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Energy and Stress Analysis of TheFree Fall Mechanism Made By Steel

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ABSTRACT:In this study, a free fall mechanism operating at a height of 10, 15, 20, 25 centimeters and masses of 500, 1000, 1500, 2000 grams was designed. The material of the free fall mechanism is steel. In this designed system, the effects of high and mass on velocity, potential and kinetic energy were investigated. By examining the situation where the system is exposed to the highest load, it is analyzed whether the system is safe or not. When the speed potential and kinetic energy stress results determined by analytical calculations and modeling are compared with each other, it has been determined that the results are compatible with each other. In this study, the maximum deformation is $7.879*10^{-7}$ mm. This result shows that the system is safe.

KEYWORDS: Energy, Free fall, Impact, Mass.

I. INTRODUCTION

[1]. Considered by many to be the father of modern science, Galileo was the first scientist to conduct experiments on free fall. He emphasized the importance of conducting experiments in a controlled manner and designed many experiments to measure the falling times of different masses of various weights. From these experiments, he realized that the mass of an object does not affect the way it falls.

[2]. A free falling body is any body that moves under the influence of gravity regardless of its initial motion. Free falling objects have an acceleration towards the center of the earth equal to the acceleration due to gravity.There are experimental, analytical and numerical studies made on free fall.

[3]. Dynamic modeling of a robot arm with 5 degrees of freedom has been performed. The modeled arm is a spatial arm with 3 limbs, each with 5 rotational joints and a total of 5 degrees of freedom. For dynamic modelling, equations of motion are derived using Lagrange-Euler equations. These extracted equations are converted into matrix-vector form. In order to see the accuracy of the obtained motion equations, the position graphs of each joint were obtained by allowing the limbs to make free fall motion.

[4]. The memory module of the Flight Data Recorder for use in helicopters was designed and produced. It has been subjected to the necessary tests to comply with international aviation standards. In the design studies, dynamic free fall, static compression and thermal permeability analyzes of the memory module were made numerically with the help of ANSYS R.16.2 Finite Element Program. In the experimental studies, the numerical analyzes made in the computer environment were tested under laboratory conditions. In the dynamic free fall test, an apparatus weighing 227 kg with a steel pin at the bottom was freely dropped onto the memory module from a height of 3 m. As a result, it was concluded that the mechanical and thermal analysis results of the memory module of the Flight Data Recorder, which was designed and manufactured, are compatible with international aviation standards.

[5]. The changes in the displacement and acceleration values of the shear strength-critical reinforced concrete simple beams with the same cross-sectional properties and reinforcement ratio under the effect of two different heights and two different impact masses were investigated. Three reinforced concrete beams with critical shear strength in 25x40 cm cross-section and 250 cm span with the same transverse and longitudinal reinforcement ratio, which were formed under the effect of free fall using different impact energies, were tested under the impact. In the direction of the obtained data, dynamic behavior of crack mechanisms in beams with acceleration-time displacement-time and impact effect was determined. As a result, the effect of different impact mass and impact height on the reinforced concrete beams under the impact of impact on the

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fracture patterns of the reinforced concrete beams and the effect of acceleration values and displacement values are expressed numerically.

[6]. In the studies of Süzen and Kayaalp, a computer-aided measurement system was designed that can be used by students who take physics courses in secondary education institutions and universities in laboratory applications. The free fall time of a steel ball of different sizes dropped from an adjustable height was measured. The transfer of the measured values to the main computer was carried out with the wifi module. In order to test the measurement accuracy of the experimental set, a free fall test was carried out with objects of 6 different heights and 4 different weights. Time was measured in milliseconds for each drop test. The 24 different durations obtained as a result of the experiments were compared with the results obtained from the theoretical calculations. A difference of about 1 millisecond was found in accuracy precision. Compared with the free fall test sets, it was found to be advantageous in terms of multi-measurement wifi and price.

In this study, a free fall mechanism made of steel operating at different heights and masses has been designed. The velocity, potential-kinetic energy and stress states of the system were analyzed by analytical and modeling.

II. MATERIAL METHOD

In this study, simple sum weighting method was used while selecting the material from which the system will be manufactured. The parameters that are important are multiplied by the appropriate coefficient to form the equation for material selection (Table 1).

The choice of steel for this system was deemed appropriate. Because steel is the best choice among other materials in terms of density and price. If a low-density material such as aluminum was used instead of steel, the system would have to be enlarged. This will not be suitable as it will take up more space in terms of volume. The positions of the center of the hollow shaft and the columns were taken into account when determining the heights. Using this, the diameters were determined (Figure 1).

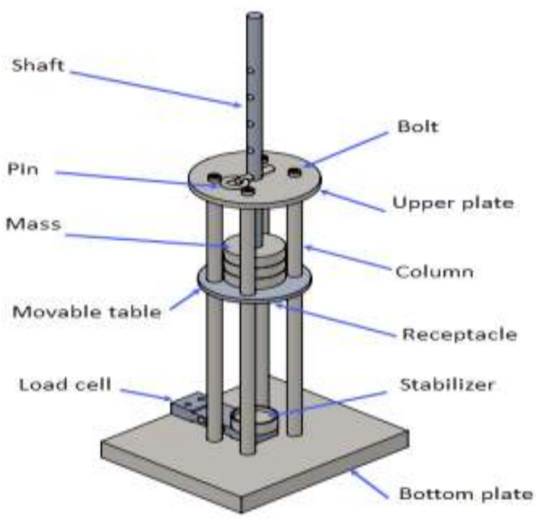

Figure 1. Free Fall Mechanism

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Table 1. Establishment of the Equation Used for Material Selection

	Materials				
	Iron	Copper	Aluminum	Brass	Steel
a=Price (USD/kg)	0.384	8.364	2.228	6.342	0.372
b=Yield strength (MPa)	300	2.58	275	240	360
c=Density (gr/cm^3)	7.25	8.9	2.7	8.5	7.8
	Equation= $\frac{3c+2b}{3a}$				
Results	539.71	21.628	83.50	26.57	666.13

III. RESULTS AND DISCUSSION

The velocity, acceleration, and duration of the motion of the object released to free fall do not depend on the mass of the objects. In this study, in free fall, when the initial velocity is V_0= 0 and air friction is neglected, the height is determined by Equation 1, velocity Equation 2, and force by Equation 3.

Height : $h = \frac{1}{2}gvt^2$(1)

Speed: $V = g \times t$(2)

Force : $F = m \times g$ (3)

Where, g is the acceleration of gravity, t is the time, and m is the mass.The gravitational acceleration of an object in free fall is constant. In this study, it was observed that the force increased in direct proportion to the mass. As the speed increased, the distance also increased. Potential energy E_p is calculated by Equation 4, and kinetic energy E_k is calculated by Equation 5.

$$E_p = mgh \quad (4)$$

$$E_k = \frac{1}{2}mv^2 \quad (5)$$

The speed increases linearly as time increases. The data obtained from the calculations made from Equation 4 are shown in Figure 2.

As the mass and height increased, the potential energy also increased. The variation of the kinetic energy found by analytical calculationsaccording to the mass is shown in Table 2.

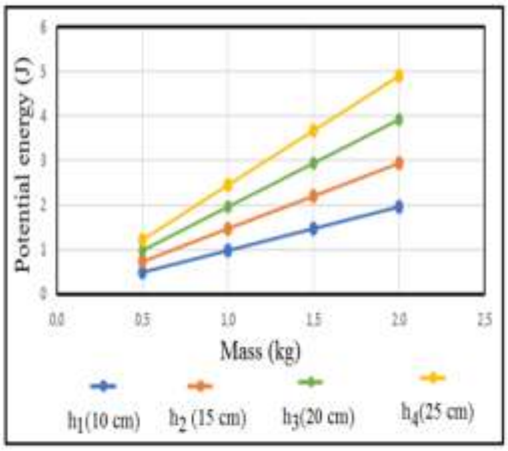

Figure 2. Change of Potential Energy with Mass

In this study, the lowest kinetic energy was determined as 0.49 J at 10 cm at 500 grams. The highest kinetic energy was determined as 4.84 J at 25 cm at 2000 grams. Solid models of the receptacle in the free fall mechanism were drawn and recorded. The recorded data were transferred to the modeling program. The optimum mesh for the receptacle in the free fall mechanism ensures the best accuracy. Force, velocity, acceleration, support values were created. Solid model and material assignment has been made over Explicit dynamics. Then the meshes were created. The velocity calculated for the free fall mechanism and the constant gravitational acceleration were applied to the system in the –y direction. After the iteration and time values were created, the desired solutions were obtained from the program and analyzes were made.

Table 2.Change of Kinetic Energy with Respect to Mass

Height (cm)	Kinetic energy (J)			
	for 500 grams	for 1000 grams	for 1500 grams	for 2000 grams
10	0.49	0.98	1.47	1.96
15	0.72	1.44	2.16	2.89
20	0.97	1.94	2.91	3.88
25	1.21	2.42	3.63	4.84

In this study, the lowest kinetic energy was determined as 0.49 J at 10 cm at 500 grams. The highest kinetic energy was determined as 4.84 J at 25 cm at 2000 grams. Solid models of the receptacle in the free fall mechanism were drawn and recorded. The recorded data were transferred to the modeling program. The optimum mesh for the receptacle in the free fall mechanism ensures the best accuracy. Force, velocity, acceleration, support values were created. Solid model and material assignment has been made over Explicit dynamics. Then the meshes were created. The velocity calculated for the free fall mechanism and the constant gravitational acceleration were applied to the system in the –y direction. After the iteration and time values were created, the desired solutions were obtained from the program and analyzes were made.

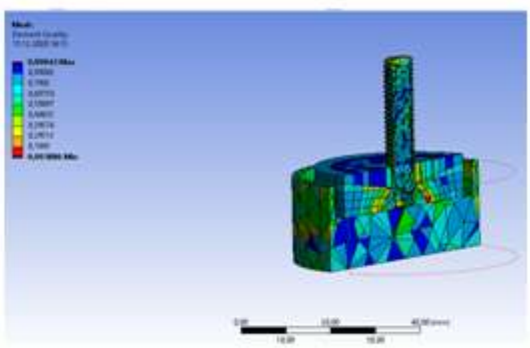

Figure 3. Meshes of the Top Plate and Columns

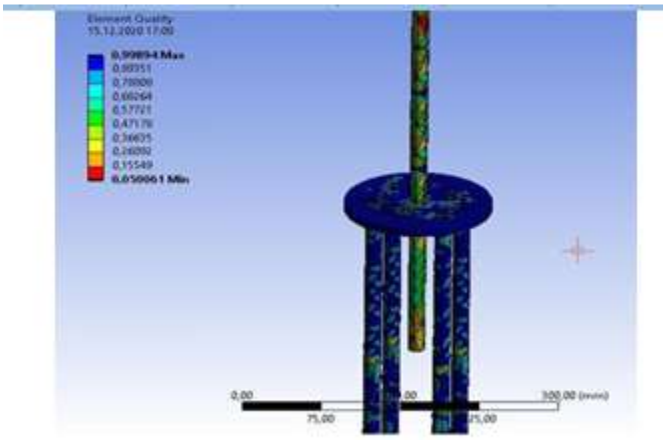

Figure 4. Meshes of and the Receptacle and the Stabilizer

In Figures 3 and 4, the meshes increases from red to blue. Mesh quality is very important for the accuracy of the analysis. In Figure 5, the changes in potential energy for 10, 15, 20, 25 cm heights are shown.

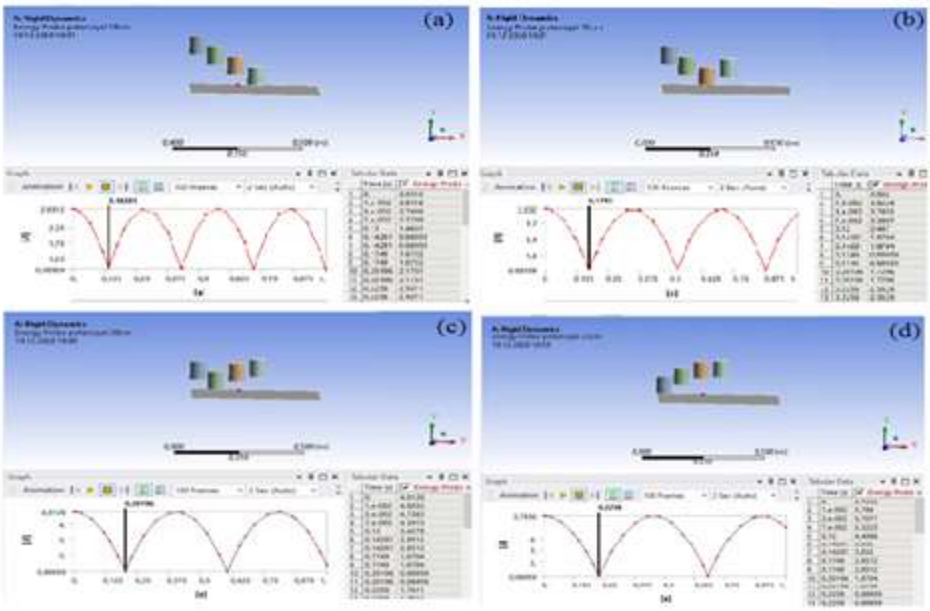

Figure 5. Change of Potential Energy with Height

a) 10 cm, b) 15 cm, c) 20 cm, d) 25 cm

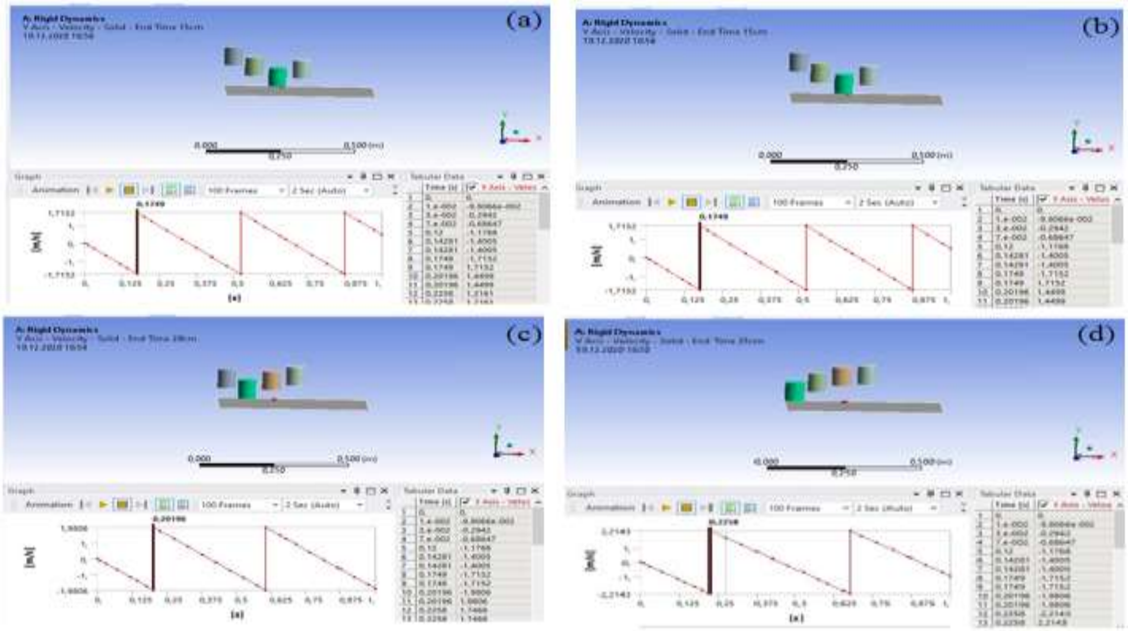

Figure 6. Change of Velocity with Height
a) 10 cm, b) 15 cm, c) 20 cm, d) 25 cm

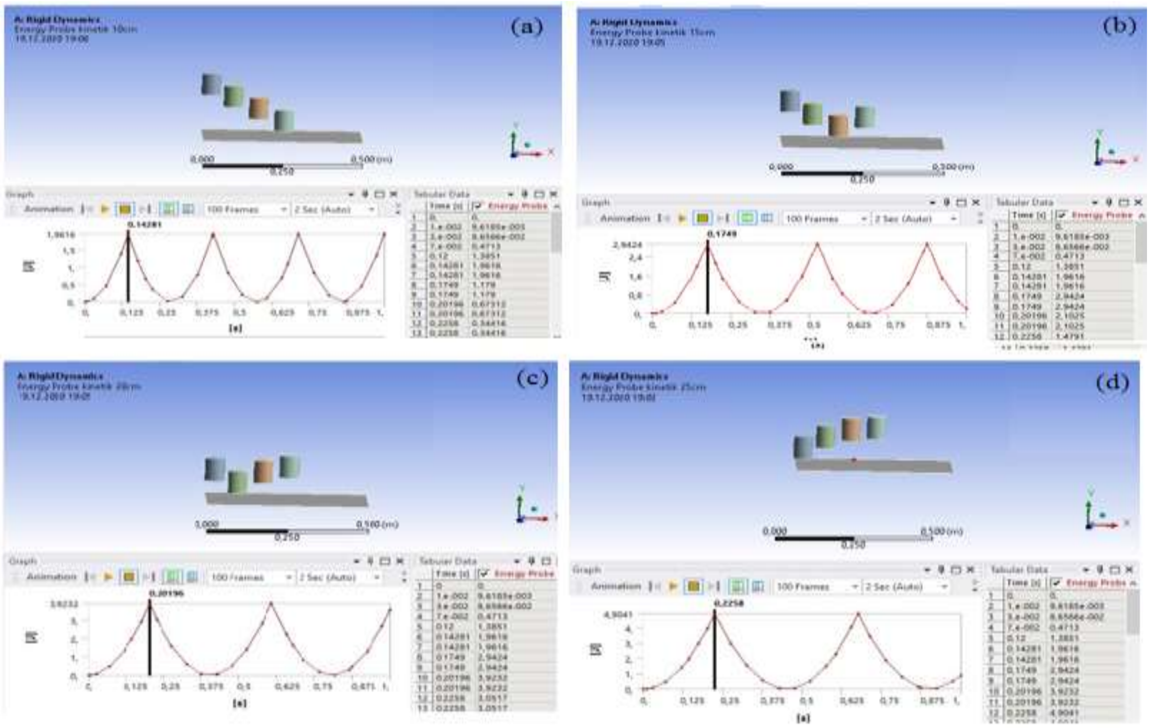

Figure 7. Change of kinetic energy with height
a)10 cm, b) 15 cm, c) 20 cm, d) 25 cm

The difference between the maximum potential energy and the minimum potential energy is shown in Figure 5. In this study, when the potential energy determined by modeling and analytical calculations was compared, it was seen that they were compatible with each other. In Figure 6, velocity analyzes for 10, 15, 20, 25 cm height are presented. In Figure 7, in kinetic energy changes is shown for 10, 15, 20, 25 cm height. When Figure 5 and Figure 7 are examined, it is seen that while the potential energy decreases, the kinetic energy increases. In this case, it obeys the law of conservation of energy. In Figure 8, the force applied to the chamber formed as a result of modeling and the amount of deformation realized in the chamber and the receptacle in Figure 9 are presented.

Figure 8. Force Applied to the Stabilizer

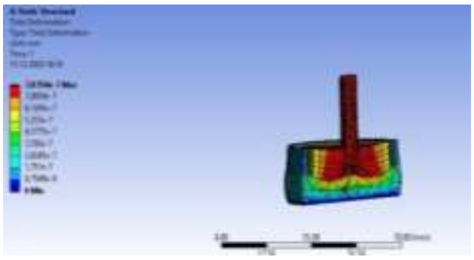

Figure 9. Deformation in the Receptacle and the Stabilizer

In this study, the maximum deformation is $7.879*10^{-7}$ mm. This is an acceptable value for the system. The Von-Mises stress is presented in Figure 10.

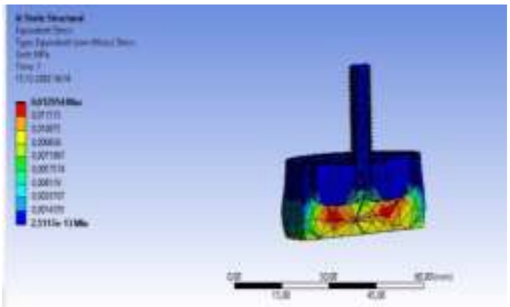

Figure 10. Von-Mises stress of the Receptacle and the stabilizer

In this study, the maximum deformation is 0.00016 mm. The maximum value of the Von-Mises stress is much smaller than the yield strength of the material. This result shows that the system is safe. The slenderness ratio (λ) depends on the characteristic length L_k of the rod and the radius of inertia i. λ is calculated by Equation 6.

$$\lambda = \frac{L_k}{i} \quad (6)$$

The radius of inertia, shown as "i" in Equation 6, was calculated by Equation 7. The moment of inertia denoted by "I" in Equation 7 is the lowest moment of inertia in the section. "A" indicates the cross-sectional area.

$i = \sqrt{\frac{I}{A}}$ (7)

The maximum force is F = 20 N and there are 4 columns. It is 5 N applied to a column. The critical buckling force is calculated by F_{cr} Equation 8.

$$F_{cr} = \pi^2 \frac{EA}{\lambda^2} \text{ or } F_{cr} = \pi^2 \frac{EI}{L_k^2} \quad (8)$$

E is the modulus of elasticity of the material in Equation 8.

F_{cr} = 111601 N

Since $F_{cr} >> F$, there will be no buckling in the columns.

IV.CONCLUSION

In this study, a free fall mechanism made of steel operating at different heights and masses has been designed. Analytical and modeling and energy and mechanical analyzes of this system were carried out. If the system is made of different materials, it is concluded that the dimensions of the system increase or decrease. It was observed that as the height increased, the speed increased accordingly. It has been determined that the maximum speed is reached when the system is left to free fall from the maximum height. It has been observed that force increases with mass, potential energy increases with mass and height, and kinetic energy increases with mass and speed. It has been observed that while the potential energy for the system released from the conservation of energy decreases overtime, the kinetic energy increases. When the system was checked with both modeling and analytical calculations, the system was found to be safe.

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