

Research Article

Design and Construction of Scaffolding with a Lifting Capacity of 300 kg Using a Drive Electric Hoist AC 220 V

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Abstract: Maintenance and repair work in a building or structure is not only in low places, but also in high places which require assistive devices. The assistive device in question is scaffolding. The design of this scaffolding begins with a literature study followed by data collection in the Mechanical Engineering Department of the Semarang State Polytechnic to obtain data on the need for height assistive devices which are used as a reference for making electric scaffolding. The purpose of this study is to design an electric scaffolding with a capacity of 300 kg and to perform the performance of the electric scaffolding made. After the design of the electric scaffolding, the dimensions of the equipment were obtained, namely 1000 mm x 1500 mm x 2000 mm and specifications that can lift goods with a maximum height of 5 m, a minimum height of 0.35 m, a maximum load of 300 kg and an AC 220 V electric hoist drive. Based on the results of the performance test, in this case the test data was taken from the weight of the load that the machine can lift based on the travel time when the machine moves up and down. The load weight of 300 kg with electric scaffolding was covered in 27.44 seconds when going up and 21.02 seconds when moving down.

Keywords: AC Electric Hoist; Electric Scaffolding; Lifting Equipment; Machine Design; Transporting Equipment

1. Introduction

The performance of a construction project is influenced by factors of manpower and related resources (Li et al., 2021)(Fang et al., 2018). Among the resources in question is scaffolding. Scaffolding is a temporary structure used to support workers, tools, and materials when working at height (Dzeng et al., 2024). Scaffolding or another name for scaffolding generally requires assembly before use, so that it forms a certain structure so that it can be used to work at height.

The structure is shaped like a platform where workers carry out their tasks and work. The structure is sometimes equipped with a net like a fishing net as seen in Fig. 1. This safety net is installed to prevent small debris from falling outside the work area and hitting people around it. Scaffolding is necessary especially for construction work that is above 1.8 meters above the ground (Andu, 2019).

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Figure 1. Scaffolding equipped with safety net

There are 2 types of scaffolding materials (shore) that have been used in construction as supports in terms of the materials used (Heinz Frick, 2002), among others:

- a. Wooden or bamboo scaffolding is a type of scaffolding material that is widely used today, as seen in Fig. 2. However, its use is generally limited to houses or buildings that are not too tall or heavy. To assemble the wooden scaffolding into a structure, rope or wire is used to tie the pieces together.

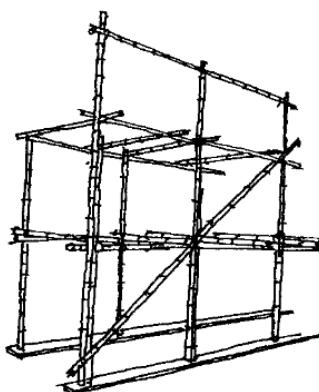


Figure 2. Wooden or bamboo scaffolding

- b. Scaffolding made from steel/iron pipe and manufactured as a product is better known as frame scaffolding. The frame scaffolding, as seen in Fig. 3, is factory-made but can be assembled on-site. This type of assembly process does not use wire or rope, but instead uses pins to lock each frame joint.

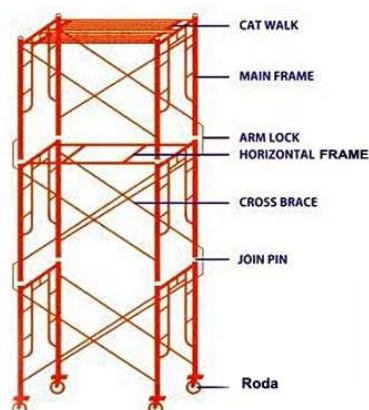


Figure 3. Frame scaffolding (Suharyani & Fathonah, 2019)

Scaffolding in construction requires the strength to support all loads placed on it, both live and dead. Scaffolding must be rigid to prevent the structure from swaying, especially under horizontal loads (Nurina Yasin, 2019). This is intended to ensure the safety of people and objects working on it and to reduce the risk of workplace accidents when working at height. Scaffolding itself, in carrying out its duties, assists workers in carrying out maintenance and repair activities at height (Silvia Angel Sormin, 2024).

From the explanation above, researchers are interested in making scaffolding based on electronic drives. This reasoning was reinforced by a survey conducted by the researcher at the Mechanical Engineering Department workshop at Semarang State Polytechnic, where obstacles related to the maintenance and repair of ceilings and lighting

were identified. The researcher intended to design and build a 300 kg capacity scaffold using a semi-automatic system with a 220 V AC electric hoist.

2. Literature Review

Several studies related to scaffolding were conducted, including by Yasin (Nurina Yasin, 2019) conducted research on the strength and requirements of scaffolding frames in building construction. The results showed that a building measuring 8 m x 8 m, assuming a distance between scaffolds of 100 cm and 50 cm, requires 40 sets of scaffolding. Meanwhile, the frame strength yields a value of 3000 kg for each scaffolding pole that supports the load. Furthermore, research conducted by Destyarini et al (Destyarini & Hartono, 2016) regarding a comparative analysis of the use of conventional steel scaffolding and modified steel scaffolding. The analysis was processed with the help of expert choice software. The results of the analysis show that the use of steel scaffolding selected from the combined results in expert choice software is a modified steel scaffold with a weight of 0.641 while the conventional steel scaffold obtained a weight of 0.359. This means that the modified steel scaffold gets a higher weighting value than the conventional steel scaffold, so it can be concluded that the modified steel scaffold is better to be used in the case study project.

Another study by Prameswara and Sutandi (Prameswara & Sutandi, 2024) the impact of scaffolding ladders on plastering and finishing project time can be significant. This study aimed to determine the impact of scaffolding ladder use on plastering and finishing time. The results showed that the use of scaffolding ladders consistently resulted in faster work, such as plastering and finishing, compared to using conventional ladders. This is reflected in the time required to climb and descend the ladder, lift and move the ladder, and retrieve equipment. The use of scaffolding not only saves time but also improves comfort and the overall quality of the work. From the studies presented, a research gap emerged, namely the limited development of scaffolding.

3. Proposed Method

The research methodology is a summary of the research process to be carried out. The methodology used refers to the Shigley model design method (Richard G. Budynas, 2015) can be seen in Fig. 4.

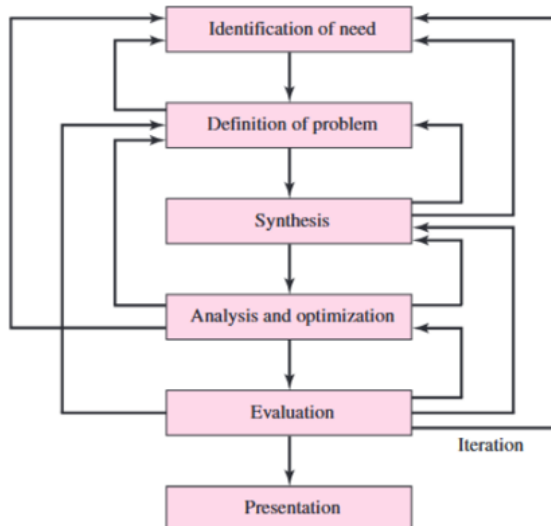


Figure 4. Designer Process Flow Diagram Shigley

Identification of needs

The first step in Shigley's model is identifying the needs of an object. Observations were conducted in the Mechanical Engineering Department workshop and discussions with several parties. From these observations and discussions, the idea emerged to provide a tool to assist in lifting/moving objects or people from heights.

Definition of problem

The second stage involves planning the construction of a lifting aid in the form of scaffolding capable of lifting a maximum load of 300 kg and a maximum height of 5 meters. It features a semi-automatic control system using a motor as the drive and is equipped with electric buttons to raise and lower the load, as well as a construction that is easy to maneuver in the Mechanical Engineering Department workshop environment.

Synthesis

The third stage is creating alternative product designs, conducting simulations, selecting materials to be realized, forming and assembling semi-automatic scaffolding and conducting trial and error.

Analysis and optimization

In the fourth stage, an analysis is conducted regarding the forces, stresses in the main frame, power requirements, and lifting power required. This aims to ensure the machine meets standards and performs optimally when used.

Evaluation

The fifth stage, the evaluation referred to here, is the evaluation of machine performance. After the machine is tested, the results are obtained. These results are evaluated to determine whether they meet the established standards.

Presentation

The sixth stage, preparation of design results documents in the form of complete three-dimensional drawings and working drawings, a list of standard components, specifications of the materials used, and performance test results in machine manufacture.

4. Results and Discussion

Design

Researchers proposed three scaffolding designs for use in the Mechanical Engineering Department workshop. These three designs were assessed by validators, and the scores were then used as a reference for design selection. The three proposed designs can be seen in Fig. 5.

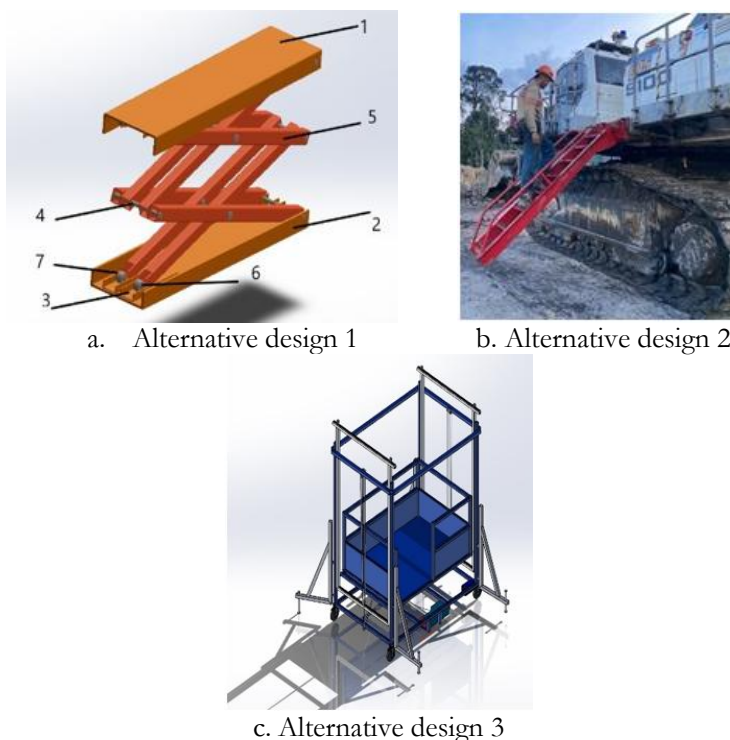


Figure 5. Alternative Design

Design assessment indicators are made based on design assessments by Cross (Nigel Cross, 2021). The results of the design assessment by the validator show that the selected design is design alternative 3.

Form Design

Before the actual design of this form, calculations were first performed regarding the machine components to be created. The material used to construct the machine, in this case, is AISI 1045 in a hollow form. The frame uses hollow iron measuring 40 mm x 40 mm x 2 mm. There are three main frames that make up this scaffolding machine, as shown.

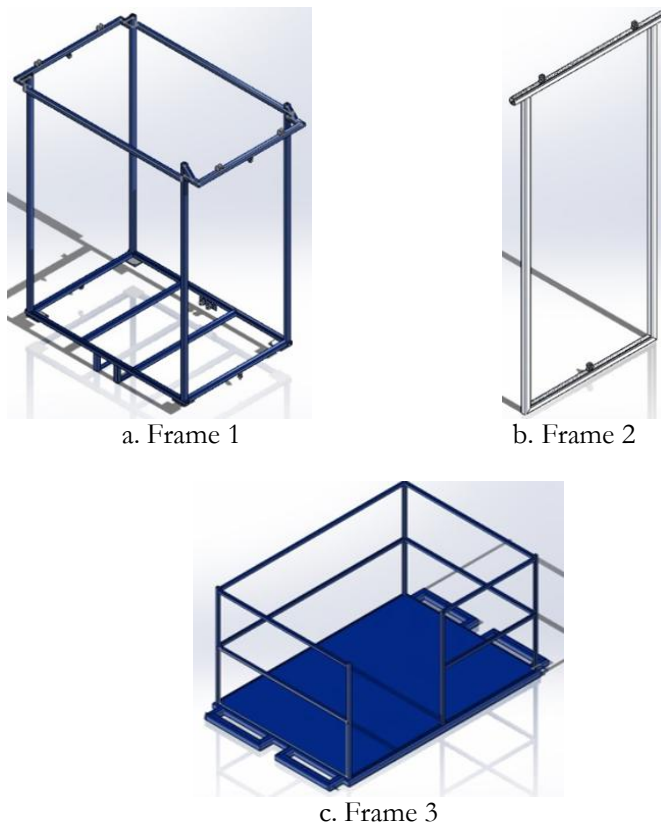


Fig. 6. Frame Design

Total Mass

The total mass generated assuming the total weight of the two operators is 180 kg and the maintenance equipment carried is 120 kg, then

$$\begin{aligned}
 m_{tot} &= \text{massa rangka} + \text{massa yang diangkat} \\
 &= 78,82 + 300 \\
 &= 378,82 \text{ kg}
 \end{aligned}$$

Style on the frame

Buckling Effect

Calculating the buckling effect

$$\begin{aligned}
 P_{cr} &= \frac{\pi^2 EI}{L^2} \\
 P_{cr} &= \frac{3,14^2 \times 20 \times 10^{10} \times 73365,3}{2000^2} \\
 P_{cr} &= 3,61 \times 10^{10} \text{ N}
 \end{aligned}$$

The total load received on frame 1 and frame 2 is 3716.5 N, while the value of the critical buckling load obtained is $3,61 \times 10^{10} \text{ N}$. So it can be concluded that the frame is safe because the actual load < critical buckling load.

Moment of Inertia

$$\begin{aligned}
 I &= \frac{b^3 - h}{12} \\
 I &= \frac{40^3 - 36}{12}
 \end{aligned}$$

$$I = 5330.3 \text{ mm}^3$$

So the moment of inertia that occurs in 40×40×2 mm hollow iron is 5330.3 mm³

Maximum deflection of frame 1

$$\delta_{\max} = \frac{PL^3}{48EI}$$

$$\delta_{\max} = \frac{1858,25 \times 2000^3}{48 \times 20 \times 10^{10} \times 5330,3}$$

$$\delta_{\max} = 2,9 \times 10^{-4} \text{ (mm)}$$

According to SNI (Indonesia, 2020) the allowable deflection with a horizontal span on the floor is $L/360$, resulting in 5.5 mm for the allowable deflection. The deflection on frame 1 is said to be safe because $\delta_{\max} < \delta_{\text{allowable}}$.

Maximum deflection of frame 2

$$\delta_{\max} = \frac{Pa}{24EI} (3L^2 - 4a^2)$$

$$\delta_{\max} = \frac{929,12 \times 200}{24 \times 20 \times 10^{10} \times 5330,3} (3 \times 2000^2 - 4 \times 200^2)$$

$$\delta_{\max} = 8,3 \times 10^{-5} \text{ (mm)}$$

The deflection in frame 2 is said to be safe because $\delta_{\max} < \delta_{\text{allowable}}$.

Section modulus

$$S = \frac{I}{c}$$

$$S = \frac{5330,3}{20}$$

$$S = 266,5 \text{ (mm}^2\text{)}$$

Bending moment

Centralized loading

$$M = \frac{PL}{4}$$

$$M = \frac{1858,25 \times 1000}{4}$$

$$M = 4,64 \times 10^5 \text{ (N. mm)}$$

Two-point loading

$$M = P \times a$$

$$M = 929,12 \times 200$$

$$M = 1,85 \times 10^5 \text{ (N. mm)}$$

Permitted moments

$$M_{\text{allow}} = S \times F_y$$

$$M_{\text{allow}} = 3668,27 \times 250$$

$$M_{\text{allow}} = 6,7 \times 10^4 \text{ (N. mm)}$$

The bending moment that occurs in a frame with a centralized load in the middle and a load at two points can be said to be safe, because $M_{\text{centralized load}} < M_{\text{allow}} > M_{\text{two-point loading}}$.

Bending stress

Centralized loading

$$\sigma = \frac{M}{S}$$

$$\sigma = \frac{4,64 \times 10^5}{266,5}$$

$$\sigma = 1741,1 \text{ (N/mm}^2\text{)}$$

Two-point loading

$$\sigma = \frac{M}{S}$$

$$\sigma = \frac{1,85 \times 10^5}{266,5}$$

$$\sigma = 694,2 \text{ (N/mm}^2\text{)}$$

Allowable stress

$$\sigma_{\text{allow}} = \frac{F_y}{SF}$$

$$\sigma_{\text{allow}} = \frac{450}{8}$$

$$\sigma_{\text{allow}} = 56.25 \text{ (N/mm}^2\text{)}$$

The AISI 1405 material is a medium carbon steel material which has a yield strength of 450.

Strength of welded joints

Weld strength of a single joint, the load received on this connection is 2940 (N).

$$P_{\text{las}} = s \times \sin 45^\circ \times l \times \sigma_t$$

$$P_{\text{las}} = 10 \times 0,7071 \times 50 \times 55$$

$$P_{\text{las}} = 19.445,25 \text{ (N)}$$

The connection strength is very safe because the load received is 2940 (N) and the welding strength is 19,445.25 (N).

Welding strength of double joints

Welding joints used: fillet joint and butt joint. The pressure load received at the welded joint is 3744.8 N.

Fillet joint, vertical and horizontal frames with 40 mm welded joints.

$$P_{\text{las}} = 2 \times s \times \sin 45^\circ \times l \times \sigma_t$$

$$P_{\text{las}} = 2 \times 10 \times 0,7071 \times 40 \times 55$$

$$P_{\text{las}} = 31.112,4 \text{ (N)}$$

Fillet joint, connection on the mounting pulley and frame 1 is 205 mm long and the pressure load is 3744.8 N.

$$P_{\text{las}} = 2 \times s \times \sin 45^\circ \times l \times \sigma_t$$

$$P_{\text{las}} = 2 \times s \times 0,7071 \times 205 \times 55$$

$$P_{\text{las}} = 19.451,05 \text{ N}$$

Butt joint, 40 mm long upper and lower frame joints.

$$P_{\text{las}} = 2 \times s \times \sin 90^\circ \times l \times \sigma_t$$

$$P_{\text{las}} = 2 \times 10 \times 1 \times 40 \times 55$$

$$P_{\text{las}} = 44.000 \text{ N}$$

Butt joint, trolley wheel mounting connection with frame 1 is 115 mm long.

$$P_{\text{las}} = 2 \times s \times \sin 90^\circ \times l \times \sigma_t$$

$$P_{\text{las}} = 2 \times 10 \times 1 \times 115 \times 55$$

$$P_{\text{las}} = 126.500 \text{ N}$$

Cable sling

Breaking strength of rope

$$MBF = k \times d^2$$

$$MBF = 0,81 \times 10^2$$

$$MBF = 81 \text{ kN}$$

Safe loading

$$SWL = d \times d \times 8$$

$$SWL = 0.394 \times 0.394 \times 8$$

$$SWL = 1,242 \text{ Ton}$$

Based on the calculation, the value obtained issafety working load on a sling cable with a diameter of 0.394 inches is 1,242 kg while the total load to be lifted is382.12 kg. From these results, it can be concluded that the cable sling's strength is safe for use with actual loads.

Pulley calculation

$$KM = W = F$$

$$KM = m \times g$$

$$KM = 382,12 \times 9,8$$

$$KM = 3744,78 \text{ N}$$

Embodiment of Tools



Figure 7. Scaffolding with Electric Hoist Drive

The results of the machine calculation analysis are then translated into finished goods, resulting in the following machine specifications:

Table 1. Machine Specifications

No	Criteria	Specification
1	Maximum height	5 meters
2	Minimum height	0.35 meters
3	Maximum load	300 kg
4	Engine dimensions	1.5 m x 1 m x 2 m
	Electric hoist	
	a. Rated capacity	600-1200 kg
5	b. Voltage/phase	220 V / 50 Hz
	c. Lifting height	6-12 meters
	d. Input power	2000 Watt



Figure 8. Machine Testing with Load Lifting

The performance of the scaffolding machine with an electric hoist drive is carried out by gradually applying the load when the scaffolding moves up and down. The gradual load is given from 60 kg – 300 kg (multiples of 60 kg). The subject of the load uses a gallon filled with water as shown in Fig. 8. The results of the scaffolding machine performance, the machine can be used well in this case the replacement of lights in the mechanical engineering department workshop as seen in Fig. 9 and the loading performance can be seen in table 2.



Figure 9. Machine Testing on Lamp Replacement

Table 2. Performance results

Load (kg)	Time required (seconds)	
	Moving up	Moving down
60	18.73	18.55
120	19.47	19.45
180	19.64	18.54
240	21.17	19.09
300	27.44	21.02

5. Conclusion

The concept design and realization of the tool resulted in a scaffolding machine with an electric hoist drive. The resulting scaffolding machine has dimensions of 1.5 m x 1 m x 2 m, a lifting capacity of 300 kg, a maximum height of 5 m, while a minimum height of 0.35 m and an electric hoist capacity of 220 V. The performance results show that the scaffolding machine with an electric hoist drive is capable of lifting a load of 300 kg in 27.44 seconds.

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Data Availability Statement: The data presented in this study are available on request from the corresponding author. The data are not publicly available due to privacy and ethical restrictions

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