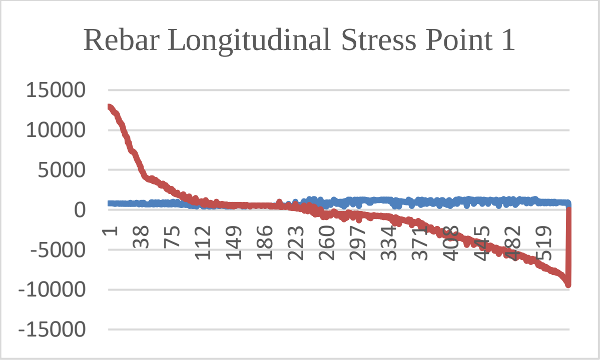


Figure 11. Rebar longitudinal stress point of MUT

The allowable stress of the reinforcing steel is 420/1.5 MPa, which is equivalent to 28000 kN/m². The calculated stress in the reinforcing steel is 12128.077 kN/m². Since the actual stress is significantly lower than the allowable stress, it can be concluded that the reinforcing steel is well within its safe working limits and is not at risk of yielding or failure. This indicates that the design of the reinforced concrete member is adequate to resist the applied loads, shown in Figure 11.

3.2.4. Customized Type 6C MUT.

For the Customized Type 6C MUT model subjected solely to pedestrian loads, the analysis will focus on determining the maximum deflection and stress within the structure. By applying a uniformly distributed load equivalent to the pedestrian load intensity, the finite element model will calculate the structural response. Key parameters such as material properties (Young's modulus, Poisson's ratio, and density) will be defined for concrete, reinforcement steel, and any other relevant materials. Boundary conditions will be established to simulate the support conditions of the MUT. The analysis will also consider factors like the geometry of the structure and any potential load combinations to ensure the safety and serviceability of the MUT under pedestrian loading conditions

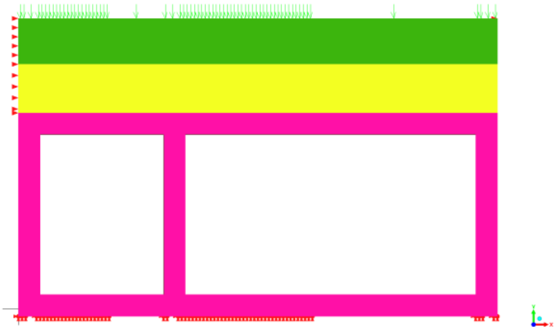


Figure 12. Customized Type 6C MUT Modeling.

Every sidewalk component wider than 600 mm needs to be built to support 5 kPa of pedestrian load intensity. On each vehicle lane, this load must be regarded as operating concurrently with the vehicular load. On the other hand, when evaluating the combined consequences of both loads, the pedestrian load can be overlooked if the sidewalk is intended to support automobile traffic. In the event that the sidewalk is ever transformed into a driving lane, the live vehicle load must be applied 250 mm out from the inner edge of the parapet while designing the other bridge components. Here, it is not necessary to take the dynamic load factor into account, shown in Figure 12.

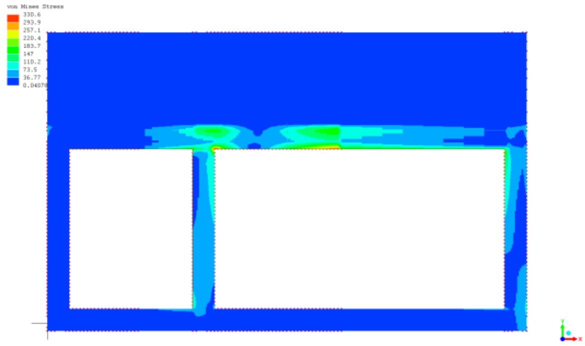


Figure 13. Stress of Customized Type 6C MUT

The material's tensile strength, the maximum stress it can withstand before fracturing, is 3.4 MPa or equivalently 3400 kN/m². The stress currently acting on the material is 330.6 kN/m². Since the applied stress of 330.6 kN/m² is significantly less than the material's tensile strength of 3400 kN/m², no cracking has occurred. The material is operating well below its safe stress limits and is not at risk of failure due to tensile stress, shown in Figure 13.

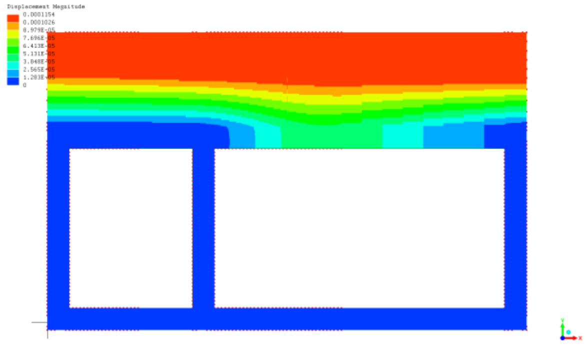


Figure 14. Deflection of Customized Type 6C MUT

The observed deflection of the structure is 0.000115 m or 0.115 mm, which is significantly less than the allowable deflection of 16.67 mm. The allowable deflection is calculated using the formula Δ Allowable = L * 1000 / 240, where L is the span of the member. In this case, the calculated allowable deflection is 16.67 mm. Since the actual deflection is well below the allowable limit, the structure is considered to be structurally sound and is not experiencing excessive deformation, shown in Figure 14.

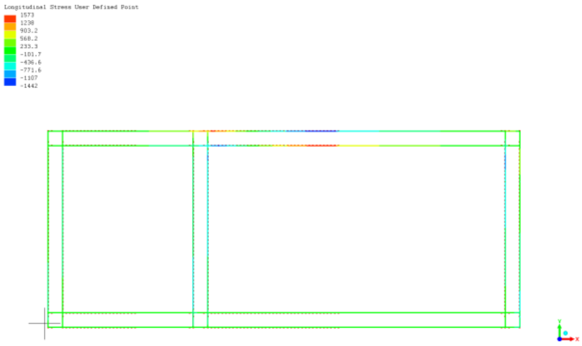


Figure 15. Rebar longitudinal stress point of Customized Type 6C MUT

The allowable stress of the material is 420/1.5 MPa, which is equivalent to 28000 kN/m². The calculated stress in the material is 1573 kN/m². Since the actual stress is significantly lower than the allowable stress, it can be concluded that the material is well within its safe working limits and is not at risk of yielding or failure. This indicates that the design of the component is adequate to resist the applied loads shown in Figure 15.

4. Conclusion

A finite element analysis was conducted on a Multi-User Toilet (MUT) structure to evaluate its structural performance under anticipated loads. The analysis incorporated detailed geometric modeling of the MUT, considering initial conditions and potential subsidence. Material properties, including Young's modulus, density, and Poisson's ratio, were defined for steel, concrete, wood, backfill soil, and the top surface layer. The MUT was subjected to a line load representing vehicular traffic and pedestrian loads.

In this study, the modeling of material parameters was conducted using the finite element method software LISA FEA V.8, adjusting the results to match the MUT plan drawing as shown in Figure 8. The materials considered include concrete with a strength of 30 MPa for walls and slabs, and various grades of reinforcement steel. The mechanical properties, including Young's modulus, density, and Poisson's ratio for materials such as steel, concrete, wood, backfill soil, and a top surface layer, were crucial for selecting appropriate materials for structural applications. These properties help determine the load-bearing capacity, weight, and deformation under stress of each material, ensuring the structure's integrity under different load conditions.

The structure was subjected to a uniform line pressure of 86.49 kN/m, representing vehicular traffic load, and the analysis confirmed that the applied stresses and observed deflections were within safe limits. The tensile strength of the material was 3.4 MPa, with the current stress at 3046 kN/m², well below the tensile limit, indicating no risk of cracking. The observed deflection of 3.9 mm was significantly less than the allowable 10 mm, affirming the structure's stability. The reinforcing steel also exhibited stress levels well within its allowable limit, ensuring the design's adequacy. These results demonstrate that the structure is both safe and efficient under the specified load conditions.

References

[1] J. Gao and Y. Liu, "Numerical Simulation of Utility Tunnel Behavior under Various Loading Scenarios," *Computers and Geotechnics,* vol. 118, pp. 103-115, 2020.

[2] J. Yang and Y. Xu, "Performance Assessment of Multi-Utility Tunnels under Seismic Loads: A Finite Element Approach," *Soil Dynamics and Earthquake Engineering,* vol. 122, pp. 104-116, 2019.

[3] Y. Feng and . J. Zhang, "Finite Element Analysis for Civil Engineering with DIANA Software," *Springer,* 2015.

[4] Q. Wang and D. Zhang, "Structural Performance Analysis of Multi-Utility Tunnels under Different Load Conditions," *Journal of Structural Engineering,* vol. 146, no. 5, 2020.

[5] K. J. Bathe, "Finite Element Procedures," *Prentice Hall,* 2006.

[6] H. Chen and X. Zhang, "Design Optimization of Multi-Utility Tunnels Using Finite Element Analysis," *Engineering Structures,* vol. 174, pp. 490-503, 2018.

[7] Y. Li and Z. Guo, "Finite Element Analysis of Urban Utility Tunnels under Traffic Load," *Journal of Civil Engineering and Management,* vol. 22, no. 4, pp. 539-547, 2016.

[8] A. Efendi, "APPLICATION OF CHATGPT IN THE ANALYSIS OF INTERNAL FORCES OCCURRING IN SIMPLE BEAMS USING LISA V. 8 FEA," *Selodang Mayang: Jurnal Ilmiah Badan ...,* 2024.

[9] A. Efendi, "Behavior of Railroad Bridge Girders Due to Brake Loads with LISA V. 8 FEA," ... *Conference on Railway and Transportation (ICORT ...,* 2023.

[10] A. Efendi, "Characteristic behavior of soil using bacterial biogrouting with LISA FEA V. 8.," *International Journal of Advanced Science and ...,* 2024.

[11] A. Efendi, "ChatGPT application in ground settlement analysis using LISA V. 8 FEA," *Research of Scientia Naturalis,* 2024.

[12] A. Efendi, "Simulation of fire exposure behavior to building structural elements using LISA FEA V. 8.," *International Journal of Advanced Science and ...,* 2023.

[13] N. S. AW Efendi, "Behavior of Cakar Ayam Modifikasi (CAM) foundation on soft soil with LISA V. 8 FEA," *Kurva S: Jurnal Keilmuan dan Aplikasi ...,* 2024.

[14] X. Xie and Z. Shi, "Urban Utility Tunnel Engineering," *Springer,* 2019.

[15] H. Meguid, "A numerical procedure for the assessment of contact pressures on buried structures overlain by EPS geofoam inclusion," *International Journal of Geosynthetics and ...,* 2017.

[16] A. W. Efendi, "Analysis of Strengthening of Soil Subsidence on Land in Tanjung Priok," *Journal of Science and Education Research,* 2022.

[17] M. Ciment and G. Heerten, "Rigid inclusions for settlement reduction and load transfer," *Proceedings of the International Conference on Soil Mechanics and Geotechnical Engineering,* 2001.

[18] J. A. Ciment and R. Cojean, "Use of rigid inclusions for foundation improvement," *ASCE Geotechnical Special Publication,* 1998.

[19] O. Z. C and R. L. Taylor, "The Finite Element Method: Its Basis and Fundamentals," *Butterworth-Heinemann,* 2005.

[20] J. I. Baez, "A design model for rigid inclusions in soft soils," *Proceedings of the 5th International Conference on Ground Improvement Techniques, Singapore,* 1995.

[21] K. R. A. J. A. A. A Ansari, "Formulation of multi-hazard damage prediction (MhDP) model for tunnelling projects in earthquake and landslide-prone regions: A novel approach with artificial …," *Journal of Earth System Science,* 2023.

[22] Z. L. S. Y. J. C. X. H. J Wu, "Source term estimation of natural gas leakage in utility tunnel by combining CFD and Bayesian inference method," *Journal of Loss Prevention in the Process ...,* 2020.

[23] B. C. ST Ariaratnam, "Underground space development resulting from increased urban migration," *Global Journal of Engineering and ...,* 2021.

[24] Z. Z. Y. X. X. N. C Zhang, "Study on the shear mechanical response and failure characteristics of prefabricated double-cabin utility tunnel joints," *Journal of Civil Structural Health ...,* 2024.

[25] J. C. X. L. L Dong, "Risk control method and practice in the whole construction process of a shield tunneling pipe gallery in complex surrounding underground environment," *ASCE-ASME Journal of Risk and Uncertainty ...,* 2022.

[26] A. Efendi, "Behavior analysis of deformation changes after sagging on the Telaga Abadi suspension bridge," *Nusantara Civil Engineering Journal,* 2022.

[27] I. Efendi, "Analysis Surface Structure Improvement of Runway Threshold 07-25 Using FAARFIELD," *Teknik: Jurnal Ilmu Teknik dan Informatika,* 2021.

[28] A. Efendi, "Analysis of Strengthening of Soil Subsidence on Land in Tanjung Priok," *Journal of Science and Education Research,* 2022.

[29] A. Efendi, "Availability of the Sangatta Pelangi Hill Slide Using Geoelectric Correlation on the Borlog," *Journal of Science and Education Research,* 2023.

[30] A. Efendi, "Computing steel frame analysis of behavior semi-rigid connection," *International Journal of Advanced Science and ...,* 2023.

[31] G. M. C. O. .. CR Vindigni, "Simple adaptive wing-aileron flutter suppression system," *Journal of Sound and ...,* 2024.

[32] Z. S. R Zeng, "Post-occupancy evaluation of the urban underground complex: A case study of Chengdu Tianfu Square in China," *Journal of Asian Architecture and Building ...,* 2023.

[33] F. T. A. D. G. L. M. F. F. .. S Ricci, "Wind tunnel system for active flutter suppression research: Overview and insights," *AIAA Journal,* 2022.

[34] T. Z. X. Q. Z Guohua, "Investment decision-making and cost recovery mechanisms of utility tunnels based on comprehensive benefit quantification," *Journal of Tsinghua University ...,* 2023.