Virtual design analysis of the sleeping structure

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Abstract. The sleeping structures are the structures which are utilized for sleep or rest purpose. The utilization of them in day-in day-out activities is common in present era. Designing of any structure, requires examining its behaviour for the applied load and boundary conditions. Designing of such sleeping structures have caught attention of many inventors from decades. This research paper focuses on brief description about the linear analysis of the sleeping structure i.e. Bed designed by authors. The new designs of sleeping structure designed by inventors have gained most attention in the development of sleeping structures. The authors design of the structure is modelled in Computer Aided Design software PTC Creo and analysed in analysis software Altair’s Hyperworks. In this paper the sleeping structure is formulated as 2D beam with three support, two supports at both end and one at middle. The aim of this paper is to analyse the behaviour of structure for maximum stress and deflection for different load stages.

1. Introduction

Most likely in all analysis evaluating bending moment and the shear stress is an essential step. Likewise, simplifying the complex real problem with two-dimensional (2D) line diagram provides ease in analysis. From the past decades, the inventors have contributed in the development of the sleeping structures [1-4]. This development is moreover observed in new product development and are based on the indigenous thoughts of inventors and researchers. The designs contribute more in space savings. The novelty of this work is to contribute by developing the linear static analysis of the sleeping structure.

1.1. Objectives

- To study the linear analysis of sleeping structure.
- To understand the behaviour at different loading stages.
- To study maximum stress region due to applied load.

The main objective of the work is to perform the linear analysis with different loading stages. The secondary objective of this work is to study the response of the structure for the applied load over the complete structure. The deflection and the Von Mises Stress generation regions and understanding their maximum values.
2. Design and analysis

The Computer Aided Design (CAD), model developed upon studying the designs invented by the inventors [1-4]. All the sleeping structure consists of frame supported with vertical element (Leg). These are the common elements observed in almost structures.

2.1. CAD Design

Combining the basic elements like frame and leg the CAD design is developed as shown in Figure 1. The vertical element supporting the frame at six distinctive locations. The model is developed combining the two basic elements of bed.

![Figure 1. The schematic CAD model of the sleeping structure.](image)

The sleeping structure is axisymmetric along length and width. While, the structure is designed to sustain the weight up-to 1200N. The architecture of the sleeping system designed to accommodate the person of 1828.8 mm x 610 mm. (length x width). The detailed dimension of the structure is 2001 mm x 762 mm (Length x Width). The height of the structure is maintained at 457.2 mm to provide comfort during resting/sleeping on the structure.

The sleeping structure is designed in a simplified manner so that the manufacturing of the structure becomes easy. The novel design part of the structure is that the structure is symmetric along both width and the total length. The middle support divides the complete structure symmetrically. The structure is designed for serviceability. That is, making it easy to manufacture any component or part of the structure in no or less time and space can be used at any location.

2.2. Formulation

The three-dimensional (3D) structure is simplified with 2D line diagram. Considering the structure as symmetric along the length. Figure 2 shows the schematic 2D Line diagram with the boundary condition (BC) as both ends are hinge support while fixed support at mid. The cross section of the 2D line is presumed as ring, with outer diameter as 30mm while inner circle diameter as 28.5mm.

![Figure 2. The schematic 2D diagram of the structure with the boundary conditions.](image)

The material used for the sleeping structure is Aluminium H9 equivalent to 6063 and Table 1 describes the mechanical properties of the material in detail. The modulus of elasticity (E), density ($\rho$), and poisson's ratio ($\mu$), Aluminium (a), Steel (s) terms used to define the mechanical properties.
Table 1: The Mechanical properties of the materials used in the Model [5]

| Material   | Property | Value (MPa) | Property | Value (g/cm²) | Property | Value |
|------------|----------|-------------|----------|---------------|----------|-------|
| Steel      | $E_s$    | 210 e3      | $\rho_s$ | 7.9           | $\mu_s$  | 0.3   |
| Aluminum   | $E_a$    | 70 e3       | $\rho_a$ | 2.6           | $\mu_a$  | 0.33  |

The loading diagram is shown in Figure 3, wherein, the application of the load is presented along the length and width of the sleeping structure. The UD load distribution is applied over the structures span based on the load distribution of the individual’s weight. Paolo [6] segmented human body and explained the average weight distribution of the individual (average of male and female). Referring the segments and further calculation the author optimized the segments to three as shown in Table 2.

Table 2: The average weight distribution of individual (male and female) [6]

| Description          | Abbreviation | Weight | Unit |
|----------------------|--------------|--------|------|
| Head                 | A            | 6.81   | %    |
| Trunk + Total Arm    | B            | 52.45  | %    |
| Total Leg            | C            | 40.74  | %    |

The span of distribution is assumed by author and shown in Figure 3 (b). To understand the response of the structure for different load stage loads assumed as 635, 910, 1500N. The assumed loads do not change with respect to time. The structure is designed for the weight 1200N with certain margin for safety.

Figure 3. The free body diagram of the sleeping structure a) the UD load along the width applied at three distinctive spans along length. b) The UD load distribution along the length.

2.3. Assumptions and calculation:
Certain assumptions used are as follows:
1. The structure acts as linear i.e. it obeys Hook’s law.
2. The forces applied to the structure/ system are static in nature.
3. All the material properties are isotropic in nature.
4. For simplification in the analytical calculation the hinge is considered as an integral part of the beam with the same cross-section.
5. Axial forces in the structure considered to be zero.
6. All properties of a material are isotropic in nature.
7. The human body is distributed into 8 approximately equal parts. Out of the 4 - are assumed as total leg length, 3 - for trunk + arm, and 1 - for the head.

To solve the above formulated problem, use of bending moment (BM), shear force (SF), and deflection diagram is necessary, the total UD load of 635N is applied and the respective, BM, SF and deflection diagram is shown in Figure 4.

From Figure 4, it was observed that the maximum BM and maximum deflection obtained for the applied load are 13.6Nm and 0.86 mm respectively. To calculate the maximum von mises stress due to the applied load of 635N, use flexural formula and von mises stress formulas mentioned in eq. (1 – 5).

The stress calculated at three distinctive locations a’, b’, c’ as shown in Figure 4 (b, c).

i) Calculation of the bending stress ($\sigma_{bm}$) [7]

\[
\sigma_{bm} = \frac{M_{bm}}{Z}
\]

\[
Z = \frac{\pi}{32} x \left( \frac{d_o^4 - d^4}{d_o^2} \right)
\]
ii) Calculation of the axial stress ($\sigma_{af}$) [7]

$$\sigma_{af} = \frac{F_{af}}{A}$$  \hspace{1cm} (3)

$$A = \pi x (R_b^2 - R_i^2)$$  \hspace{1cm} (4)

iii) Calculation of the Shear stress ($\tau_s$) [7]

$$\tau_s = \frac{F_{sf}}{A}$$  \hspace{1cm} (5)

iv) Calculation of the Von mises stress ($\sigma_v$) [7]

$$\sigma_v = \sqrt{(\sigma_a - \sigma_b)^2 + (3\tau_s)^2}$$  \hspace{1cm} (6)

The obtained values of bending moment, from Figure 4, as $a' = 13.6\text{Nm}$, $b' = 11.1\text{Nm}$, $c' = 8.9\text{Nm}$, the modulus of elasticity ($Z$) obtained as $4.92e-7 \text{ m}^3$. By equating the values in equation (1) to (6), the obtained results are shown in Table 3.

**Table 3:** The bending stress ($\sigma_{bm}$), axial stress ($\sigma_{af}$), shear stress ($\tau_s$) and the von mises stress on the sleeping structure for the applied UD load of 635N.

| Locations | $\sigma_{bm}$ (MPa) | $\sigma_{af}$ (MPa) | $\tau_s$ (MPa) | $\sigma_v$ (MPa) |
|-----------|---------------------|---------------------|----------------|------------------|
| a'        | 27.66               | 0                   | 0.580          | 27.678           |
| b'        | 22.275              | 0                   | 2.162          | 22.883           |
| c'        | 18.101              | 0                   | 0.711          | 18.143           |

2.4. Validation:
The CAD model shown in Figure 1 is imported in Altair’s HyperMesh software (academic version) for analysis and validation of analytical result. The CAD model imported in the HyperMesh is shown in Figure 5.

![Figure 5](image)

**Figure 5.** The schematic of the sleeping structure in the Altair HyperMesh with the applied UD Load and the boundary conditions.

2.5. Results and discussion
Upon applying the UD load of 635N over the span of the structure the stresses obtained in Altair’s Hypermesh are presented in the figure 6. The Figure 6 (a) indicates the stresses developed at location a’ as 25.64MPa and Figure 6 (b) indicates the stresses developed at location b’ as 22.14MPa.
Figure 6. The von mises stresses developed in the Altair HyperMesh /HyperView environment (a) indicates the stress developed at location a’ while (b) illustrates the stresses developed at location b’ and (c) illustrates the maximum deflection developed in the structure.

Upon comparing the results obtained Analytical calculation and the analysis performed in Altair’s HyperMesh it is observed that the Maximum stress variation between analytical calculation and analysis in Altair Hypermesh is around 7.36% which can be said in the permissible range due to certain assumptions these variations comes into picture. Whereas, the deflection values obtained by analytical calculations was on the higher side by around 30.23% than that of maximum deflection obtained by Analysis in Hypermesh. Since the variation in the stress and deflection values are closure, more two load stage applied in analysis to understand the behaviour. The maximum Von mises stress observed for the load of 910N and 1500N were 36.75 MPa and 60.58 MPa respectively. Whereas, deflections obtained were 0.86mm and 1.42mm respectively.

3. Conclusion

In this work we contribute the linear analysis of the sleeping structure. First the simplification of the sleeping structure is shown then, with the support of the analytical calculation the stresses and the deflection obtained for the complex problem. The results obtained by analysing the CAD model in Altair Hypermesh environment. And the results obtained the closeness in the results was observed. The variation could be further reduced by developing and working upon the assumptions considered in this work. The maximum stresses region can be further strengthened by applying the material and secondary support in the nearby region.

It was also observed that the sleeping structure was able to sustain the load of 1500N even when designed for the weight of 1200N. This indicates the structure is safe based on analysis. Hence, it served the purpose of work conducted.

References

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