



## Foldable Bed Design Concept for COVID-19 Patient: A Machine Design Case Study

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### ABSTRACT

Coronavirus disease 2019 (COVID-19) has become a serious problem around the world. The pandemic has given several bad impacts, especially in the medical operation. Hospitals are facing problems in which they are lacking the patient bed facility. The objective of this paper is to propose an adjustable medical bed that can be folded as a chair for COVID-19 patients. This foldable bed is employing the hydraulic system as the lifting mechanism. It can raise up from 0.62 to 1 meter height and withstand loads up to 400 kg. Other supporting features and mechanisms will be explained in this paper. Furthermore, the theoretical strength analyses of this proposed design are conducted under the static and fatigue loading. In the static analysis, the safety factor due to the normal and shear stress is 7.5 based on the Maximum Shear Stress failure criterion theorem. Meanwhile, in the fatigue analysis, the safety factor based on the Modified Goodman and ASME-Elliptic criteria are 3.6 and 3.9, respectively. The infinite life of this design is predicted. In addition, this paper is expected to be used as a reference for developing a more reliable design for COVID-19 patients due to lack of bed facilities.

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## 1. INTRODUCTION

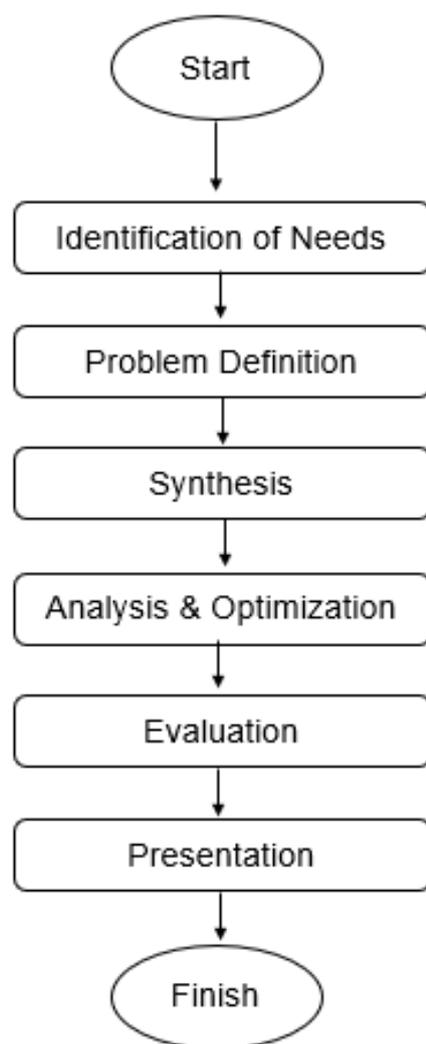
The world now is facing a crisis made by COVID-19 virus. This virus now making a historical pandemic era which causing many problems for many countries (Kundu et al., 2020). This crisis is also making so many issues related with economy, communication, and importantly health. Due to COVID-19 pandemic a lot of patient that need professional care from doctor. However, the problem that most of hospital facing now is lack of facility such as bed. Bed in hospital is important because the bed can give the patient the feel of relaxation, and by that they can rest and increase their immune (Zhou & Wiggermann, 2021). Unfortunately, pandemic era is also causing a crisis for hospital bed (Iacobucci, 2020).

In order to deal with the crisis for hospital's bed, an idea of using foldable bed can considered. A foldable bed is beneficial as not only it can reduce space when it is not used, but also it can be portable and function as a chair (Passos et al., 2021). However, there are still some important features that need to be considered in a foldable bed, especially for the handling of COVID-19 patients. These features include foldability to function as a chair, adjustability of the height, and ability to be extended to match the patient body. These adjustable features are important to match the need of the doctor to professionally to check the patient (Xu et al., 2021).

In this paper, a foldable bed design concept for COVID-19 patients is introduced. This design is different with any others product that already available in the market. One of the needs of the feature of 180° extend and adjustable height. Also, the other lack that is found is such small space for the patient to sleep which is one important thing for the user to feel the feeling of relaxation is their space to rest (Firmansyah et al., 2020). Considering those lack, the invention is made mainly to deal what medical personal and patient needs. The chair also aimed to be foldable to reduce space used for medical bed. The design specifications listed here are collected from several references, papers, journals, and other online media. All components presented in this paper are being evaluated under the static loading analysis. Fatigue analysis is provided to give the data whether this idea is safe or not and to predict the life prediction.

## 2. METHODS

In this paper, the basic data for designing the foldable bed are obtained from some literature review, websites, video lectures, and video tutorials. There are four important aspects that need to be considered in the process design (Macmillan et al., 1999; Regan et al., 1998; Zulaikah et al., 2020) which shown in **Figure 1**. Besides from the research method, this paper also provides the proposed design by using 3D software drawing in the synthesis stages. This aims to make it easier for the reader to understand the mechanism design that being proposed. To achieve the several objectives of this adjustable medical bed that can be folded as a chair, there are some stages that need to be completed as shown in **Figure 1**. Furthermore, the obtained data from this methodology chapter will be used for stress and safety factor analysis in both static and fatigue analysis.



**Figure 1.** Stages of mechanical design

### 2.1. Synthesis Procedure

In the synthesis stage, there are three proposed models created by considering the design requirements. All three proposed models mostly have similarities in dividing the main part of the design, which are the supporting rod (hydraulic) and the seat base. The differences among the three proposed models are the folding and extending mechanism of the chair design. The first proposed model has a connecting part between the backrest and footrest which allows them to fold or extend at the same time. The second proposed model has a slider at the backrest which connected to the seat base and it allows the chair to fold or extend at the same time with the hand-support part. The third proposed model has a screw pin which used to fold and extend the backrest and footrest where the chair can be used in sitting position (see **Figures 2 and 3**) and sleeping position (shown in **Figure 4**). Therefore, the third proposed model is chosen as the final design where the backrest - seat base part and seat base - footrest part is connected by a hinge. The hinge is used to flip up one of the two parts that connected each other. The dimension of the chair design (shown in **Figure 2**) is decided by considering the Asian average height including Indonesian based on data from ([Abd Rahman et al., 2018](#)).

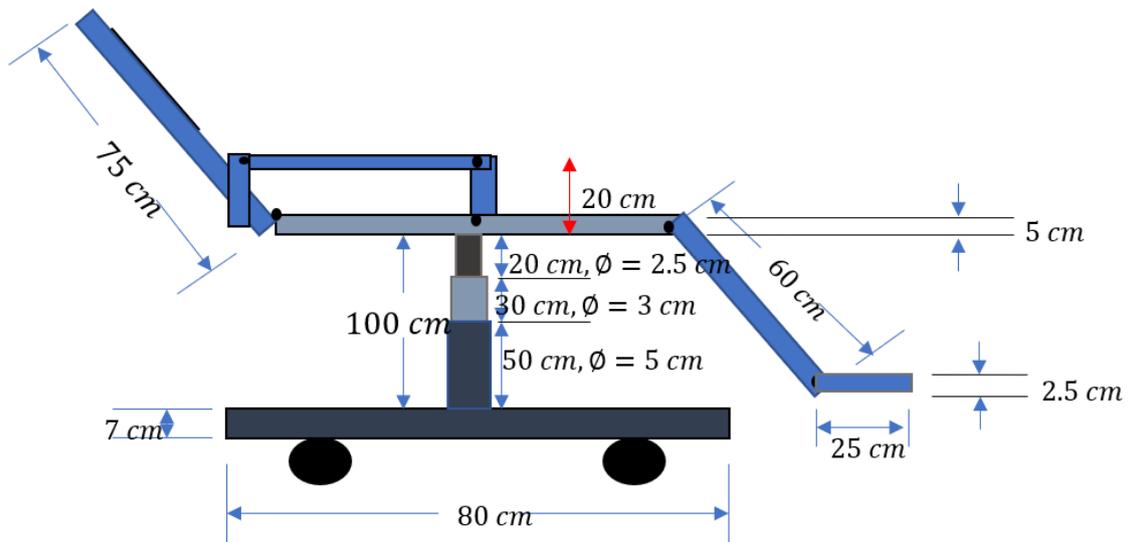


Figure 2. Two dimensional drawing of the chair.

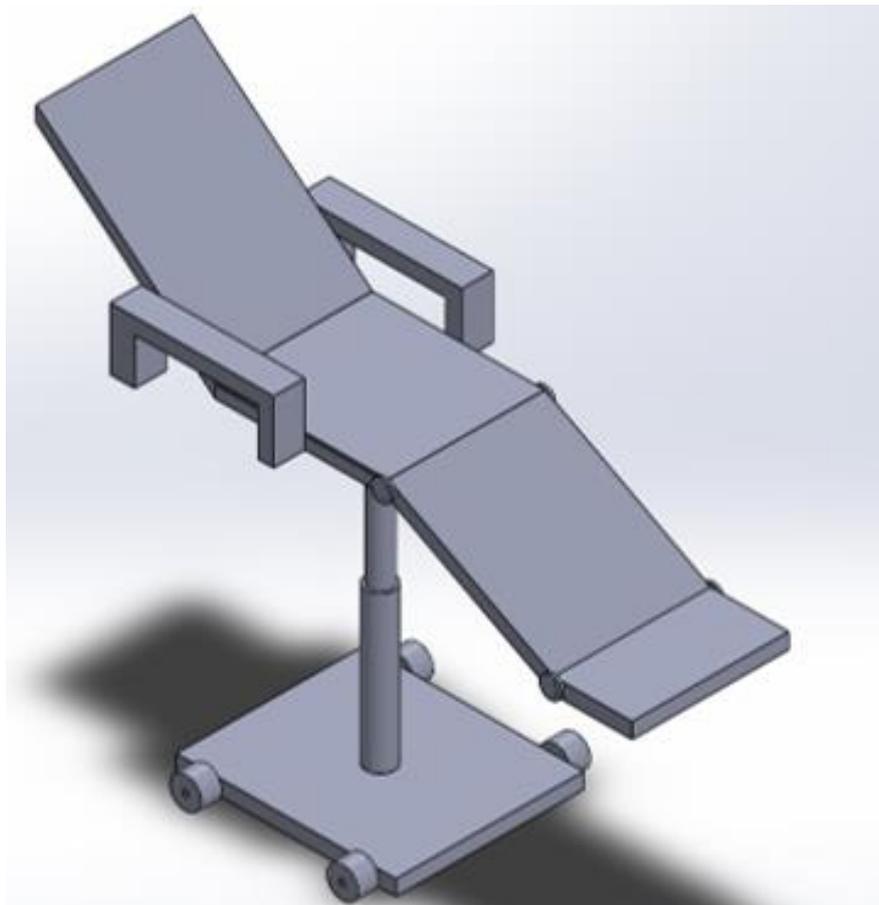
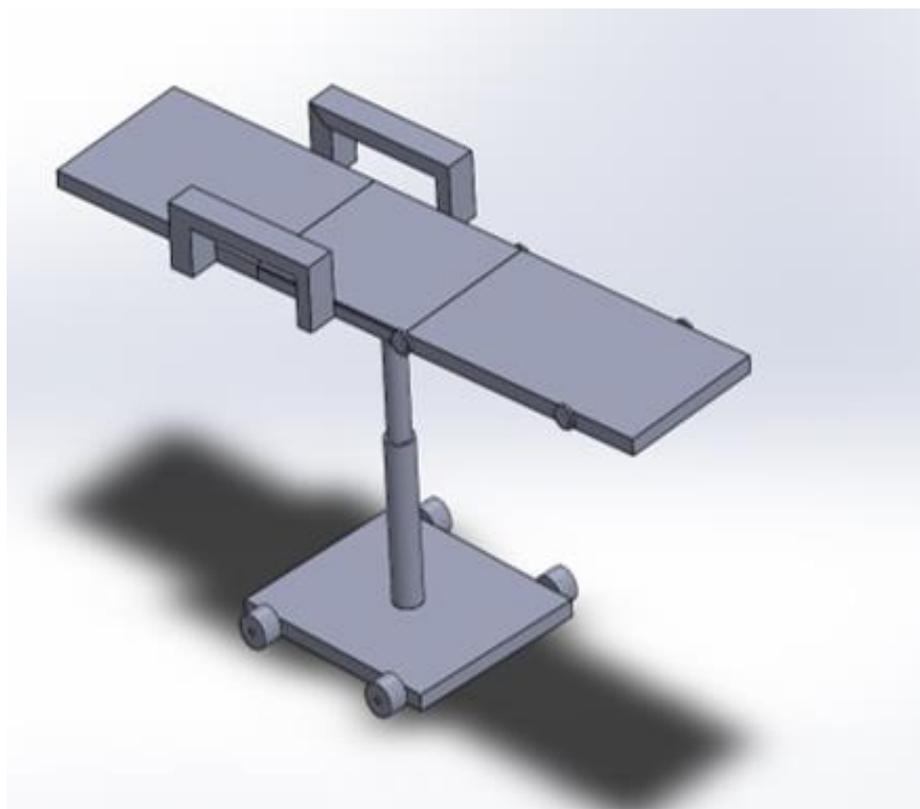


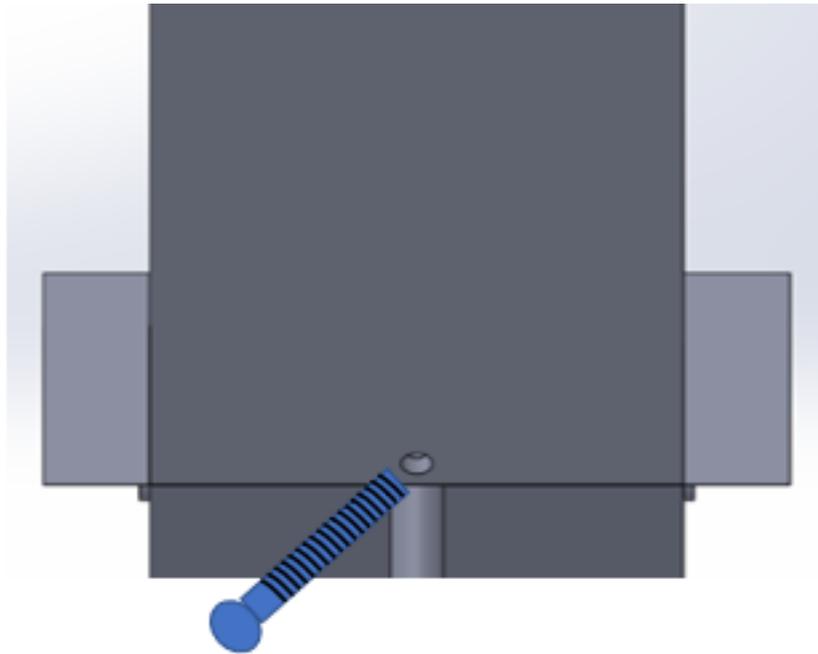
Figure 3. Sitting position



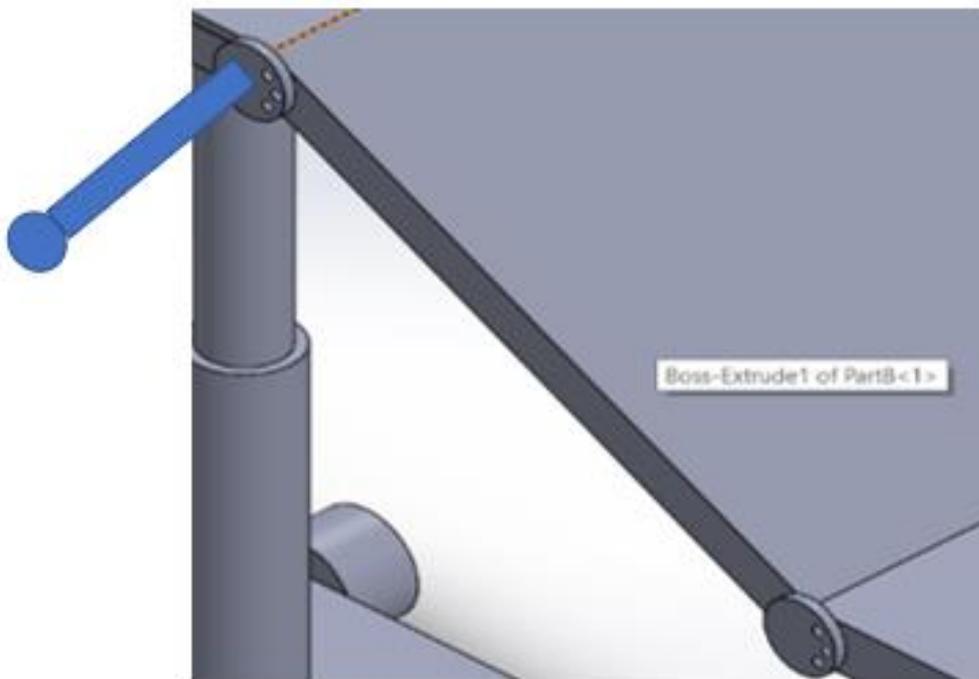
**Figure 4.** Sleeping position.

## 2.2. Design Concept

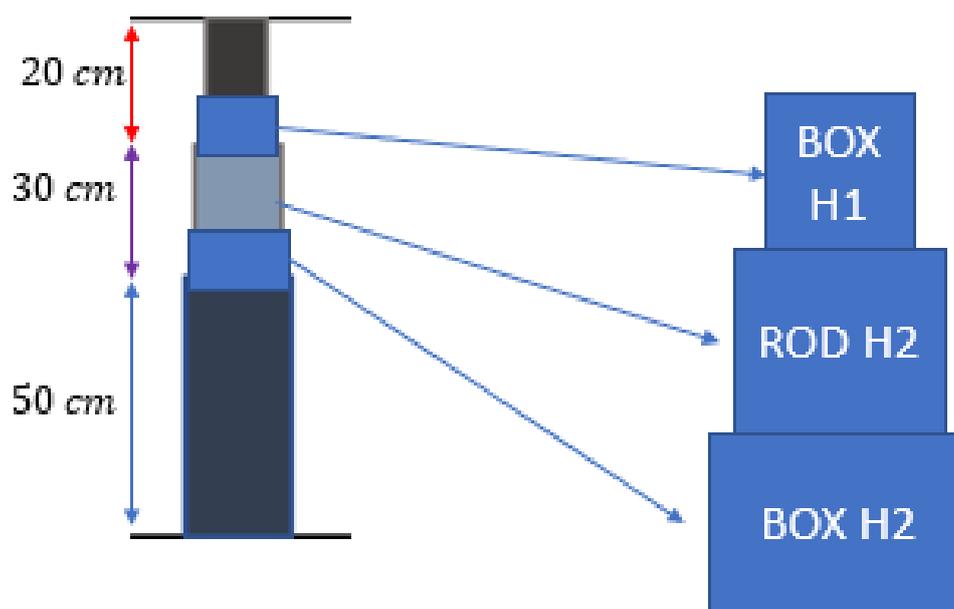
The chair design consists of three main mechanism which are the folding mechanism, extending mechanism, and adjustable height mechanism. The mechanism of folding the chair is by tightening the screw pin that placed behind the backrest part near the hinge which shown in **Figure 5**. For the footrest part, the pin can be installed and removed. By plugging it into different hole position (shown in **Figure 6**), the footrest position can be adjusted based on the user's need. For the mechanism of extending the chair, it can be done by loosen the screw pin behind the backrest part (shown in **Figure 5**) or placed the pin at the lowest hole position on the footrest (shown in **Figure 6**). For the adjustable height, the hydraulic working system is employed at the supporting rod which shown in **Figure 7** that used is the hydraulic pump systems type CB - F18C –FL (Pan *et al.*, 2015). There are two hydraulics use stacking arrangement, used in some research, which give a higher force as it gives a larger length. Therefore, by using hydraulic working system, the chair can be adjusted the height based on the needs.



**Figure 5.** The adjustment of the screw pin at backrest of the chair.



**Figure 6.** The adjustment of the pin at footrest of the chair.



**Figure 7.** Schematic of the leg support by employing the hydraulic system as the adjustable height.

In addition, for adjusting the height of the design, the lifting mechanism system is operated by using the hydraulic system. By using 2 hydraulics with stacking arrangement aimed to give a larger force as giving higher length. According to (Pan *et al.*, 2015), the allowable stress of the hydraulic systems that used for adjusting the height of the mechanism design:

$$\sigma_{allowable_1} = 73.55 \text{ MPa}; \sigma_{allowable_2} = 98.07 \text{ MPa}$$

By considering the connection of the hydraulic system with the road by taking 5 cm diameter of the road. The diameter of hydraulic pipe is 25 mm (Pan *et al.*, 2015). Then, the allowable stress that can be obtained in the lowest height which is 61.8 cm is 98.61 MPa. Therefore, this design able to withstand the loads up to 400 kg in the sitting position and more than 400 kg in the sleeping position. (Note:  $mass_h=1.5\text{kg}$  and  $t_{rod}=1.5\text{mm}$ ).

### 2.3. Material Selection

This adjustable medical bed that can be folded as a chair aims to assist health workers in dealing with patient COVID-19 whose transmission is increasing (Puspita & Mustakim, 2021). This is because many hospitals are overwhelmed by this condition due to the lack of medical bed facilities. So, this design requires a material that is lightweight and must be strong. The weight of this design should be light to meet the requirements of the design's objectives which are able to be placed in the minimum space, simple transportability, and easy mobility. Based on that requirements, stainless steel material is a suitable option for the selected materials. The stainless steel materials become the selected material because it has many advantages which are high and low temperature resistance, hygienic properties, corrosion resistance, ease of fabrication, material's strength, has a durable life cycle feature (Gardner, 2005; Uthhoff *et al.*, 1981). These advantages can meet the requirements of the specification design proposed. In addition, stainless steel has a life cycle characteristic, which is a durable and low maintenance material that making it less expensive than the other material (Gardner, 2005).

After analysis of some literature reviews, the type of the stainless-steel material from austenitic family with AISI 304 grade stainless steel is used. The advantages of the material are firstly coming from the fact this stainless steel coming from austenitic family which means it is corrosion resistance and creep resistance while remaining great for welding (Gardner, 2005; Shanmugam, 2008). This welding become an important thing since the rod that employing the hydraulic system is being welded with the middle plate of the design. AISI 304 stainless steel austenitic family is a superior absorber which will result in a higher weld penetration compared to other materials (Shanmugam, 2008). Due to this condition, this AISI 304 stainless steel is used in several industries includes medical facilities (Shanmugam, 2008). In addition, this material is also ease to fabricate such as cut, formed, and machined (Fu et al., 2008; Shanmugam, 2008). By referring to the Shigley's book (Budynas, 2015), table A-22, other mechanical properties can be obtained. This material is in the annealed condition. Moreover, the yield strength and the ultimate tensile strength of AISI 304 stainless steel is 276 MPa and 568 MPa, respectively. Those value is used for the stress analysis.

#### 2.4. Strength Analysis Procedure

In the strength analysis, there are two main position that being analysed. The first position analysed when the adjustable medical bed being folded as a chair (sitting position). Meanwhile, for the second position which is analysed when the adjustable medical bed in the sleeping position. Both positions stand at a maximum height of 1 meter. To analyse the strength analysis on the frame, it can be conducted by using these following equations.

$$\sigma_{bending} = \frac{M_{max}}{S} \quad (1)$$

$$S = \frac{1}{6}bh^2 \quad (2)$$

$$\sigma = \frac{P}{A} \quad (3)$$

$$\tau = \frac{3V}{2A} \quad (4)$$

$$\sigma_{max,min} = \frac{\sigma_x + \sigma_y}{2} \pm \sqrt{\left(\frac{\sigma_x - \sigma_y}{2}\right)^2 + \tau_{xy}^2} \quad (5)$$

$$\tau_{max} = \sqrt{\left(\frac{\sigma_x - \sigma_y}{2}\right)^2 + \tau_{xy}^2} \quad (6)$$

$$n = \frac{S_Y}{\sigma_{max} - \sigma_{min}} \quad (\text{under normal stress}) \quad (7)$$

$$n = \frac{1}{2} \frac{S_Y}{\tau_{max}} \quad (\text{under shearing stress}) \quad (8)$$

$$S_e = k_a k_b k_c k_d k_e k_f S'_e \quad (9)$$

$$\sigma_a = \frac{k_f(\sigma_{max} - \sigma_{min})}{2} \quad (10)$$

$$\sigma_m = \frac{kf(\sigma_{max} + \sigma_{min})}{2} \tag{11}$$

where:

- $\sigma_{bending}$  = bending stress (Pa)
- $\sigma$  = normal stress (Pa)
- $\tau$  = shear stress (Pa)
- $S$  = section modulus ( $m^3$ )
- $\sigma_{max,min}$  = principal stress (Pa)
- $n$  = safety factor
- $S'_e$  = endurance limit strength (MPa)
- $S_e$  = endurance strength (MPa)
- $\sigma_a$  = amplitude of alternating stress (MPa)
- $\sigma_m$  = midrange stress (MPa)

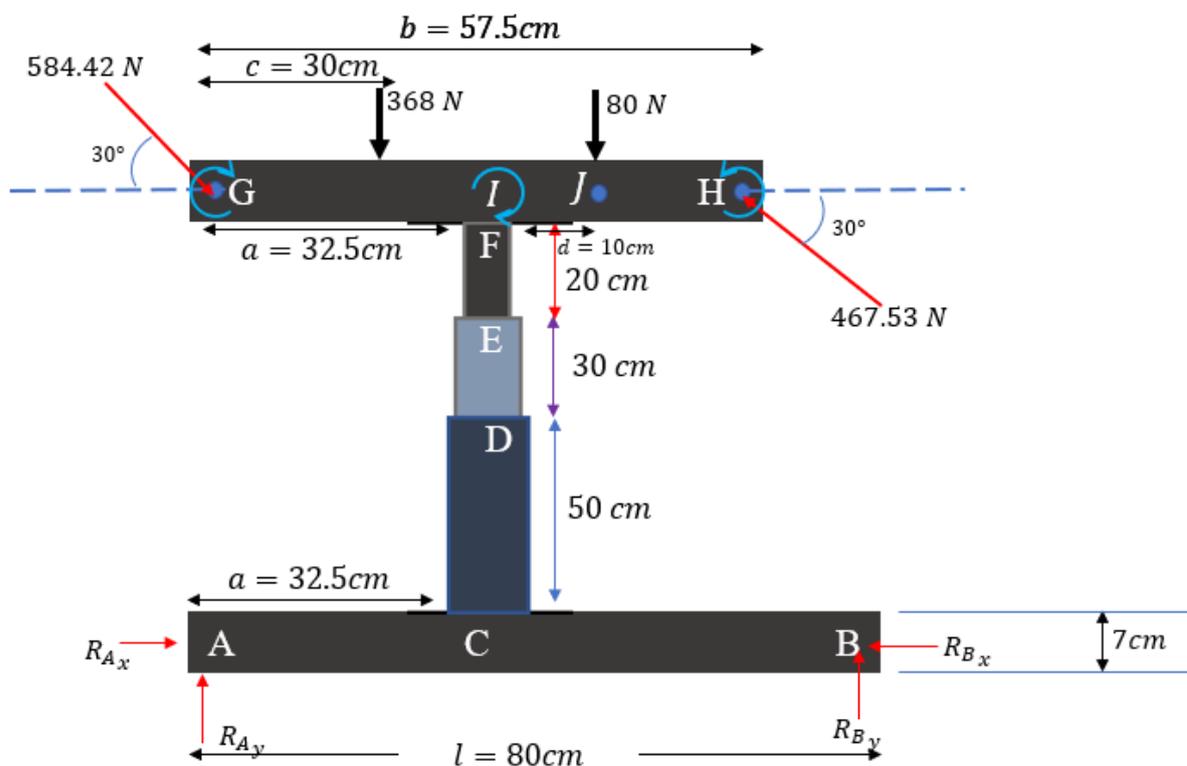
By using the theoretical equation above, the stress and safety factor can be analysed. The given cross section of this design is the rectangular beam cross section with the dimension of the thickness,  $b = 2.5\text{ cm}$ , and the width of,  $h = 3\text{ cm}$ . Therefore, based on the calculation, the obtained section modulus is  $S = 3.75 \times 10^{-6}\text{ m}^3$ .

### 3. RESULTS AND DISCUSSION

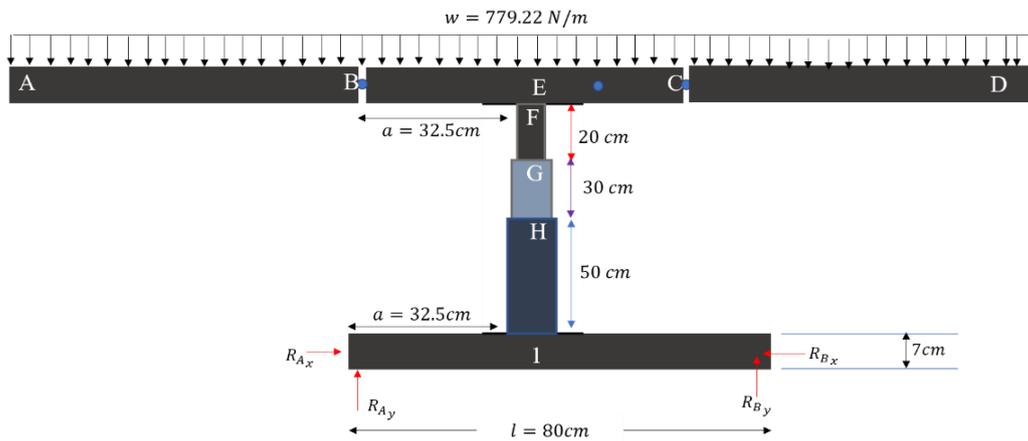
#### 3.1. Free Body Diagram (FBD) Analysis

After deciding the final product design, the next step is analysing the stress analysis on the product design. In this chapter, the analysis part is done only on the critical part of the design that may cause failure. The free body diagram of the product design as whole system in the critical part is shown in **Figure 8**.

Another critical part that must be considered when the design in the sleeping position. There is not much difference from FBD in sitting position, however, the distributed load is found along the body of the design which shown in **Figure 9**.



**Figure 8.** FBD of the design in the sitting position.



**Figure 9.** FBD of the design as a whole system in the sleeping position.

There are several assumptions used in the analyses as listed in the following:

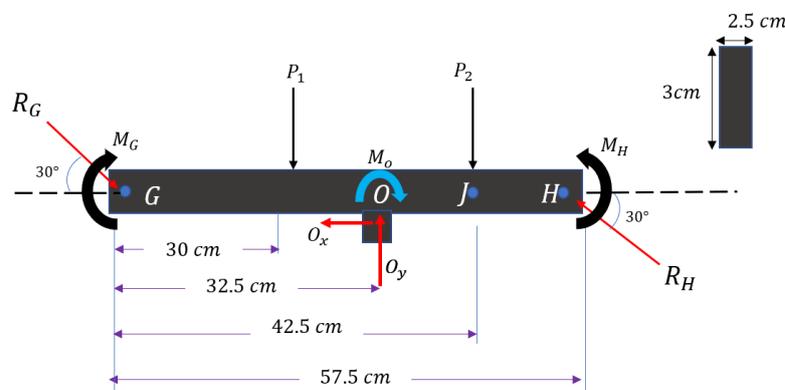
- Neglect the friction force.
- Neglect the spring constant of the adjustable height.
- Applied load 1500 N
- Made of stainless-steel austenitic family type 304.
- Yield strength,  $S_y = 276 \text{ MPa}$
- Tensile strength,  $S_{ut} = 568 \text{ MPa}$
- Young's Modulus,  $E = 190 \text{ GPa}$

### 3.2. Stress and Static Safety Factor Analysis

In this stress and static fatigue factor analysis, there are two main position that being analysed. Those positions are expected become the critical points when the load is applied. This can be indicated by analysing the fluctuated value that can be obtained from Equation (5) before the static safety factor being calculated. The stress analysis on each position was calculated theoretically. This analysis is assumed as the loading and unloading condition. The applied load that is assumed in this analysis is 1500 N. As the result of the calculation, the data is shown in the table below of each position.

#### Sitting position stress and static safety factor analysis

From the FBD in the sitting position as a whole system that shown in **Figure 8**, then it can be simplified to obtain the applied and reaction force in the sitting position (shown in **Figure 10**). Therefore, the stress and safety factor can be analysed that shown in the **Table 1**.



**Figure 1.** Free body diagram in the sitting position.

**Table 1.** Shear force (V) and bending moment (M) value in the sitting position.

Section	V(N)	M (N.m)
1	-292.21	-82.88
2	-660.21	-87.66
3	-153.76	137.48
4	-233.76	-69.73

From the calculated parameters of the applied and reaction force of the FBD in the sitting position, the fluctuated stress is gained. Since the section modules have been calculated in the strength analysis sub-chapter, the result of the maximum stress due to the bending is  $36.66 \text{ MPa}$ . By employing equation (5), the principal stress obtained are  $\sigma_{max} = 36.66 \text{ MPa}$  and  $\sigma_{min} = 0 \text{ MPa}$  due to the loading and unloading condition. Moreover, the maximum shear stress also can be obtained which is  $\tau_{max} = 18.33 \text{ MPa}$ . Therefore, the theoretical analysis by using the MSS theorem to determine the static safety factor was obtained. There are two kind of the static safety factor which are due to normal stress and due to the shearing stress. The static safety factor due to the normal stress is equal with the static safety factor due to the shearing stress by employing Equations (7) and (8) which is  $n = 7.5$ . Based on the result, this condition is safety enough for the applied load 1500 N.

### Sleeping position stress and static safety factor analysis

After obtaining the applied and reaction force parameter in the sleeping position that shown in **Figure 10**, the shear force and moment value can be obtained as shown in the **Table 2**.

According to the calculated result that generated from SFD and BMD analysis of the sleeping position, the stress due to bending is  $86.27 \text{ MPa}$ . The principal stress can be obtained by applying Equation (5) due to loading and unloading condition which gives results  $\sigma_{max} = 86.27 \text{ MPa}$  and  $\sigma_{min} = 0 \text{ MPa}$ . For the maximum shear stress, it can be generated by considering the principal stress which gives result  $\tau_{max} = 43.14 \text{ MPa}$ . From here, the MSS theorem is considered to calculate the static safety factor. Same as the static safety factor analysis of the sitting position, by applying Equation (7) and (8), it gives result  $n = 3.2$ . Therefore, the design is safe enough with 1500-N-applied load.

**Table 2.** Shear force and moment value in the sleeping position.

Section	V(N)	M (N.m)
1	-526.54	-219.16
2	-584.42	-323.53
3	915.59	-160.31
4	525.41	0.00

### 3.3 Fatigue Analysis

In this fatigue analysis, there are some important aspect that need to be considered such as the marine factors and the endurance limit of the materials (Cui et al., 2011). Based on the given data in the methodology chapter, the endurance limit of the materials can be obtained as follow:

- Yield strength,  $S_Y = 276 \text{ MPa}$
- Tensile strength,  $S_{ut} = 568 \text{ MPa}$
- Non-rotating bending
- Machined and cold drawn

Since the tensile strength is less than 1400 MPa, so the endurance limit will be:

$$S'_e = \frac{1}{2} S_{ut} = 284 \text{ MPa}$$

After some calculation, the marine factors value can be obtained as shown in the **Table 3** below to determine the endurance strength of the material. Where  $k_a$  = surface factor;  $k_b$  = size factor;  $k_c$  = loading factor;  $k_d$  = temperature factor;  $k_e$  = reliability factor;  $k_f$  = miscellaneous factor.

Therefore, by using Equation (9), the endurance strength that can be obtained from the value of the marine factors is  $S_e = 212.38 \text{ MPa}$ . After the endurance strength is obtained, the result of the midrange stress and the amplitude of the alternating stress in the sitting position and sleeping position with 1500N applied load is gained. As the results, the values are  $\sigma_a = \sigma_m = 18.33 \text{ MPa}$  and  $\sigma_a = \sigma_m = 43.14 \text{ MPa}$ , respectively. The same value of the  $\sigma_a = \sigma_m$  is due to the constituents a prescription of no notch yielding. Thus, the fatigue safety factor of this design in both positions can be calculated by using the Modified Goodman and ASME-elliptic criteria. By using tis following equation, the life cycles of the design can be predicted.

$$\frac{1}{n_f} = \frac{\sigma_a}{S_e} + \frac{\sigma_m}{S_{ut}} \quad (\text{Modified Goodman Criteria})$$

$$n_f = \sqrt{\frac{1}{\left(\frac{\sigma_a}{S_e}\right)^2 + \left(\frac{\sigma_m}{S_y}\right)^2}} \quad (\text{ASME - Eliptic Criteria})$$

Thus, the fatigue safety factor can be simplified as shown in the **Table 4**.

**Table 3.** Marine factors value.

Marine factor	Value
$k_a$	0.8399
$k_b$	0.8903
$k_c = k_d = k_e = k_f$	1.00

**Table 4.** Fatigue safety factor result.

Failure Criteria	Sitting Position	Sleeping Position
Modified Goodman Criteria ( $n_f$ )	8.4	3.6
ASME-Elliptic Criteria ( $n_f$ )	9	3.9

Based on the result of the fatigue safety factor by using the Goodman Criteria and ASME-Elliptic Criteria, it can be concluded that the infinite life of this design is predicted, since  $n_f > 1$  whether in the sitting position or in the sleeping position (Pan *et al.*, 2015). It also can be implied that the sleeping position are more critical than the sitting position since the fatigue safety factor is smaller. In addition, this design able to withstand the loads up to 400 kg.

#### 4. CONCLUSION

In this work, a concept design and the strength analysis of the adjustable medical bed that can be folded as a chair and safely used by 1500 N load is introduced. The bed design features some abilities which include foldability to function as a chair, adjustability of the height by hydraulic mechanism, and ability to be extended to match the patient body. The seat base and the supporting rod are considered as the most critical part because these parts hold the whole weight and loads that may create a failure if they are not designed and analysed carefully. From the stress analysis and safety factor calculation of the chair design, the sitting position gives result of safety factor  $n=7.5$  and the sleeping position gives result of safety factor  $n=3.2$ . Since the safety factor is more than one, therefore, the design is considered safe and strong enough to deal with 1500 N applied load. The proposed design of foldable bed is expected to contribute in the design product reference for medical or furniture equipment.

#### 5. AUTHOR'S NOTE

The authors confirm that there is no conflict of interest regarding the publication of this article, and the paper was free of plagiarism.

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