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Design Analysis of Pancanaka 2000 Tooth Bucket Structure Using Finite Element Method

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ABSTRACT

This study tests the structural performance of the Pancanaka 2000 tooth bucket, a common heavy-duty excavation component. The goals are to determine the component testing method, analyze the findings of finite element simulation sub-modeling, and identify the causes of structural failure. Shining 3D scanning created a detailed model of the Pancanaka 2000 tooth bucket. ANSYS simulation software performed a Finite Element Analysis on this model. A 10-ton static force was applied to imitate working circumstances on the bucket teeth tip. The simulation monitored mechanical reactions, including total displacement, von Mises stress, and safety factors, which indicate structural reliability. The study found numerous noteworthy findings. First, the computerized model of the bucket teeth allowed for an exact analysis of loading stress. The simulation revealed a region susceptible to failure under high loads, characterized by a maximum total displacement of 0.38883 mm, a maximum von Mises stress of 321.5 MPa, and a minimum safety factor of 1.328. Qualitative analysis identified material as the leading cause of fracture. Wear and scraping were noticed at the bucket tooth-adapter interface. Mechanical failure was also linked to component gaps exceeding design tolerance. These flaws lead to inappropriate load distribution and stress concentration, resulting in structural failure during operation. According to this study, the durability and performance of excavator components, such as the Pancanaka 2000 teeth bucket, depend on correct design, strict material selection, and precise assembly tolerances.

1. Introduction

Infrastructure development benefits various sectors, including economic, educational, social, cultural, agricultural, and others [1]. Developing countries like Indonesia continually undertake development initiatives in various sectors across the country. The number of development projects, both government and private, continues to grow over time. Apart from human resources, this development requires heavy equipment to provide support [2]. Technically, heavy equipment resources are the central element in implementing road projects. Heavy equipment is necessary to carry out road construction work efficiently and to meet predetermined goals. Heavy equipment (excavators) advantages include fast time, large power, and economic value. Heavy equipment (excavators) is a vital tool in the current era of development [3]. Therefore, special care is necessary to maintain the appearance of these devices. However, in some cases, the equipment is damaged.

Heavy equipment production continues to grow in Indonesia to meet the needs of consumers across various sectors, including agriculture, forestry, construction, and mining. According to data (Industrial Confidence Index January 2023 Increases Sharply, Industry Optimistic of Higher Growth in 2023) published by the Ministry of Industry of the Republic of Industry. The most significant increase in sales from January to August 2021 occurred in heavy equipment for the mining sector, which rose to 206% to 3,062 units from 1,001 units in the same period in 2020 [4]. The forestry sector increased by 84% to 1,487 units, the construction sector increased by 64% to 3,449 units, and the agro sector by 54.7% to 823 units. Heavy equipment production is estimated to reach 6,000 units by the end of 2021, representing a 75% increase from 2020, when around 3,427 units were produced [5]. Excavators are heavy equipment widely used to dig holes and make foundations in construction, mining, agriculture, and waste management [6]. Excavators have three primary structural components: the upper structure, the front attachment, and the undercarriage. One of the main components of the front attachment is the boom, arm, and bucket [7]. Front attachments have a significant role in executing tasks performed by excavators. An operator needs to understand the proper method of operating an excavator so that the tool is not vulnerable to damage [8].

The tooth bucket is one of the most important parts of the excavator bucket. Bucket teeth are useful as hard-breaking materials that function to avoid wear and damage to the bucket [7]. Bucket tooth damage due to wear will reduce the effectiveness of excavator work. Replacement of worn bucket teeth leads to high excavator operating costs. PT BISA Ruang Nuswantara is a social enterprise company that bridges and aligns education with the industrial sector to create opportunities for access to quality jobs. The company was officially established in April 2023 and is based on Delta Dunia Group's commitment to Environmental, Social, and Governance (ESG) aspects. In the same month, PT BISA Ruang Nuswantara separated from BUMA and operated as an independent entity, with a strong foundation in the Environmental, Social, and Governance (ESG) principles upheld by the Delta Dunia Group. PT BISA Ruang Nuswantara continues to play a crucial role in the group and is ambitious to expand its scope beyond the mining sector, exploring other sectors, including hospitality, to support government programs [9].

PT BISA Ruang Nuswantara is committed to empowering communities and ensuring a sustainable future through vocational education, innovation in the circular economy, and community empowerment initiatives. By leveraging its resources, expertise, and partner network, BIRU seeks to create value for all stakeholders while addressing some of Indonesia's most pressing social and environmental challenges today [9]. Through its vocational education program, PT BISA Ruang Nuswantara is dedicated to equipping young people with the essential skills, knowledge, and certifications necessary to succeed in the rapidly evolving job market. In addition, PT. BISA Ruang Nuswantara collaborates with universities in the country to design, manufacture, and distribute waste recycling products based on proven research. Through community empowerment initiatives, BIRU also supports micro, small, and medium enterprises (MSMEs) in creating new economic opportunities for communities and ensuring the sustainability of these enterprises [9]. PT BISA Ruang Nuswantara implements circular economy principles in industrial waste management to reduce environmental impact and support sustainability. By recycling low-carbon steel waste into value-added products such as tooth buckets and Allugoro hammers that meet high safety standards, PT BISA Ruang Nuswantara successfully reuses previously considered waste. In addition, the innovation of Eco-on Engineering Tools, which improves fuel efficiency, reflects BIRU's commitment to optimizing resource use, reducing carbon emissions, and creating a greener and more sustainable future for the industrial sector [9].

The problems I encountered with the Pancanaka 2000 tooth bucket involved several important technical aspects, including damage to the bottom of the tooth bucket, unstable conditions during installation, and repeated fractures over a relatively short period (by hour meter) can be show in Fig. 1. In addition, erosion resulted in a rounded tooth shape and made it difficult to penetrate the material, especially when 70% of the tooth length remained. These issues indicate design or material deficiencies that impact the durability and performance of the bucket teeth in difficult operational situations [10].

Figure 1. The tooth bucket bottom was broken

The cause of damage to the tooth bucket can be identified through several technical factors. One of them is excessive endplay dimensions, which result in uncontrolled movement and instability during operation. The design of tooth side angles that are too sharp can also accelerate the wear process and cause damage to the structure [11]. Additionally, undetected laminations can reduce the material's strength, thereby increasing the likelihood of fracture [12]. The high hardness of the material makes the tooth more susceptible to cracks. At the same time, worn adapters contribute to malfunction, as they reduce the effectiveness and stability of the tooth's joining under severe working conditions.

This research is necessary to investigate the causes of Pancanaka 2000 bucket tooth damage by employing a simulation approach through submodeling and interviews. Sub-modeling simulation examines in detail the stress distribution and mechanical factors that contribute to the occurrence of damage. At the same time, interviews are conducted to collect information directly from relevant parties regarding operational conditions, materials used, and other possible causes. Combining these two methods aims to gain a more comprehensive understanding, enabling the implementation of appropriate solutions to prevent similar damage from recurring in the future.

2. Methodology

This research employs evaluation and testing methods to investigate the causes of cracks in the Pancanaka 2000 tooth bucket, focusing on structural analysis using Ansys software simulation. If the simulation results did not provide a solution, the research continued with validation through interviews with the supervisor and staff regarding the common causes of tooth bucket fractures, based on 2021 company data. Additional references from interviews or field studies were also conducted, where possible, to confirm the veracity of the problem based on the chronology and on-site facts. This research refers to the following approach: 1) Primary observation, which involves examining the company's 2021 data regarding the physical condition of the Pancanaka 2000 tooth bucket, and 2) 3D scanning, which is done by scanning real objects to undergo a simulation testing process using software, and 3) Consists of pre, process, and evaluation stages.

Researchers reviewed various literature sources to identify existing problems and collect research data. The data used in this research includes types of evaluations and testers obtained from literature sources such as relevant journals, books, and articles. The data collection process is carried out by referring to the Pancanaka tooth bucket damage data in 2021 and collecting coherent information according to the research topic. Writing in the literature study stage involves incorporating quotes of facts from the field that aim to support this research.

The researcher scans the object under test using Shining 3D and dimensional instruments, adjusting them based on geometry and details to accurately and realistically replicate the toothed bucket the company has cast. This process aims to develop a model that can be applied in load analysis according to the specific needs in the field. The data obtained from the scan is then applied in 3D modeling using Ansys software. Ansys software is used to simulate static structural testing carried out by researchers.

Meshing breaks a continuous structural model into smaller components [13]. Better meshing quality, indicated by a larger number of elements the software can read, will result in higher convergence rates, reflecting better analysis accuracy. Given the complexity of the geometry required in tooth bucket modeling, it is crucial to determine suitable meshing techniques and methods at this stage so that the number of elements and nodes in the tooth bucket model can be evenly distributed efficiently. The simulation process is the stage that presents the analysis results based on the boundary conditions and loads determined during the Simulation Pre-Processing stage. In general, the results of this analysis display load contours marked with colors that reflect annotated values and directions, as well as specific information presented in both tabular and graphical form. Simulation processing is performed by analyzing the area at risk of cracking. Several loading result parameters appear until the discretization process is complete, focusing on three (3) main parameters.

Furthermore, the data summary stage aims to obtain a comprehensive summary of simulation testing results based on three key parameters. The data summary is presented as tables and graphs illustrating the simulation results. With this data summary, the author can conduct a more informed discussion in theoretical data analysis. In a theoretical context, the data analysis presents results and discussions that include the relationship between the findings obtained from the simulation and the relevant theories in this study. The data analysis process aims to extract useful information from data, which can be used to inform decisions and solve problems. The results of the data analysis will be presented in the form of conclusions that summarize the results obtained by researchers, both qualitatively and quantitatively, in the subsequent discussion of the simulation results.

The research conducted by the researcher lasted for 5 months, from February 16 to June 30, 2024. This research was conducted at the Research and Development department in the Engineering Department of PT BISA Ruang Nuswantara (BIRU), located at South Quarter Tower A, Penthouse Floor, Jalan R.A. Kartini Kav. 8, West Cilandak, Jakarta 12430. Research variables in the study "Design Analysis of Pancanaka 2000 Tooth Bucket Structure Using Finite Element Analysis Method" include independent variables, namely Ansys software as a loading simulation tool; dependent variables, namely the loading conditions of the analyzed Pancanaka 2000 tooth bucket; and controlled variables, namely factors that affect the results of computer testing, which require recalculation in case of errors or invalid data. An analytical model is a systematic approach to designing, conducting, and evaluating a study. Various research methods can be employed, and the selection of a method is determined by the research question, the objectives to be achieved, and the type of data required to address the problem under study.

3. Result and Discussion

Through the Shining 3D software, the original shape of the tooth bucket can be identified. A three-dimensional representation can be generated and converted into the format to be applied in this study, as shown in Fig. 2. Three-dimensional data of the Pancanaka 2000 tooth bucket was collected using the Shining 3D software, which scans a physical object to generate a highly detailed 3D model with X, Y, and Z coordinate axes in the desired direction. Despite being relatively new, this 3D scanning technology is considered accurate, fast, and effective. The scanning procedure was conducted according to SOPs to ensure data accuracy and consistency. The resulting 3D model serves as the basis for the testing and simulation stage, utilizing Ansys software to analyze product performance through simulations of material strength, load resistance, and environmental impact. These simulations aim to ensure the product meets quality standards and provide insights for further development.

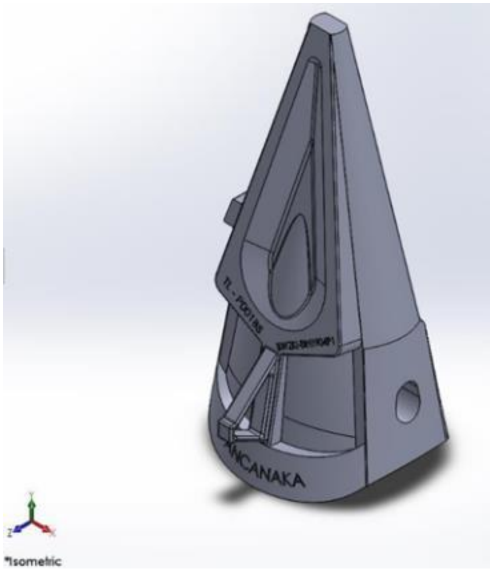

Figure 2. 3D scan results have been converted

Three-dimensional data of the Pancanaka 2000 tooth bucket were collected using Shining 3D software, which scans physical objects to produce highly detailed 3D models in the desired direction along the X, Y, and Z coordinate axes. Despite being relatively new, this 3D scanning technology is considered accurate, fast, and effective. The scanning procedure was conducted according to SOPs to ensure data accuracy and consistency. The resulting 3D model serves as the basis for the testing and simulation stage, utilizing Ansys software to analyze product performance through simulations of material strength, load resistance, and environmental impact. These simulations aim to ensure the product meets quality standards and provide insights for further development. The approach applied in testing the tooth bucket structure is through simulation modeling. This method analyzes the cracking area as part of the test. The cracking area analysis stage displays the overall simulation conditions, including the bucket used at the site, which has a capacity of 13.7 m^3, allowing for a material lift of 20 tons per lift. When digging 10 tons, the converted load is 98,066 N.

A thorough analysis was conducted to identify the part of the bucket tooth that experienced the heaviest loading, which was marked with a red contour for further analysis. A simulation of the cracking area was conducted, considering three analysis parameters, to validate the tooth bucket's ability to withstand the load. Assuming a similar fixed support position. Total deformation reflects the state of loading that causes dislocation or deformation before reaching the yield strength point. In this context, the deformation occurs in an elastic state, allowing it to return to its original position. This aspect is important because it affects the safety and durability of materials used in construction. The higher the applied test stress, the greater the displacement, which in turn results in decreased safety.

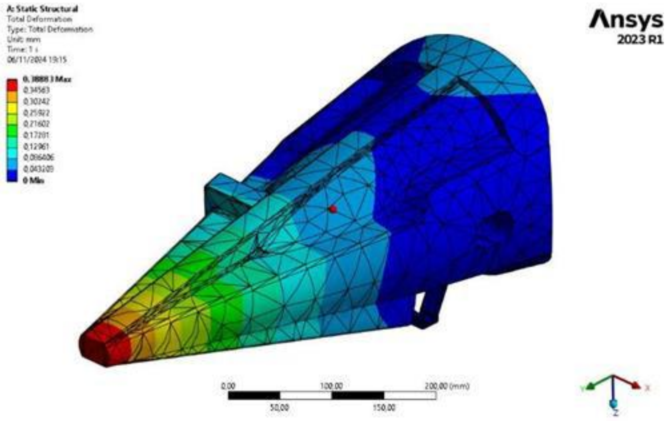

Figure 3. Total deformation results

Based on Fig. 3, it can be seen that the red contour shows a high deformation rate of 0.38883 mm. This value reflects a minimal deformation of less than 1 mm, which allows the tooth bucket to return to its original position. Meanwhile, the lowest deformation value was recorded at 0 mm at the back of the bucket tooth, indicating that the area was not subjected to significant stress. In von Mises stress, there is a relationship between the loading conditions and the stress distribution in the material, so a simulation is performed to illustrate the value of von Mises stress. The von misses stress is an indicator to assess the possibility of material failure by analyzing the results of the three main stresses, which are often referred to as principal stresses. Material failure can be predicted when the von Mises stress value exceeds the yield stress of the material ($\sigma v > \sigma y$).

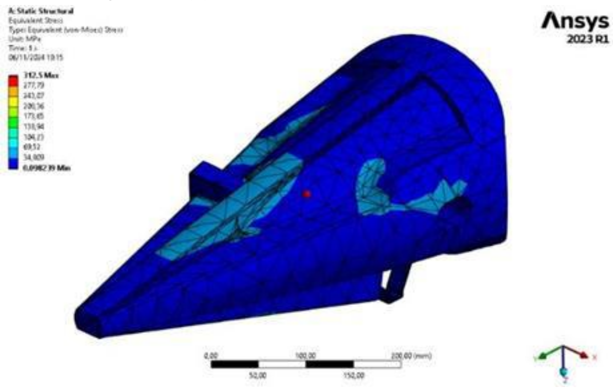

Figure 4. Von misses the stress results

In Fig. 4, the von misses stress analysis shows that the largest stress occurs inside the bucket tooth, which functions to withstand the load during the excavation process. The maximum measured stress value reached 312.5 MPa. Meanwhile, the low-stress value is 0.0982 MPa. An important parameter that supports static structural analysis is the safety factor. The safety factor plays a crucial role in ensuring that the system remains safe when facing loads exceeding calculations, so the design does not fail under these conditions. A higher safety factor value indicates that the construction has a better and stronger ability to withstand loads. In this study, the minimum safety factor is set at 1.5, which is considered based on material safety aspects.

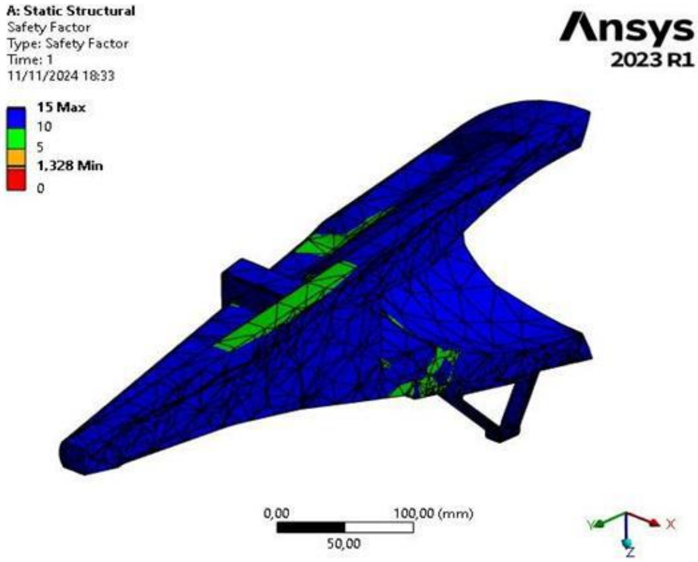

Figure 5. Safety factor analysis results

Fig. 5 shows that the highest safety factor value reaches 15 in the control zone area and its surroundings, which are marked in several annotated sections. Meanwhile, the low safety factor value is 1.328 in the safety zone. Although some elements fall below the minimum standard, this does not affect the existing loads. The analysis results show that von misses stress occurs inside the bucket tooth, which functions to withstand the load during the excavation process. The maximum measured stress value reached 312.5 MPa, while the lowest was only 0.0982 MPa. According to the data, the maximum stress that occurs is still below the characteristic yield strength of AISI 4140 material, which is 655 MPa. This shows that the material can withstand the workload. However, areas with high stress still require special attention to prevent potential damage in the future [14].

The results of the total displacement analysis show that the largest deformation occurs at the tip of the bucket tooth, where this elastic condition allows the material to return to its original position after the load is released. The maximum deformation value measured reached 0.38883 mm. In comparison, the lowest deformation value was 0 mm, indicating a variable load distribution on the component. This indicates that the tip of the tooth bucket is the most vulnerable area to deformation due to the working load. However, the deformation that occurs remains within reasonable limits for the material used, consistent with its elasticity characteristics. Sun, Yuan, et al. [15] stated that the tip of the tooth bucket often experiences the highest deformation when it receives the maximum working load under digging conditions. The safety factor indicates that the construction has a better and stronger ability to withstand loads, ensuring the structure can withstand extreme conditions. The maximum safety factor value measured reached 15, indicating that the structural design is significantly stronger than the facing load. Meanwhile, the low safety factor value of 1.328 indicates that the minimum safety factor result is still below the set 1.5, considering material safety aspects [13, 16].

4. Conclusion

Based on the results of the research and discussion that have been carried out regarding the Design Analysis of the Pancanaka 2000 Tooth Bucket Structure using the Finite Element Analysis Method, several conclusions can be drawn as follows:

1) The analysis was carried out with parameters, including total displacement, von Mises stress, and safety factor, through simulation using Ansys software. A load of 10 tons was applied, corresponding to a loading of 98066 N, which was distributed to the part where cracking was found.
2) Simulated test results show Total Displacement: 0.38883 mm, Von Mises-Stress: 312.5 MPa, and Safety Factor: 1,328. The company's product is structural steel material. The current loading condition allows the Pancanaka 2000 tooth bucket to return to its original state by maintaining its shape.
3) Factors that cause the Pancanaka 2000 tooth bucket to break include material erosion of the tooth adapter, resulting in the tooth bucket gap exceeding the tolerance limit (0.5 mm to 1.5 mm), and environmental factors that affect operational units in two areas: rocky and sandy. In rocky conditions, the tooth bucket often breaks on its back. The tooth bucket is corroded in sandy conditions, or the tip is blunted quickly.

Conflict of interest

The authors declare that they have no conflict of interest.

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