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Design Analysis of a Disabled Tricycle Electric Bike Frame Using Finite Element Analysis (Fea)

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Abstract-- *Mobilization is very important to meet the needs that require a person to move places or travel, especially for people with disabilities. According to the Badan Pusat Statistik (BPS) report, the number of Indonesian workers with disabilities in 2022 rose 160.18% from the previous year, which means a significant increase. One solution to help people with disabilities is to design vehicles that are flexible and safe for them. To find out whether the design is safe or not is by Finite Element Analysis (FEA) simulation. This research was conducted to analyze three electric bicycle frame designs for people with disabilities made using Solidworks software which were then simulated using Ansys Workbench software which produces output in the form of von mises stress values, deformations, and safety factors. The selection of this design is based on the simulation results which show that the von mises stress obtained is 62.669 MPa, the maximum deformation value is 0.32879 mm, and the safety factor obtained is 6.6221. This simulation uses a load of 80 kg and there is an additional battery at the bottom weighing 10 kg. The simulation results show that design 3 provides the best performance, this is because the design obtained the highest safety factor.*

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1. INTRODUCTION

Mobilization is very important to meet the needs that require someone to move or travel, especially for people with disabilities. Therefore, innovation is needed that can be utilized by people with physical disabilities in meeting mobility needs [1]. According to the Badan Pusat Statistik (BPS) report, the number of workers with disabilities in Indonesia reached 720,748 people in 2022. It was recorded that the number of disabled workers in Indonesia in 2022 increased by 160.18% from the previous year (year-on-year/yoy). To make it easier for workers to carry out their work properly, one solution is to use transportation. Therefore, a vehicle is needed that can support people with disabilities to carry out daily activities or work [2].

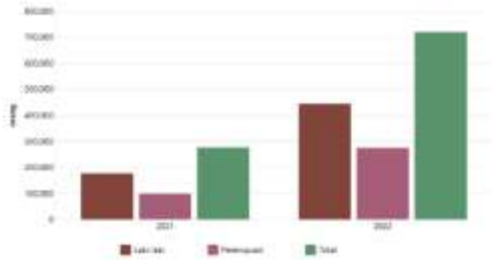

Figure 1. Data On The Number Of Workers With Disabilities in Indonesia

Disabled vehicles that we often find on the highway are the result of modifying existing motorbikes and only using existing materials without paying attention to the frame structure, modifying vehicles also costs a lot of money. This is also regulated in the Regulation of the Minister of Transportation of the Republic of Indonesia Number PM 45 of 2023 concerning Customization of Motor Vehicles, in Article (1) paragraph (2) which reads "Customization of Motor Vehicles is a change to the wheelbase, construction, and/or materials as well as replacing the engine brand and engine type of a motor vehicle to a Motor Vehicle type for personal or individual interests." Changes to the motorcycle frame are included in the customization category. However, this change must comply with applicable provisions. Changes to the frame without taking into account the feasibility test can cause damage to accidents.

Bicycles are one of the practical and environmentally friendly means of transportation, but the range and speed of this bicycle are very limited. Along with the development of technology, bicycles have begun to be fitted with engines that are driven by electric motors [3]. However, in Indonesia there is no bicycle industry that develops vehicles for the disabled [4]. One solution to help the disabled is to design flexible and safe vehicles for them.

To find out whether the design is safe or not is by simulation, one of which is Finite Element Analysis (FEA). In terms, FEA can be interpreted as a numerical solution method to solve engineering and mathematical physics cases by dividing the case modeling into elements with certain limitations [5]. Ansys Workbench is one of the Computer Aided Design (CAE) software that can handle various problems with the FEA approach, this software is designed to make it easier to use by its users [6].

There is previous research that discusses the design of electric bicycles for disabled people and frame analysis using Ansys Workbench software that has a more complex rear two-wheel configuration and there is a drive shaft component as a rear wheel drive that makes it difficult to maintain the component [7]. There is also previous research that discusses the design of a three-wheeled electric bicycle frame for disabled people that has a front two-wheel configuration and no drive shaft component so that maintenance is easier [4] and this configuration allows for a more varied selection of designs and types of suspension.

Therefore, this study aims to analyze the design of a three-wheeled electric bicycle frame for the disabled using the Finite Element Analysis (FEA) method. The results of this study are expected to be used as additional references, especially in the field of transportation for the disabled.

2. METHODOLOGY

This study was conducted to analyze three designs of electric tricycle frames for disabled people made using Solidworks software which were then subjected to Finite Element Analysis (FEA) simulations which produced output in the form of von mises stress, deformation, and safety factor values. The material used in this study was chromoly 4130, then the mass of the rider used was 80 kg and for its location referring to Standar Nasional Indonesia (SNI) 1049:2008 which contains a percentage (seat tube 7.7%, head tube 61.54%, and bottom bracket 30.76%) [8] and there is an additional battery with a mass of 10 kg at the bottom.

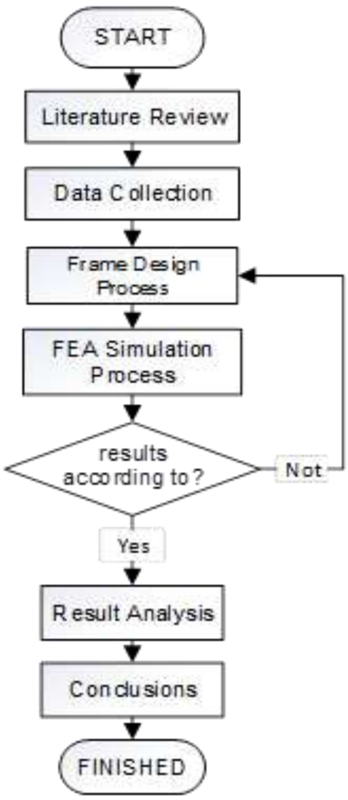

Figure 2. Research Flowchart

Before designing the frame, researchers searched for references and literature studies on research needs. Literature studies are used to collect related scientific articles that are used as research references. Data and references are used to solve problems related to the research later, the data used is a study on research on three-wheeled electric bicycle frames that were tested using FEA simulations. The concept and model used in this bicycle frame design use a tadpole configuration (reverse trike) with two wheels at the front and one wheel at the back [9].

Data collection was obtained from references from previous research data that examined the design of a three-wheeled electric bicycle frame for the disabled. The data was used to design and simulate the three-wheeled electric bicycle frame for the disabled. The data that has been obtained for this study is the concept of the design of a three-wheeled electric bicycle frame for the disabled with a tilting mechanism on the front.

In the design process, the stage carried out is the creation of a 3D design plan of the three-wheeled electric bicycle frame as a reference, namely the reference and data that have been obtained previously. The frame design was made in three different design variations, which were used as simulation objects. The design was carried out using Solidworks software. The previous three-wheeled electric bicycle frame design process produced three different design variations, the designs that have been made are as follows,

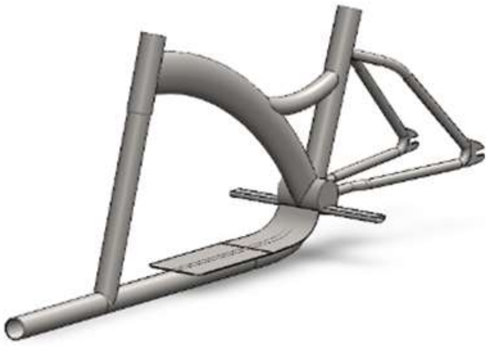

Figure 3. Frame Design 1

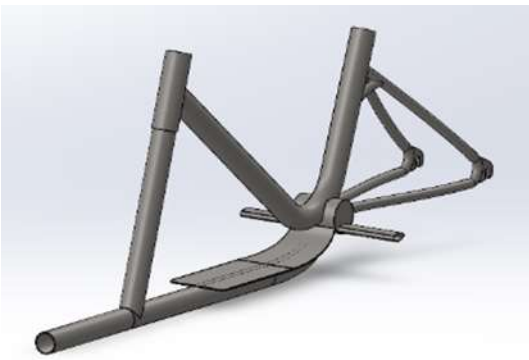

Figure 4. Frame Design 2

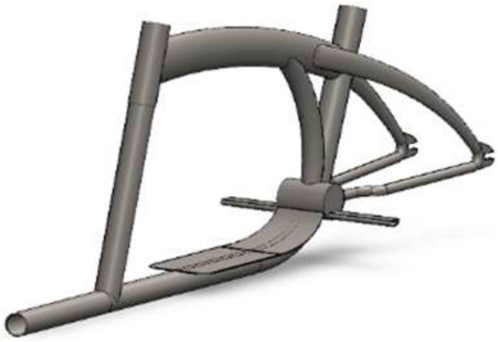

Figure 5. Frame Design 3

Based on the three designs that have been adjusted in concept and dimension based on the references obtained. These designs will later be subjected to FEA simulation using Ansys Workbench software.

Simulation Finite Element Analysis (FEA) at this stage the activity carried out is a design simulation with predetermined materials. The design of the three-wheeled electric bicycle frame that has been made previously is then simulated using the Finite Element Analysis (FEA) method. The simulation is carried out using Ansys Workbench software. The stages carried out when conducting a simulation using the FEA method include:

Engineering Data in this process is done to select the input value of material properties according to the material used during the simulation. In this study, metal materials are used which have many types and uses [10]. The materials that will be used in this study are chromoly 4130 is a low alloy chromium-molybdenum series steel that has excellent strength, toughness, and hardenability. This type of steel has many uses in pressure vessels, pumps, valves, pinions, shaft gears, ball studs, screws, general purpose profile steel, vehicle parts, oil and gas industry, aviation, bicycle frames, etc. [11], with material table properties as follows:

Table 1. Material Table of Chromoly 4130 [12]

Chromoly 4130	
Mass Density	7.85 g/cc
Yield strength	415 MPa
Ultimate Tensile Strength	670 MPa
Young's Modulus	190 GPa
Poisson's Ratio	0.27

Import geometry is the step of entering each geometry of the frame design that has been created using Solidworks software. All designs, both design 1, design 2, and design 3, will be entered into the Ansys Workbench software for simulation.

The setup process is one of the steps in the FEA simulation which aims to determine the boundary conditions required between the object and the surrounding environment. Meshing is also done during the setup process, the mesh size used in this study is 2 mm and uses the tetrahedron meshing method. The smaller the meshing size given, the more representative the model will be in describing the simulation [7]. The skewness obtained in each design is also very good because it gets a value of less than 0.5 which indicates that the value is very good [13]. In this study, there are boundary conditions, namely the provision of fix support (clamp-clamp), one clamp located on the tilting mechanism (front) and one more clamp located on the wheel shaft holder (rear), and for the provision of loads that refer to the percentage of SNI 1049: 2008 standard and the addition of a battery load of 10 kg. The three design variations will be subjected to the same fixed support and loading points [14]. An explanation of the fixed support and loading can be seen in the following figure,

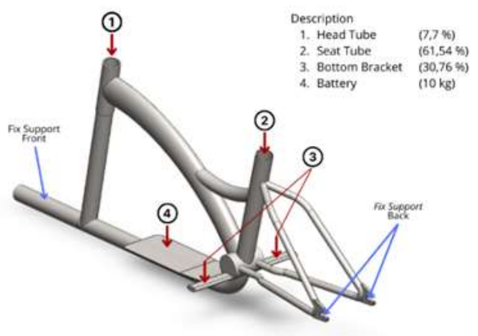

Figure 6. Loading Point and Fix Support

The results of the simulation that has been carried out obtain the values of von mises stress, deformation, and safety factor. The resulting von mises stress value must not exceed the yield strength value of the material used. The deformation value is the magnitude of the value of the change in shape caused by the load, so the value must be as small as possible. The safety factor value shows how safe a test component is, the value must exceed the specified value, namely the minimum safety factor above 1.5 (one and a half) [15]. A larger value indicates that the part is safer. Based on these values, it will later be used to analyze the results of the simulation of the three designs and to find out which design is the best.

3. RESULTS AND DISCUSSION

In this study, von mises stress, deformation, and safety factor analysis were conducted using Ansys Workbench software for simulation testing, so that the time and cost used were less. The design simulation used with the provision of a rider load of 80 kg in accordance with SNI 1049:2008, namely the percentage (seat tube 7.7%, head tube 61.54%, and bottom bracket 30.76%) and there was an additional 10 kg battery, with one type of material, namely chromoly 4130 according to the material table properties table 1.

In design 1, the meshing step produces an average skewness value of 0.35165, indicating that the meshing is very good and produces 731.367 nodes and 370.339 elements. The design simulation used with the provision of fix support has 2 parts, namely the front (for the tilting mechanism) and the rear (for the rear wheels). While for the rider's load of 80 kg which is in accordance with SNI 1049: 2008 and the addition of a battery at the bottom of the bicycle frame weighing 10 kg as previously described. Based on the meshing, fix support and loading, obtained the test value in the figure 7, 8, 9 as follows;

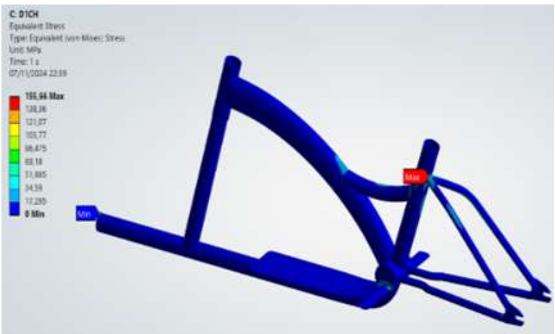

Figure 7. Von Mises Stress Design 1

Based on figure 7, the maximum von mises stress is located at the connection of the upper swing arm with the seat tube, the red color is visible for the maximum stress with a value of 155.66 MPa.

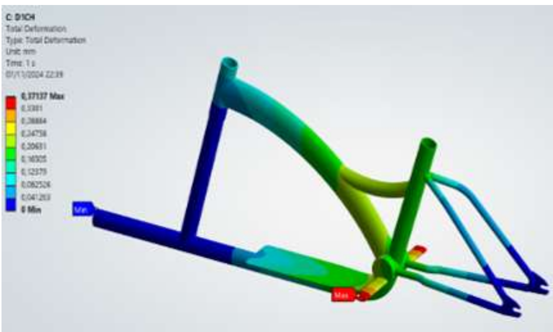

Figure 8. Deformation Design 1

Based on figure 8, the maximum deformation that occurs in the footrest which obtains a deformation value of 0.34299 mm.

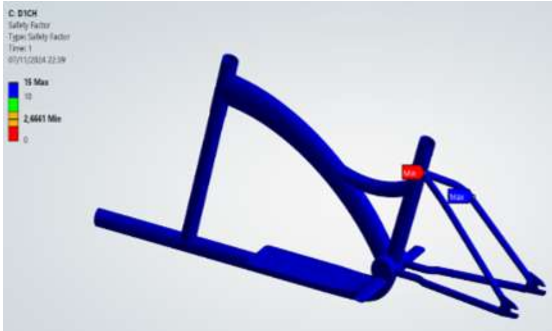

Figure 9. Safety Factor Design 1

Based on figure 9, the minimum value safety factor obtained is 2.6661 which is considered safe because it is more than 1.5.

In design 2, the meshing step produces an average skewness value of 0.34019, indicating that the meshing is very good and produces 626.198 nodes and 318.017 elements. The design simulation used with the provision of fix support consists of 2 parts, namely the front (for the tilting mechanism) and the rear (for the rear wheels). While for the rider's load of 80 kg which is in accordance with SNI 1049: 2008 and the addition of a battery at the bottom of the bicycle frame weighing 10 kg as previously described. Based on the meshing, fix support and loading, obtained the test value in the figure 10, 11, 12 as follows;

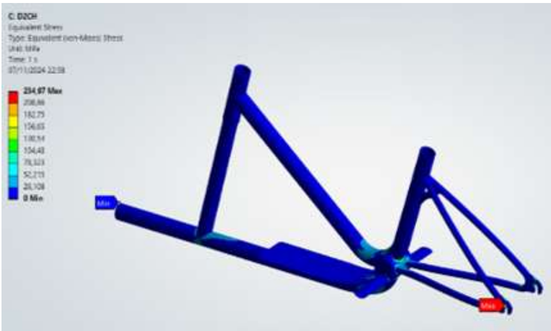

Figure 10. Von Mises Stress Design 2

Based on figure 10, the maximum von mises stress is located on the swing arm of the wheel placement section, the red color is visible for the maximum stress with a value of 234.97 MPa.

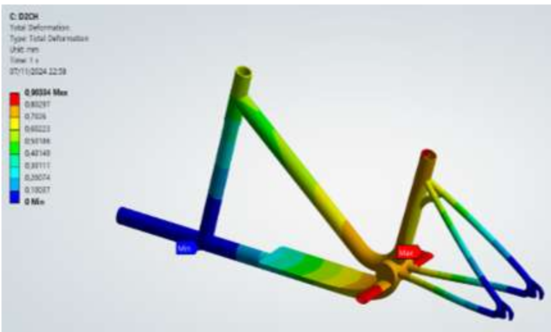

Figure 11. Deformation Design 2

Based on figure 11, the maximum deformation that occurs on the footrest which obtains a deformation value of 0.90334 mm.

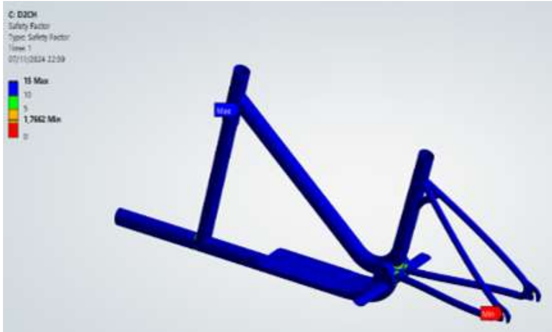

Figure 12. Safety Factor Design 2

Based on figure 12, the minimum value safety factor obtained is 1.7662 which is considered safe because it is more than 1.5.

In design 3, the meshing step produces an average skewness value of 0.35296, indicating that the meshing is very good and produces 754,370 nodes and 382,505 elements. The design simulation used with the provision of fix support consists of 2 parts, namely the front (for the tilting mechanism) and the rear (for the rear wheels). While for the rider's load of 80 kg which is in accordance with SNI 1049: 2008 and the addition of a battery at the bottom of the bicycle frame weighing 10 kg as previously described. Based on the meshing, fix support and loading, obtained the test value in the figure 13, 14, 15 as follows;

Figure 13. Von Mises Stress Design 3

Based on figure 13, the maximum von mises stress is located on the swing arm near the footrest, the red color is visible for the maximum stress with a value of 62.669 MPa.

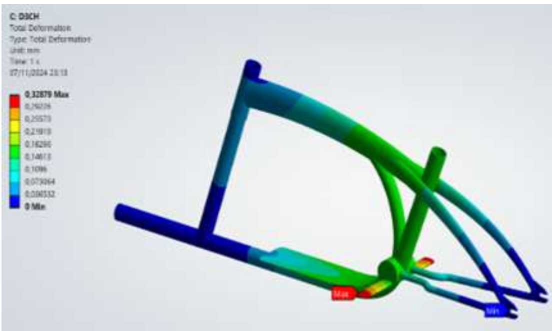

Figure 14. Deformation Design 3

Based on figure 14, the maximum deformation that occurs on the footrest which obtains a deformation value of 0.32879 mm.

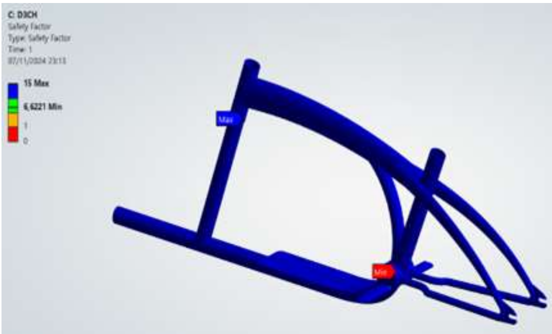

Figure 15. Safety Factor Design 3

Based on figure 15, the minimum value safety factor obtained is 6.6221 which is considered safe because it is more than 1.5.

Based on figure 7 to figure 15, it is the simulation result of the design variations that have been made previously using Solidworks software. From the three, each of the images displays different results in the form of von mises stress, deformation, and safety factor. The difference in color gradients in each design shows that each design obtains different results. Each design of the three-wheeled electric bicycle frame shown in Table 2 will be used to determine the most superior design in terms of strength and safety. The test result data is shown in Table 2, as follows:

Table 2. Simulation Design Results

Design Type	**Test Results**		
	Von mises stress (MPa)	**Deformation (mm)**	**Safety factor**
Design 1	155,66	0,37137	2,6661
Design 2	234,97	0,90334	1,7662
Design 3	62,669	0,32879	6,6221

Based on table 2 above, the various designs produce different values of von mises stress, deformation, and safety factor. In design simulation 1, the test results were obtained von mises stress of 155.66 MPa, the maximum deformation value is 0.37137 mm, and for the value safety factor obtained 2.6661. Design simulation 2 obtained a value of von mises stress is 234.97 MPa, the maximum deformation value is 0.90334 mm, and the value safety factor is 1.7662. Meanwhile, for design simulation 3, the test results obtained von mises stress 62.669 MPa, for the maximum deformation value of 0.32879 mm, and safety factor obtained a score of 6.6221.

Based on the simulation results that have been described previously, the results will be used to determine which design is the most superior. The design that obtains von mises stress minimum and safety factor the highest then that design is the most superior design. Because safety factor is a comparison between yield strength the material used with the actual value of the stress that occurs during the simulation, then safety factor is inversely proportional to von mises stress.

3.1 Von Mises Stress

Based on the FEA simulation that has been done, the von mises stress obtained from design 1 is 155.66 MPa, the von mises stress obtained from design 2 is 234.97 MPa, and the von mises stress obtained from design 3 is 62.669 MPa where the greater the load received by each bar on the frame, the greater the resulting stress [16]. Based on these results, it shows that design 3 has the smallest von mises stress compared to design 1 and design 2, which means that design 3 is the most superior design because it has the smallest von mises stress, while design 2 is the worst design because it has the largest von mises stress.

3.2 Deformation

Based on the FEA simulation that has been done, the deformation obtained from design 1 is 0.37137 mm, the deformation obtained from design 2 is 0.90334 mm, and the deformation obtained from design 3 is 0.32879 mm. Based on these results, it shows that design 3 is the most superior design, because it has the smallest deformation value compared to design 1 and design 2, while design 2 is the worst design because it has the largest deformation.

3.3 Safety Factor

Based on the FEA simulation that has been done, the safety factor obtained from design 1 is 2.6661, the safety factor obtained from design 2 is 1.7662, and the safety factor obtained from design 3 is 6.6221. Based on these results, it shows that design 3 is the most superior design, because it has the largest safety factor value compared to design 1 and design 2, while design 2 is the worst design because it has a safety factor.

The results obtained found that there were differences in results in each design due to differences in models and supports on the frame. Seen from figure 4 related to design 3 is a design that has a support at the bottom. With the support at the bottom, it can provide better performance.

Based on these three values, design 1 and design 2 can basically still be used as other references. The design is still feasible to use, but the design has a higher von mises, larger deformation, and a smaller safety factor than the design of the three-wheeled electric bicycle frame for the disabled. Therefore, the most superior frame design is design 3 with chromoly 4130 material.

The research conducted obtained the most superior design (design 3) compared to other studies that have similar topics and analysis. The comparison results are obtained in the following table;

Table 3. Compare with Other Research[17]

Simulation	Test Results		
	Von mises stress (MPa)	Deformation (mm)	Safety factor
Design 3	62,669	0,32879	6,6221
Pramono, 2024	65,67	0,381	4,9

Based on table 3, the comparison of the two simulations is obtained, namely the two simulations have quite similar results for von mises stress and deformation values, with differences that can be considered small.

4. CONCLUSION

Based on the simulation results and discussion above, this simulation uses a load of 80 kg, the percentage of which refers to SNI 1049:2008 and there is an additional battery at the bottom weighing 10 kg. In the design simulation 1, the test results were obtained von mises stress of 155.66 MPa, the maximum deformation value is 0.37137 mm, and for the value safety factor obtained 2.6661. Design simulation 2 obtained a value of von mises stress of 234.97 MPa, the maximum deformation value is 0.90334 mm, and the value safety factor is 1.7662. Meanwhile, for design simulation 3, the test results obtained von mises stress 62.669 MPa, for the maximum deformation value of 0.32879 mm, and safety factor obtained a value of 6.6221. The simulation results show that design 3 provides the best structural performance and reliability, this is because the design obtains safety factor the highest is 6.6221, making design 3 the most superior design compared to design variations 1 and 2.

REFERENCES

[1] H. Davidson, “Pengembangan Sistem Roda Dan Penambahan Baterai Pada Electric Bicycle Brushless DC Roda 3 Untuk Penyandang Disabilitas Tunadaksa,” 2021.
[2] C. M. Annur, “Jumlah Pekerja Disabilitas Indonesia Meningkat Pada 2022, Didominasi Laki-Laki,” Kadata Media Network. Accessed: May 08, 2024. [Online]. Available: https://databoks.katadata.co.id/datapublish/2023/06/22/jumlah-pekerja-disabilitas-indonesia-meningkat-pada-2022-didominasi-laki-laki
[3] B. Setyono, Mrihrenaningtyas, and Abdul H., “Perancangan Dan Analisis Kekuatan Frame Sepeda Hibrid ‘TRISONA’ Menggunakan Software Autodesk Inventor,” Jurnal IPTEK, vol. 20, pp. 37–46, 2016.

[4] C. H. Kurniawan, “Perancangan Rangka Sepeda Listrik Roda Tiga Ramah Disabilitas,” 2023.
[5] F. Hilmy, Metode Elemen Hingga. Magelang: Pustaka Rumah C1nta, 2021.
[6] U. Brawijaya, Modul Training Ansys Workbench PT. BOMA BISMA INDRA. 2014.
[7] R. Febritasari et al., “Design of a Post Stroke Tricycle with Electric Mechanism,” 14 JMEMME, vol. 7, no. 1, 2023, doi: 10.31289/jmemme.v7i1.7552.
[8] Badan Standardisasi Nasional, SNI 1049:2008 Sepeda - Syarat Keselamatan. Indonesia, 2008.
[9] G. T. Chandrasa, H. Suryoatmojo, B. Tambunan, and Soedibyo, “Design and Performance a Lightweight Electric Reverse Trike with Multiple Energy Storage,” National Research and Innovation Agency (PRKKE-BRIN), 2023.
[10] Suyitno, Bahan Teknik Untuk Rekayasawan. Yogyakarta: Pustaka Pranala, 2021.
[11] F. L. Nurulhadi, R. Hanifi, and Oleh, “Analisis Kekuatan dan Desain Frame Mini Bike 20 Inch Menggunakan Pendekatan Finite Element Method (FEM),” Jurnal Ilmiah Wahana Pendidikan, vol. Vol. 8, no. 7, pp. 362–367, 2022.
[12] S. Hastuti, W. Ramadhani, and N. Mulyaningsih, “Analisis Kekuatan Pada Rangka Sepeda Motor Listrik Dengan Metode Elemen Hingga,” Jurnal Foundry : Politeknik Manufaktur Ceper, vol. 5, no. 2, pp. 1–11, 2022.
[13] M. A. K. Guhardiputra, M. N. Kustanto, S. Mulyadi, D. Dwilaksana, and M. Trifiananto, “Desain Chassis Mobil Urban TITEN EV-2 Akibat Beban Dinamis,” ROTASI, vol. 25, no. 1, pp. 25–32, 2023.
[14] R. R. Gunawan, F. Hilmy, and I. Taufik, “Design Analysis of a Manhole Mining Ambulance with a Hilux 4×4 WD Single-Cabin Chassis Unsing Finite Element Analysis (FEA),” Jurnal E-Komtek (Elektro-Komputer-Teknik), vol. 8, no. 1, pp. 191–198, Jun. 2024, doi: 10.37339/e-komtek.v8i1.1824.
[15] T. Mulyanto and A. D. Sapto, “Analisis Tegangan Von Mises Poros Mesin Pemotong Umbi-Umbian Dengan Software Solidworks,” PRESISI, vol. 18, no. 2, 2017.
[16] A. Saifullah, “Analisis Pembebanan Vertikal pada Frame Sepeda Menggunakan Metode Elemen Hingga dengan Bantuan Ansys,” Prosiding SENTRA (Seminar Teknologi dan Rekayasa), pp. 145–150, 2021.
[17] G. E. Pramono, B. Hartono, E. Sutoyo, and J. P. Romadon, “ANALISA DESAIN RANGKA SEPEDA MOTOR LISTRIK GRACIA TMK19 TIPE DOUBLE CRADLE MENGGUNAKAN FINITE ELEMENT ANALYSIS (FEA),” Jurnal Ilmiah Teknik Mesin, vol. 10, no. 2, pp. 108–114, Sep. 2024, [Online]. Available: http://ejournal2.uika-bogor.ac.id/index.php/ame/index