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Bed-Stretcher for Burial Process of COVID-19 Corpse: A Preliminary Design and Strength Analysis

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A B S T R A C T

The number of COVID-19 corpses is highly increased since 2020. This situation tends to risk the health workers directly interacting with COVID-19 victims during the burial process. According to the Ministry of Health of Indonesia, the conventional method of burial process requires four to eight health workers. This paper aims to propose a bed-stretcher that assists the burial process of the COVID-19 corpses efficiently. Hence, the number of people involved can be reduced. The design considers a maximum weight of 2000 N of the coffin, which includes the corpse inside. The device is equipped with a shaft-pulley system, gear, and ratchet mechanism to lower the coffin inside the grave. The strength analysis of the shaft-pulley system by theoretical approach is conducted under static and fatigue loading conditions to estimate the service life. As a result, the calculated safety factor demonstrates a value of more than one, indicating the structure is safely used under both static and fatigue loading conditions. Moreover, the device can be operated by only two health workers. In addition, this work is expected to contribute to the innovative idea of engineering products to overcome the Pandemic of COVID-19.

A R T I C L E   I N F O

1. INTRODUCTION

After the first case was reported on March 2nd, 2020, the spreading of the coronavirus in Indonesia has accelerated considerably. Coronavirus emerged and infected about 5,000 people in April. This case causing a high mortality rate with a Case Fatality Rate(CFR) of 8,9% and a total of 582 death on April 19th, 2020. This high mortality rate causing exceed on global CFR of 5,85% on April 19th, 2020. Furthermore, between March 25th, 2020 to April 19th, 2020, an estimate of more than 100 individuals were confirmed affected by the coronavirus day after day (Al Farizi & Harmawan, 2020; Jimenez-Sotomayor *et al.,* 2020). At the end of 2020, Indonesia received 612,000 people COVID-19 infections among approximately 4 million tested of the 270 million population (Elyazar *et al.,* 2020). This situation became worst since the delta variant of COVID-19 is entering Indonesia two months after it appears in India. The mortality rate in early 2021 contributes high demand for the health service system to handle COVID-19 corpses (Kirana & Bhawiyuga, 2021).

The rising number of burials put the health workers under strain since they had to bury a large number of corpses in a single day. The burial of the corpses was handled out in the COVID-19 case or under emergencies to decrease the threat to humans. Conducting a preliminary review and risk assessment, employing PPE or Personal Protective Equipment, limiting the number of workers exposed to COVID-19, and implementing unique protocols to manage large numbers of casualties bodies are the broad principles for handling human remains with COVID-19 (Finegan *et al.,* 2021).

There are no specific tools to assist health workers in burying COVID-19 corpses. In this current situation, the burial of COVID-19 corpses is carried out using a rope to support the coffin's weight and lower it slowly into the ground and health workers holding each end of the rope. By using a manual procedure like this, health workers may have physical contact with corpses which cause virus infection through the funeral process at that time. Meanwhile, the bed-stretchers in the hospital did not provide specific assistance in helping to bury the corpse. Indeed, they can only be used to carry the corpse into the ambulance. Whereas, we need a tool that can assist the burial process after taking out the corpses from the ambulance. Some factors considered are safety, mobility, and user comfort become challenges and must be prioritized when designing this tool (Wardani *et al.,* 2021).

Currently, various types of bed stretchers have been initiated and planned to be made to help health workers (Asriyanti et al., 2021, Khoiriyah *et al.,* 2021). One example is the coffin lowering machine which is useful for lowering the coffin into the gravel pit. This tool is designed by modifying a bed stretcher using 2 pairs of gear with the coffin on the top of the straps. The gear's brakes provided will be pulled off once the coffin has safely arrived at the bottom (Khoiriyah *et al.,* 2021). In terms of functionality, this tool is very useful but lacks mobility in straps use through the small shaft. It is possible to complicate the work of health workers even harder if the coffin load is too heavy. It meets less productivity and higher cost in changing straps in one burial process.

Therefore, this paper aims to propose a device for the burial process of COVID-19 corpse that can be operated by only two people with easy-to-use and mobility features. Based on qualitative data collected from journals, papers, and other online media, the design specifications were developed to determine the preliminary design and strength analysis. We modified the concept of the ambulance bed-stretcher or hospital bed-stretcher by also concerning the current needs. The safety factor of the proposed design is analyzed by the theoretical approach under static and dynamic (fatigue) loading conditions. Discussion on the structural strength is provided.

2. METHODS
2.1. Design Concept

The mechanical device for the burial mechanism was designed to assist health workers during the burial process of the COVID-19 corpse as shown in **Figure 1**. This tool uses a bed-stretcher as a reference for concept design. Compared to an existing modified bed-stretcher, the device can only transfer the patient from one bed to another or repeatedly change from a wheelchair to a bed-stretcher. Based on the design from the IJITEE journal on multipurpose bed-stretchers, the device's objective is combining to flip the use of wheelchair and bed-stretcher in one design (Arunkumar *et al.,* 2019). The bed-stretcher concept is developed, some aspects are changed by utilizing the folding concept of bed-stretcher.

This device aimed to reduce the risk of transmission to health workers who assist the burial process. The design must fulfill three requirements to achieve the main objectives: (1) the material should be strong enough to hold the load with a total load up to 2000 N, (2) the dimension of the bed-stretcher should be adjustable to the body of the ambulance with a minimum dimension of 2.7 x 1.5 (in meter), (3) the design of this mechanical device can be folded up and quickly accessible in the ambulance and graveyard.

The proposed design as shown in **Figure 2** is built to fulfill the requirements of the design. There are several components of the design provided to be accessed by the health workers during the burial process (see **Table 1**).

2.1.1. Shaft Mechanism

A shaft is a rotating machine element with a circular cross-section that is used to transfer power from one component to another, or from a power-producing machine to a power-absorbing machine. The load from the coffin is distributed along with two pairs of the shaft system as shown in **Figure 2**. By using two pulleys, the most critical part is on the shaft mechanism.

2.1.2. Gearbox

During the COVID-19 burial process, the gearbox system would make the lifting process easier. Before lowering the coffin, it must be tied to the pulley by a rope. A pulley that is used to lower the coffin has been installed and connected directly to the shaft on both sides of the device. On the other hand, the gear system is placed inside the box as shown in **Figure 3**. The gearboxes on the left and right will be operated by two health workers. The system will use two connected gears and utilized the gear ratio to reduce the load that can be carried by the health workers. The ratchet mechanism and the locked system are used to optimize the gear system to control the pulley.

2.1.3. Removable Plate

The removable plate is shown in **Figure 2**. It is used to hold the coffin before the pulley lowers it down. To reduce any possibilities of failure, the removable plate helps the pulley to hold the coffin. Thus, the removable plate should be removed first before the coffin needs to go down.
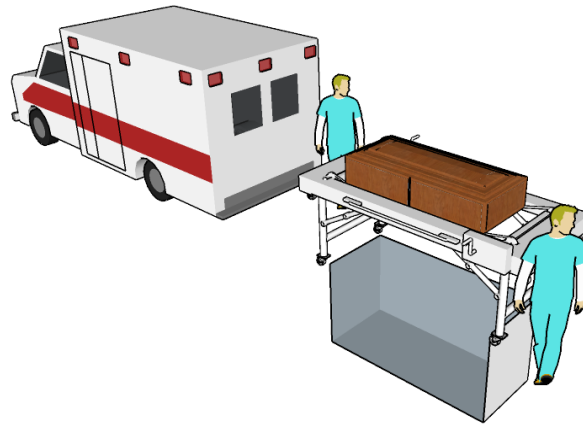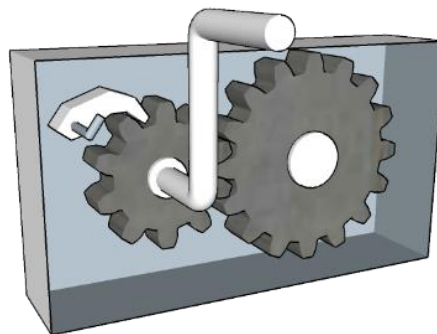
Figure 1. Illustration of Bed-Stretcher Mechanism.
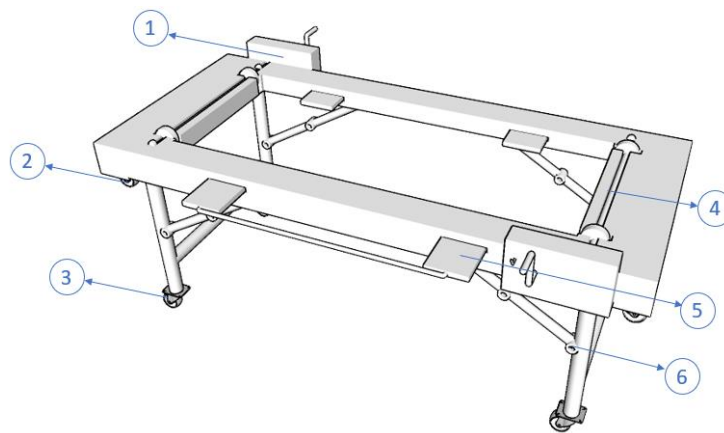
Figure 2. The components of the proposed design.

Table 1. Bed-Stretcher features.

COMPONENT NUMBER	FEATURES
1	Gearbox
2	Upper-locking system wheel
3	Lower- locking system wheel
4	Shaft
5	Removable plate
6	Foldable mechanism

Figure 3. Gearbox using a ratchet mechanism

2.1.4. Wheel Locking Casters

This mechanical device will use both the upper-locking system wheel and the lower-locking system wheel as shown in **Figure 2**. The wheels should be suitable for the condition of the area both in the ambulance cabin and graveyard hole. The rollerblade casters and soft casters are both suitable for this system. The rollerblade casters will be attached to the legs of our system, while soft casters will be installed under the bedframe. On soft and carpeted flooring, hard casters have greater "roll-ability". Rollerblade casters are made of high-quality rubber materials similar (Bronzino & Peterson, 2006). They move smoothly on both rough and carpeted surfaces.

2.2. Material Selection

The material selection was conducted to select suitable materials for the proposed design. This process is important to minimize any failure (Nurprasetio *et al.*, 2017) The materials should be strong but light, and not permeable to water. The weight should be light enough to ease the coffin transfer process from the ambulance to the graveyard.

The material used for the shaft and removable plate is AISI 1018 Cold-Drawn Steel. The most widely available grade in the world is AISI 1018 carbon steel, which is a free-machining grade (Do DucTrung *et al.*, 2020, Saptaji *et.al.*, 2019). Regardless of the lack of unique mechanical properties, it can still be easily created, machined, welded, and fabricated. Most of the conventional welding processes, such as gas, oxyacetylene, resistance, and submerged melt welding can be used for AISI 1018. Spindles, shafts, rods, pins, sprocket assemblies, and other machine parts typically use this material. The yield strength and tensile strength of AISI 1018 Cold-Drawn Steel are 370 MPa and 440 MPa (Kumar *et al.*, 2018).

The material used for the bed frame is ASTM A36 which is a structural quality mild carbon steel that is widely used in mild and hot-rolled steel applications. It can be used for several applications such as welding, fabrication, and bending. The ultimate strength and yield strengths are 400-550 MPa and 250 MPa.

2.3. Strength Analysis Procedure

Static and fatigue analyses are used to find the safety factor for critical components. In this case, the safety factor calculation only focuses on the shaft in **Figure 2**. Based on the analysis of the removable plate, the shear stress experienced by the plate does not exceed the ultimate strength of the selected material. The theoretical analysis was done using Equations (1) - (10) (Budynas & Nisbett, 2015, Zulaikah *et al.*, 2020).

$$\sigma = \frac{32M}{\pi d^3} \tag{1}$$

$$\tau = \frac{16T}{\pi d^3} \tag{2}$$

$$\sigma_{1,2} = \frac{\sigma}{2} \pm \sqrt{\left(\frac{\sigma}{2}\right)^2 + \tau^2} \tag{3}$$

$$\tau_{max} = \sqrt{\left(\frac{\sigma}{2}\right)^2 + \tau^2} \tag{4}$$

$$\sigma' = \sqrt{\sigma_x^2 - \sigma_x \sigma_y + \sigma_y^2 + 3\tau_{xy}^2} \tag{5}$$

$$S_e = k_a k_b k_c S_e' \tag{6}$$

$$n = \frac{S_y}{\sigma_1 - \sigma_2} \tag{7}$$

$$\sigma_a = \frac{\sigma_{max} - \sigma_{min}}{2} \tag{8}$$

$$\sigma_m = \frac{\sigma_{max} + \sigma_{min}}{2} \tag{9}$$

$$\sigma_{rev} = \frac{\sigma_a}{1 - \left(\frac{\sigma_m}{S_{ut}}\right)^2} \tag{10}$$

where M is the bending moment (Nm); T is the torque (Nm); σ is the normal stress (MPa); τ is the shear stress (MPa); $\sigma_{1,2}$ is the principal stress (MPa); τ_{max} is the normal stress (MPa); σ' is the distortion energy (MPa); S_e is the endurance strength; k_a is the surface factor; k_b is the size factor ; k_c is the loading factor; n is the factor of safety; S_y is the yield strength (MPa); and σ_{rev} is the completely reversed stress (MPa).

3. RESULTS AND DISCUSSION
3.1. Static Analysis

Figure 4 shows the dimension of the bed-stretcher (in mm). This dimension will be used for static analysis calculation. Static analysis is conducted to analyze the strength of the structure, especially in the removable plate and shaft. The force experienced by the removable plate is coming from the weight of the coffin in each plate. While the shaft force is coming from the force given by the weight of the coffin connected with a rope. The weight of the coffin is equally shared on each of the four plates and each of the pulleys. This condition has occurred since the distance between each pulley and plate of the device has the same length as shown in **Figure 4.**

As shown in **Figure 5,** the reaction force on the shaft is calculated using the static condition. Point A and D represent the bearings of the shaft, point B and C represent the pulleys, and point E represents the gear position. The 2000 N coffin's weight is equally distributed on each of the four pulleys or equal to 500 N on each of the pulleys with 15 degrees between the rope and the y-axis.
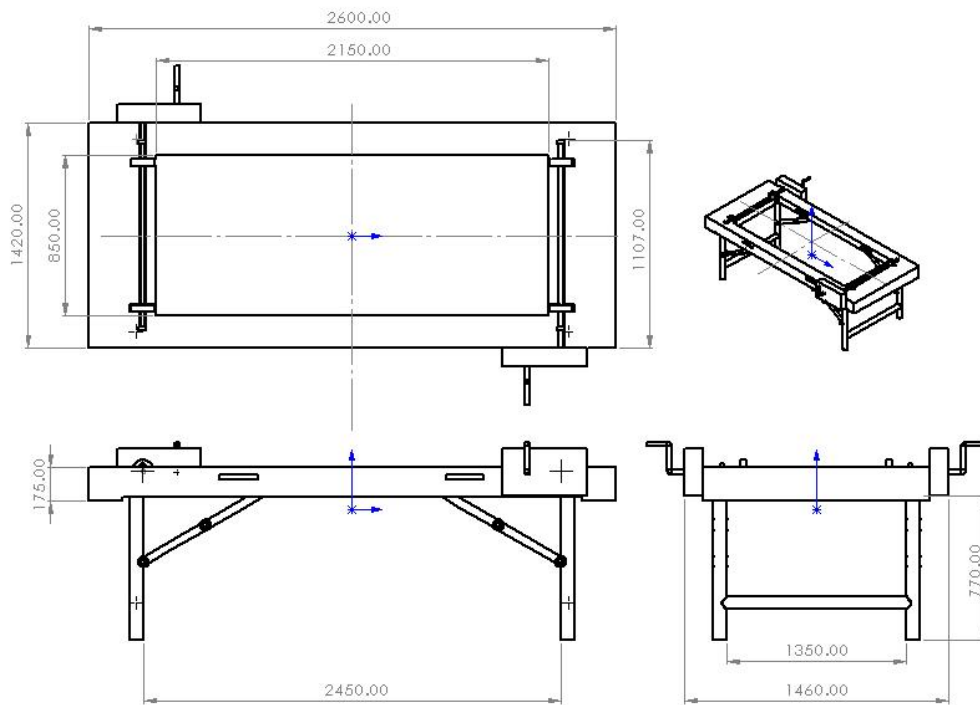
Figure 4. Dimension of the bed-stretcher device (in mm)**.**
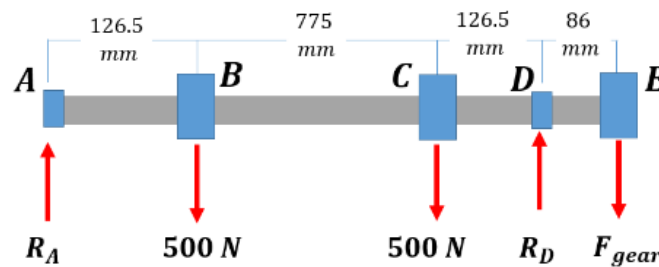
Figure 5. Free body diagram of the shaft.

By using shear force and bending moment diagrams analysis, points B and C on the shaft is experienced a maximum shear force and a bending moment. Based on the sheer force and bending moment diagram analysis, the value of the maximum shear force and bending moment are shown in **Table 2.**

For this reason, it is necessary to obtain the maximum tensile and compressive stress on the shaft using the principal stress from Equations (1) until (4), resulting $\sigma = 45.01 \, MPa \cdot \tau = 10.68 \, MPa$; $\sigma_1 = 47.42 \, MPa$ as the maximum tensile stress; and $\sigma_2 = -2.41 \, MPa$ as the maximum compressive stress. By input the value of maximum tensile and compressive stress to Equation (7), the safety factor of the shaft can be obtained, $n = 7.42$. Since the value of n > 1, yielding does not occur in this critical part.

Table 2. SFD and BMD value of the shaft.

Shear Force Diagram *(N)*	Bending Moment Diagram *(Nm)*
$V_A = 482.96 \, N$	$M_A = 0$
$V_B = 0$	$M_B = 61.09 \, Nm$
$V_C = -482.96 \, N$	$M_C = 61.09 \, Nm$
$V_D = 0$	$M_n = 0$

In order to ensure the number of safety factors, the distortion energy calculation to find the safety factor using Equation (5) is corrected as follows.

$$\sigma' = \sqrt{\sigma_x^2 - \sigma_x \sigma_y + \sigma_y^2 + 3\tau_{xy}^2}$$

$\sigma' = 48.66 \, MPa$

$n = 7.6$

If it is checked using the distortion energy formula, the result is still $n > 1$, which means that there is no yielding occurred.

3.2. Life Prediction Analysis

Life prediction analysis focuses on the critical part of the shafts. To gain the value of life prediction, endurance strength, alternating stress, and mid-range need to be considered. During the calculation of the endurance strength, the marine factors that need to be considered are the surface factor, size factor, and loading factor. By Equation [6], the endurance strength is obtained, where $k_a = 0.9$; $k_b = 0.88$; $k_c = 1$ (due to bending); $S_e' = 220 \, MPa$; $S_e = k_a \times k_b \times k_c \times S_e'$; and $S_e = 174.24 \, MPa$.

Mid-range and alternating stress is obtained to find the reversed stress using Equations [8] and [9]. Therefore, the Modified Goodman fatigue criteria are used, where $\sigma_a = 24.9$; $\sigma_m = 22.5$; and $\sigma_{rev} = 24.97 \, MPa$.

With the reversed stress value, the value is less than the endurance strength. By this claim, an infinite life occurs on this shaft. The comparison of both values can be seen in the following table and **Figure 6**. Since it has an infinite life, the life cycle is not needed to be calculated.

We found that the reversed stress and the endurance strength were 24.97 and 174.24 MPa, respectively. Then it is the infinite life. If the reversed stress exceeds the endurance strength, the shaft does not experience an infinite life, and the material and dimensions should be evaluated to receive an infinite life. For this reason, a stress analysis using a simulation to see the failure condition and characteristics will be carried out.

The results showed that $V_{max} = 500 \, N$; $\sigma_{max} = 0.1 \, MPa$; $M_{max} = 48.75 \, Nm$; and $\sigma_{max} = 0.0395 \, MPa$. The maximum shear force and also bending moment results from the equation above is not exceeding the value of the yield strength of the plate material. It can be concluded that the plate is safe enough to hold the coffin.

3.4. Gear and Handle Analysis

Figure 7 shows the dimension of the attached handle on the gear. Point B represents the place for the gear. While the hand position for the handle is on the top of the side of the shaft with 120 mm in length. The force received by the operator comes from the torque generated by the pulley when lifting the coffin. Then, the resulting torque will be received by the gear and continued to the user through the handle. To reduce the load from the force generated by the pulley, a gear ratio with a radius ratio of 15: 4 is used, where $\frac{r_A}{r_B} = \frac{T_A}{T_B}$, resulting $T_B = 15.47 \, Nm$. Thus, the torque needed to move the gear is 15.47 Nm. Based on the maximum torque that the human hand can handle which is 155 Nm. Hence, this torque still can be overcome by humans (McMulkin & Woldstad, 1995).
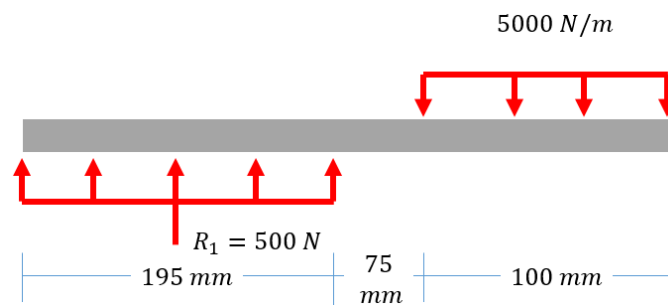
Figure 6. Free body diagram of the removable plate.
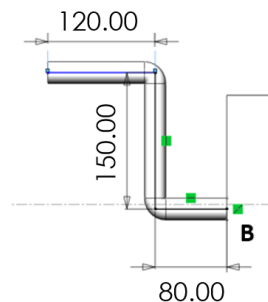
Figure 7. Gear and handle analysis.

4. CONCLUSION

This paper proposes a component design and strength analysis of the modified bed-stretcher. This device will help the health workers in the burial process of COVID-19 corpses. This device is equipped with several components, and the most important components are the removable plate and the shaft. The shaft will be a critical point because it is experiencing static loading. Therefore, it is necessary to check the yielding and the lifecycle of the shaft. Based on the static and fatigue analysis, it is proven that there is no yielding occur in the shaft. Moreover, the shaft is also confirmed to have an infinite life and good safety factor. The safety factor for the shaft is 7.6, which means that this part is strong enough to withstand a greater load. Besides shaft, the analysis is also carried out on gears. Based on the gear analysis, it is shown that the torque required for lowering the coffin is 15.47 Nm, which can be overcome by one person.

5. AUTHORS' NOTE

The authors declare that there is no conflict of interest regarding the publication of this article. The authors confirmed that the paper was free of plagiarism.

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