Energy and Stress Analysis of the Free Fall Mechanism Made of Cast Iron with a Mass of 500, 1000, 1500, 2000 Grams and Working at 10, 20, 30, 40 Centimeters Height

Kevser Dincer[1], Kadir Eren Tekiner[2], Yusuf Yılmaz[3]

[1, 2, 3]Konya Technical University, Faculty of Eng. & Natural Sciences, Department of Mechanical Engineering Konya, Turkey
*kdincer[at]ktun.edu.tr, kadirerentekiner[at]gmail.com, yyilmaz[at]ktun.edu.tr

Abstract: ***In this study, a free fall system mechanism with a mass of 500, 1000, 1500, 2000 grams was designed. The free fall mechanism works from a height of 10, 20, 30, 40 centimeters. The mechanism parts in accordance with the specified values of the system performed are sized for castiron. The 3 - dimensional solid model of the system has been created. For stresses, deformation, kinetic and potential energy a change according to the height and mass values of the system by modeling analyzes were conducted. The maximum tensile force that can occur on the material for the maximum mass and height of 2 kg and 40 cm height was evaluated. It has been observed that the potential and kinetic energy values calculated depending on the mass and velocities are maximum at the largest mass and excess height values.***

Keywords: Energy, free fall, impact, iron, mass, pressure.

1. Introduction

The remarkable observation that all free falling objects fall with the same acceleration was first proposed by Galileo Galilei nearly 400 years ago. An object that falls through a vacuum is subjected to only one external force, the gravitational force, expressed as the weight of the object [1]. Free – fall movement is the linear motion that is correctly accelerating without the first speed. Therefore, the first speed is the links used in the free fall motion if the acceleration (g) is written instead of accelerating (a) in accelerating linear motion connections [2].

In order to make experimental measurements for free fall, the height at which the object is released and the fall time must be known. Determining the height and measuring the fall time can be determined by different techniques. For example, the fall time can be measured with a chronometer [3]. In free weight drop tests, a known amount of weight is dropped from a fixed height. It covers the examination of different physical and profile properties of the area affected by this weight. Numerous controllable test parameters can be examined by weight drop tests [4, 5].

There are experimental, analytical and numerical studies made on freefall [6 - 9]. In this study, a system designed was made for a free fall mechanism made of iron with a height of 10, 20, 30, 40 centimeters and a mass of 500, 1000, 1500, 2000 grams. Stress and energy analyzes of this system were made for different height and mass values.

2. Material Method

When an object is released from a certain height without initial velocity in a frictionless environment, the motion that is made by gravitational acceleration regardless of mass is called free fall. To illustrate this situation, when a bird feather and a metal ball of the same mass are released from the same height, they fall to the ground at the same time. The designed system is in free fall, the velocity of hitting the ground and the time of hitting the ground are calculated.

Material Selection; Since there are more than one criterion in material selection, the appropriate material was selected with the simple sum weighting method (Table 1 and 2).

Table 1: Volumes of some materials corresponding to a mass of 500 grams (g/cm^3)

Material	Aluminum	Copper	Bronze	Iron
Density g/cm^3	2.7	8.96	8.56	7.87
Volume cm^3	185.19	55.80	58.41	63.53

Table 2: Decision matrix

	Aluminum	Copper	Bronze	Iron
Cost (₺/kg)	66.25	86.40	85.20	19.25
Volume (g/cm^3)	185.19	55.80	58.41	63.53
Brinell Hardness (MPa)	245	85	183	450

Copper, which is the most suitable material in terms of volume, has a very low value in terms of hardness. It is also more expensive than iron. Therefore, the most suitable material in terms of cost, volume and hardness has been determined as cast iron. The three – dimensional view of the assembled version of the designed free fall mechanism is presented in Figure 1and 2.

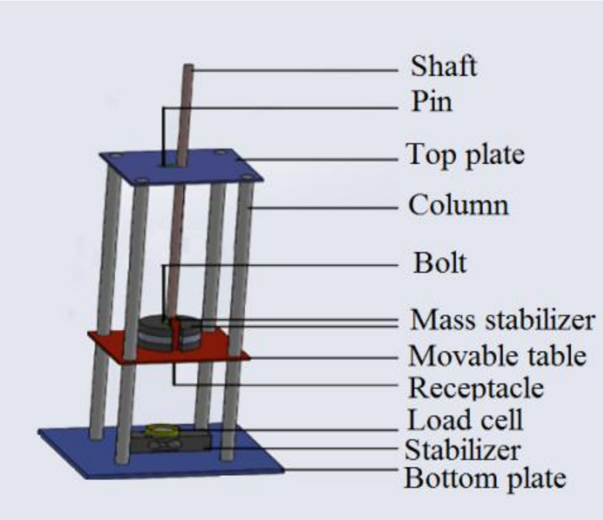

Figure 1: Three - dimensional view of the design

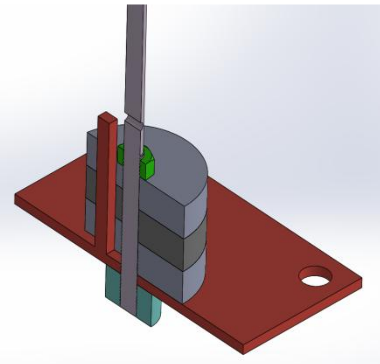

Figure 2: Sectional view of the moving mechanism

Properties of cast iron: Cast irons are shown in the region from 2% to 6.67% when we look at the Fe - C diagram. However, since the high carbon ratio causes brittleness, they are known as a Fe - C - Si alloy containing up to 4.4% carbon and up to 3.5% silicon in practice. Although cast irons are brittle and have lower strength properties than steels, they are inexpensive. Their pourability is easier. In addition, it is possible to change the properties of any type of cast iron over a wide range with proper alloying, good casting control and suitable heat treatments. It shows a wide range of mechanical/physical properties. They can be processed perfectly at high speed and production capacities. It has high resistance to abrasion and corrosion. Production steps are quick and easy. They have low melting temperatures (1150 - 1300°C). It is also inexpensive due to its low melting temperature [10].

3. Results and Discussion

The Tresca criterion is preferred more frequently in engineering applications. In this study, stress calculation was made using Tresca criterion (Eqs.1 - 5).

$$\text{Compressive stress: } \sigma_b = F/A \quad (1)$$

$$\text{Momentum: } Me = F.\, d \quad (2)$$

$$\text{Strength: } W_y = b.\, h^2/6 \quad (3)$$

$$\text{Bending stress: } \sigma_e = M_e/W_y \quad (4)$$

$$\text{Tresca criterion: } \sigma_{eq} = (\sigma_{total}^2 + 4\tau^2)^{1/2} \quad (5)$$

In Eqs.1 - 5, F is the force, A is the area, d is the diameter of the receptacle, h is the height, and τ is the shear stress.

The stresses that the load will create on the plate in the system. While calculating the surface area of the receptacle, the calculation was made with the mounted rod mechanism. The reason for this is to check the suitability of the design by determining the maximum stresses that the system will create in the plate while it is mounted. The bending stress will be maximum at the center point of the plate.

Yield values of materials are taken as basis. After a material leaves the elastic region and undergoes plastic deformation, the material is permanently deformed. Therefore, the critical strength is the yield strength. In this study, the yield strength (σ_y) for iron was taken as 172 MPa. The factor of safety value is usually taken in the range of s = 1.2 - 2 according to the criticality of elastic materials. Here, the critical part, the plate, has been determined as the critical material because its thickness is very thin. Therefore, the factor of safety (σ_s) is taken as (s) = 2 (Eq.6).

$$\sigma_s \leq \sigma_y/s \quad (6)$$
$$\sigma_s \leq 86 \text{ MPa}$$

Since the condition 26.16 MPa ≤ 86 MPa is met, this design is a safe design.

3.1 Energy and Stress Analysis

The properties of cast iron, which is the material used in the design, are entered as material data in the program. In this study, there is an impact in the free fall mechanism. A time dependent structural analysis module was used to examine this multiplication. The initial time step value used in the analysis was determined. The initial time step value is found in the Modal module depending on the natural frequencies of the system. Therefore, firstly, a modal analysis was performed and the initial time step value was obtained depending on the natural frequencies of the system. After performing the modal analysis, time dependent transient analysis was performed. Height analysis was performed separately for each mass value. For each analysis, after impact, the part bounces up and vibrates. However, since these vibrations cause sinusoidal deviations in energy and voltage values, the graphs must be considered until the moment of impact.

Energy Analysis: In free fall, an object moves vertically by converting its potential energy into kinetic energy. Potential energy acceleration varies with altitude and mass. According to the law of conservation of energy, the total energy of the object is equal to the potential energy it had when it first started moving.

The potential energy is presented in Eq.7 and the kinetic energy is shown in Eq.8.

$$E_p = mgh \quad (7)$$

$$Ek = 1/2\, (mv^2) \quad (8)$$

In Eqs.7 - 8, m is mass, g is acceleration of gravity, v is velocity.

According to the model analysis of the system in free fall, the velocity values are the same as the values found in the analytical calculations. According to the analysis, it is seen that the speed values change depending on the height. The obtained data confirmed the accuracy of the expression $V=½ gt^2$ used in the calculations. It has been observed that the potential and kinetic energy values calculated depending on the mass and velocities are maximum at the largest mass and excess height values. Velocity analysis of 0.5 kg mass dropped from 40 cm height is presented in Figure 3.

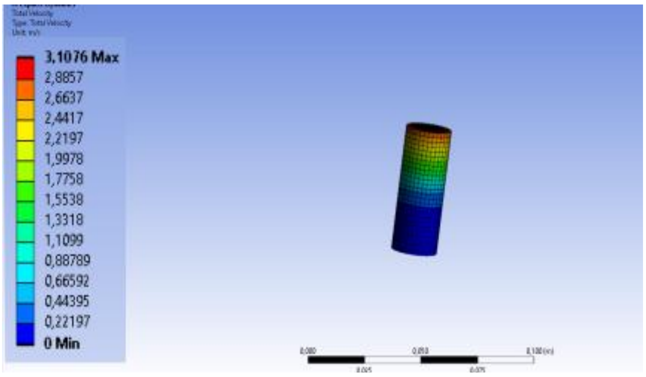

Figure 3: Velocity analysis of 0.5 kg mass dropped from 40 cm height

Potential energy values change depending on mass and height. According to this analytical analysis, the amount of transformed energy changes depending on the mass. The object that will make free fall moves vertically in the downward direction by converting the potential energy it has from the height into kinetic energy. The initial potential energy turns into kinetic energy when the object begins to fall. The energy changes with respect to the mass are shown in Figure 4.

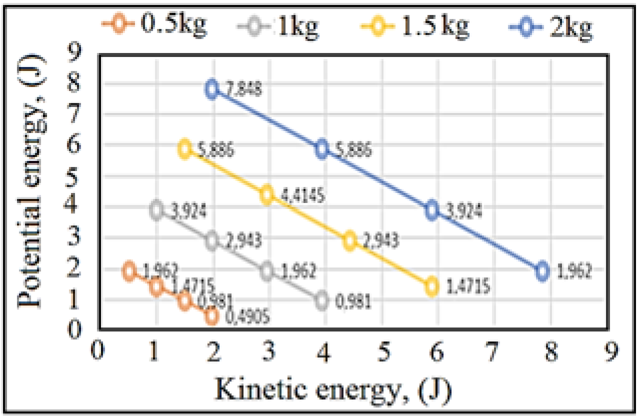

Figure 4: Energy changes by mass

As seen in Figure 4, the least kinetic and potential energy energy was formed in 500 gram mass. The highest potential and kinetic energy was formed in the mass of 2000 grams.

According to the distribution analysis of the energy due to impact seen in Figure 5, there is an energy transfer that is distributed from the center to the periphery. It is observed that the one - to - one overlapping of the receptacle's and material's surface areas is an important factor in this energy distribution. According to this modeling, it is seen that the unsupported parts of the part placed on the load cell, which are not in contact with the load cell, are more suitable for bending.

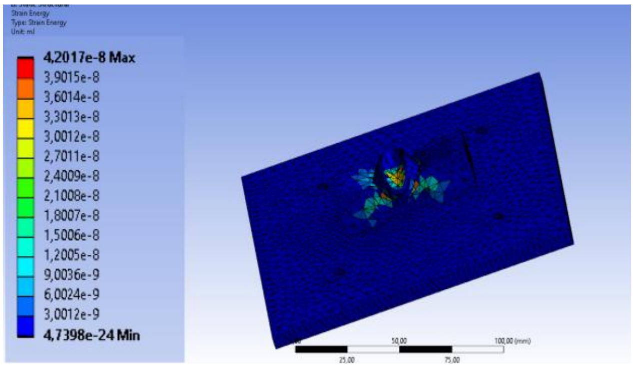

Figure 5: Energy analysis of the sub - plate

Friction and disruptive factors were not taken into account in the analysis calculations. The averages of the analytical analysis and model analysis data on energy give the correlation coefficient when compared with each other. The correlation coefficient was found to be 1. The fact that the correlation coefficient (R^2) came out in this way confirms the accuracy of the calculations. The accuracy of the system is confirmed as the model analyzes overlap with the analytical solutions (Figure 6).

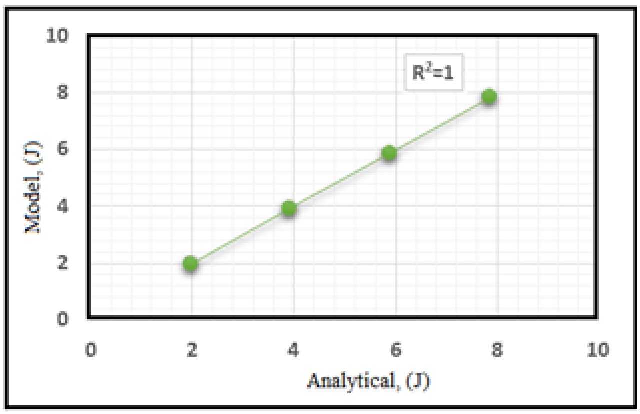

Figure 6: Correlation coefficient (for kinetic energy)

Stress Analysis: The essential stresses in a free fall system are compression and bending stresses. It has been seen in the analyzes that the released masses try to bend the material during contact with the bottom plate. It has been determined that the bending stress accumulates in the parts of this circular material, which is placed on the loadcell, which cannot receive support from the bottom (Figure 7).

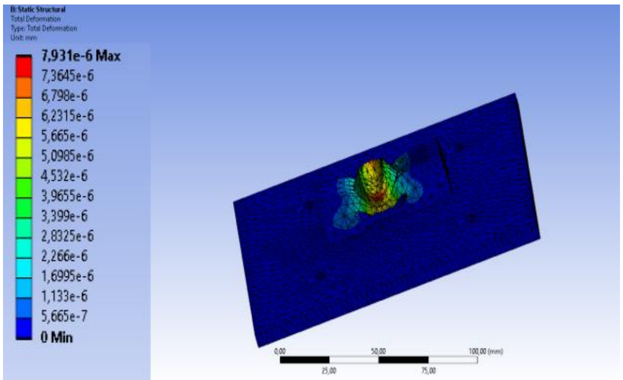

Figure 7: Deformation analysis of the bottom plate

The maximum tensile force that can occur on the material for the maximum mass and height of 2 kg and 40 cm height was evaluated within the framework of the Von Mises criterion. According to the data obtained from the model analysis, a maximum stress of 332.98 kPa occurred (Figure 8).

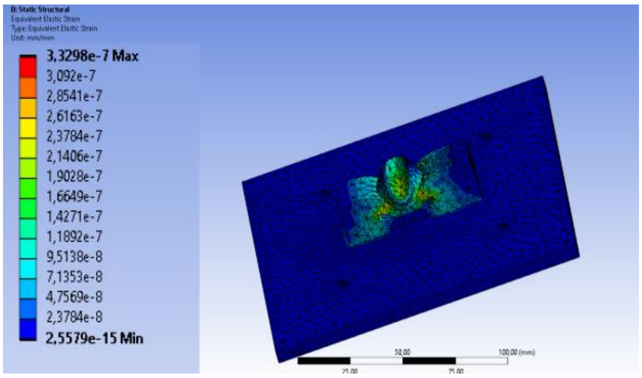

Figure 8: Von Mises analysis of the bottom plate

According to the analyzes made, an increase in stress and deformation is observed depending on the height of the receptacle hitting the table. It has been determined that the deformation value depending on the height is between 0.000012 mm and 0.000024 mm.

4. Conclusion

It has been observed that mass and height are important in the free fall mechanism. It has been analyzed that the energy that the system can produce varies in direct proportion to the mass and height. The energy of the system with a mass of 0.5 kg and released from a height of 10 cm was 0.4905 J, while the energy of the system released from a height of 2 kg and 0.40 m was determined as 7.848 J. In the free fall mechanism, it was observed that the velocity changes independently of the mass. It has been observed that the impact velocities of different masses released from the same height are equal. The velocity of the masses released from a height of 10 cm is 1.403 m/s, the velocity of the masses released from a height of 20 cm is 1.981 m/s, the velocity of the masses released from a height of 30 cm is 2.426 m/s and the velocity of the masses released from a height of 40 cm is 2.801 m/s. In the design, the bending stress was calculated as σ_e = 3.08 MPa and was determined as the critical stress. It has been observed that the potential and kinetic energy values calculated depending on the mass and velocities are maximum at the largest mass and excess height values.

An important issue is the variation of the stresses that occur between the change in the materials chosen for the receptacle and the chamber pair to which the receptacle will strike. Especially when materials with low yield strength will be used, mass and height values should be determined very carefully so that the system can remain within the safety limits. It has been observed that the geometries of the designed components and the dimensions of these geometries also affect the safety situation.

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