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DESIGN AND MANUFACTURING OF SHAKING TABLE FROM SCRAP/USED PARTS

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ABSTRACT

Structures are exposed to different loadings throughout their lifespan. One of these loadings is the vibration loading caused by earthquakes. Examining the effects of these loading conditions on structures is very important in terms of structural safety. Examining the vibration characteristics of structures using a shaking table is frequently preferred. It has been determined from the literature review that shaking tables can be designed and used as one, two or three axes. However, no study has been found that produces one axes shaking tables using scrap/used parts. Therefore, in the study, a low-budget and environmentally friendly shaking table was designed and produced using scrap/used parts.

Keywords: Earthquake, Shaking table, Scrap/used parts.

1 INTRODUCTION

Earthquakes are sudden vibrations caused by fractures in the earth's crust, and the main reasons for past structural fractures have usually been engineering defects or inadequate inspection. In order to reduce earthquake risk, it is of great importance to determine the earthquake resistance of building materials and subunits in advance [1].

Due to their dynamic nature, earthquakes are generally the greatest threat that structures face throughout their service life. This dynamic force can affect the structure in many different ways. It would be correct to evaluate characteristic parameters such as the height, geometry and load-bearing system of the structure and the effects of the earthquake together. Carrying out the structural design by considering these dynamic threats plays an important role in ensuring that the structure meets the expected service standard [2].

Shaking tables are one of the methods used to investigate the effects of dynamic earthquake loads on structures. Therefore, when the boundary conditions are correctly adapted in shaking tables, important information can be obtained about the behavior of structures during earthquakes. Additionally, full-scale structures can be tested on this table [2,3,4].

In the literature review, a limited number of studies on shaking table design and manufacturing were found. When these studies are examined; Durgun et al. (2013) [5], examined the dynamic characteristic changes of the structure by applying forces at different frequencies to the structure and recording free vibrations. Birdal et al. (2015) [6], performed dynamic experiments using a 1/3 scaled reinforced concrete model of a prototype structure. As a result of the experiment, they determined that the damage to the structure generally occurred at the nodes due to the shear effect. Bayhan et al. (2013) [7], present the numerical analysis results of the shaking table experiments conducted in the "blind guess" competition at the 15th World Conference on Earthquake Engineering. It was stated that the analytical results successfully followed the displacement motion measured in consecutive experiments, but there was a 20-35% error margin in high-intensity experiments. Ağcakoca (2019) [8], tested a scaled 30 floor shear wall building model on the shaking table in order to examine the behavior of the structure under earthquake load. The finite element analysis results of the structure were compared with the experimental results and it was determined that the finite element model provided a sufficient approach for the examined structure. Şahin et al. (2017) [4], carried out vibration tests on the shaking table on a scale model of a real 6 floor reinforced concrete structure in order to determine the seismic capacity of the structures. Künkcü et al. (2023) [9], applied Multi-Criteria Decision Making methods for the selection of the shaking table test model. The ranking results of the applied methods were compared and it was shown that these methods are frequently used in similar studies in the literature. Kan et al. (2025) [10], conducted a review study on the adjustment of the scale and seismic vibration wave input that should be taken into consideration when using the shaking table in testing samples. Çelik et al. (2013) [11], introduced the low-cost unidirectional shaking table with electric motor, designed and manufactured at Pamukkale University. They stated that they obtained acceleration values up to 600 cm/s^2 and speed values up to 30 cm/s with the shaking table. Tayfur et al. (2020) [2], developed a two-axis shaking table as an alternative to existing high-cost shaking tables within the scope of the study. They determined that the produced device can simulate the desired earthquake data with 0.05 mm precision. Torun et al. (2009) [3], designed and manufactured a two-axis shaking table that can visually produce the L-wave oscillation motion in order to experimentally examine the dynamic behavior of structures under the effect of earthquakes.

As a result of the literature review, it was seen that the majority of the studies on the shaking table were used for testing the samples. However, it was determined that a small number of studies were on the design and manufacturing of the shaking table. In addition, no study was found on the design and production of shaking tables using scrap or used parts. For this reason, scrap/ used parts were used in the study for the design and production of the shaking table. Considering the scrap/used parts provided, the mechanical design was first created in a computer environment with solid modeling. The dynamic examination of the most optimum mechanical design was carried out and its suitability for application was checked. The production and assembly of the parts belonging to the clarified mechanical design were carried out. The electrical infrastructure was created for the movement of the table in the mechanical design according to the earthquake vibration data. The final shaking table obtained was examined dynamically and its suitability was determined. As a result of the study, a low-cost single axis shaking table was designed and produced using scrap/used parts and a different perspective was presented to the literature. In addition, the study has originality because there is no environmentally friendly shaking table obtained by using scrap/used parts in the literature.

2 MATERIAL AND METHODS

2.1 Material

2.1.1 Parts Used in the Design

- Main chassis: A main chassis consisting of L-shaped profiles (50x50x6 mm^3) obtained from scrap was used in the design and manufacturing of the shaking table. As the scrap main chassis was already durable and rigid, it was directly employed in the design without modifications (Figure 1). The cost of creating a main chassis from scratch was eliminated with the scrap main chassis used.

Figure 1. Scrap main chassis

-Table: Since the shaking table used was supplied together with the main chassis obtained from scrap, it was used directly in the table design. Since the used table was suitable for the designed shaking table sample dimensions, it was used directly without any extra processing (Figure 2). The dimensions of the table used are 500x500x6 mm^3.

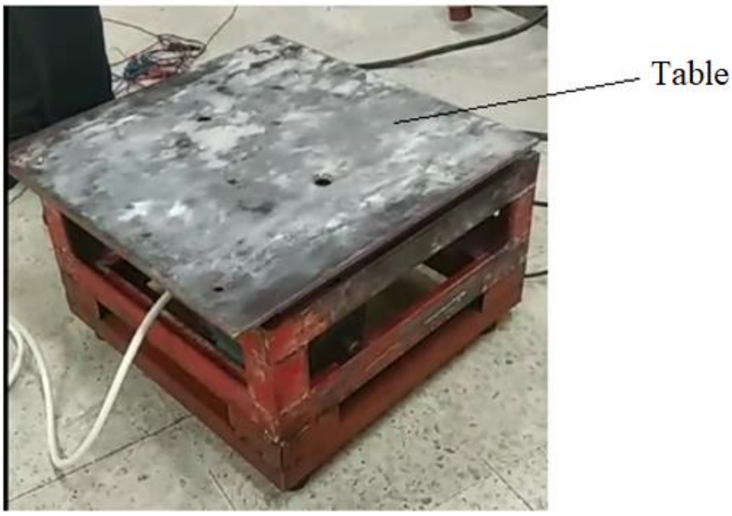

Figure 2. Scrap table

- Induction motor: The induction motor is the most widely used type of electric motor in industry, powered by alternating current (AC). It is called "asynchronous" (non-synchronous) because its main characteristic is that the rotor speed lags behind the rotating speed of the stator field. The basic principle of operation of asynchronous motors is based on electromagnetic induction [12]. It was ensured that the induction motor used was powerful enough to move the table with the sample on it. For this reason, a 1.5 kW induction motor was preferred (Figure 3). The motor was also supplied from a scrap dealer. The deficiencies on the motor were completed and used in the design.

Figure 3. Induction motor obtained from scrap

- Sled: In order to reduce the cost in the shaking table design, a vehicle seat sled suitable for the working conditions was used. While custom-made or ready-made sleds could normally be used for the design, they were not used in this design. A used vehicle seat sled was obtained and incorporated into the design (Figure 4). In addition, the suitability of the used sled for the sample load to be carried (Maximum load 100 kg) was determined by considering the working conditions in the normal vehicle. The design cost was reduced in this part with the used ready-made sled.

Figure 4. Vehicle seat sled preferred in design

- Variable frequency drive: Variable frequency drive, also known as variable speed drive, is an electronic device used to control the rotational speed and torque of alternating current motors by varying the frequency and voltage of the supplied power [13]. A variable frequency drive (VFD) converts a constant frequency alternating current supply into direct current using a rectifier, then uses power electronic switches to produce an alternating current output with adjustable frequency and voltage [14]. By controlling the frequency, the motor speed is precisely regulated, which is not possible with direct grid connection [15]. Used in many applications, VFDs are also important for soft-start motors, reducing inrush currents and shocks [16]. In the study, a variable frequency drive was used to change the speed of the electric motor rotating at a fixed speed (Figure 5). In this way, the linear movement of the table was obtained at the desired speed.

Figure 5. Used variable frequency drive

- Tie rod: An arm and a disc were used in the design to convert the circular motion coming out of the motor into the linear motion of the table. A vehicle tie rod with a circular profile of sufficient strength was used in the design to move the loaded table linearly (Figure 6). Since the tie rod used has sufficient strength considering where it is used in the vehicle, it was interpreted that it would not cause any problems in terms of strength in the design. In addition, the preferred cantilever tie rod piece was used for the shaking table because its shape and dimensions were suitable.

Figure 6. Tie rod removed from the vehicle

- Tie rod and main chassis connection rod: This part is a part obtained by welding scrap parts (Figure 7). With this part, the tie rod and main chassis connection is provided and the circular motion of the motor is converted to linear and transferred by the mechanism.

Figure 7. Tie rod and main chassis connecting rod

- Square profiles: Extra square profiles were added under the main chassis to create a more aesthetic design by placing the engine and mechanisms inside the main chassis used. The height of the design was increased by 80 mm with the new profiles added. Scrap square profiles of 40x40x2 mm^3 were used for ground elevation (Figure 8).

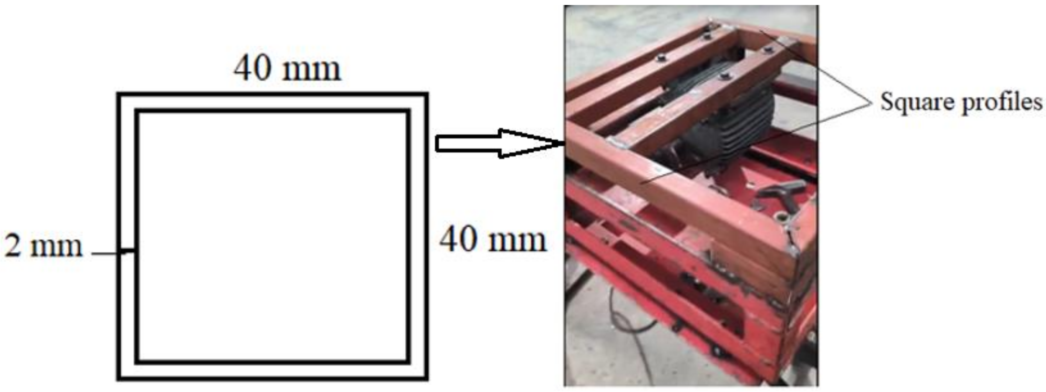

Figure 8. Square profiles

- Disk at the motor end: A 95 mm diameter and 10 mm thick disk was used to convert the circular motion coming out of the motor into linear motion and was mounted to the motor end with a wedge channel in the mechanism (Figure 9). The motor motion was transferred to the table by moving the arm with the disk used. The design cost and recycling were contributed by providing the circular disk used from scrap.

Figure 9. Scrap disc used and its assembled form

2.2 Method

2.1.1 Shaking Table Design

For the design of the shaking table, preliminary work was carried out using solid modelling in a computer environment, taking into account the parts obtained from scrap/used. The shaking table was solid modelled by taking into account the dimensions and geometries of the parts used (Figure 10).

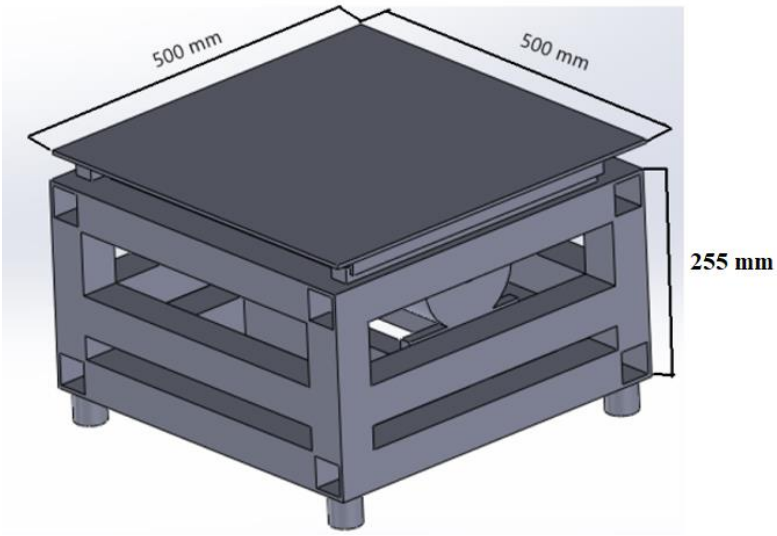

Figure 10. Solid modeled shaking table design

The linear movement limit of the table (±25 mm) was determined. In order to obtain the determined linear movement, the mechanism frequently preferred in the literature [3] was used to convert the circular movement coming from the electric motor into linear movement in Figure 10. In the mechanism used, the circular movement obtained from the motor was converted to linear by a wedge on the motor shaft and a disc and jointed arm welded from a point (to limit the axial movement on the shaft) (Figure 11).

Figure 11. Mechanism used to convert circular motion into linear motion

2.2.2 Shaking Table Manufacturing, Assembly and Painting

The scrap/used parts provided were revised in order to make them suitable for use in the design at the first stage. The drilling operations in Figure 12 were performed for the assembly of the sled to be used on the main chassis. The vehicle seat sled used was divided into two and revised for assembly on the main chassis. The locking mechanism on the seat sled was cancelled and the sled was easily used on the shaking table. The tie rod was adjusted to be suitable for assembly. The connection pole to which the tie rod would be mounted was formed by welding the scrap parts to the main chassis. The strength of the structure was increased by placing triangular supports on the edges of the connection pole (Figure 12). Since there was not enough volume under the main chassis for the engine and movement mechanisms, an addition was made by welding scrap square profiles underneath. Afterwards, the electric motor was mounted on the added square profiles with bolts. The table used on the shaking table was mounted on the sled without any revision process by welding (bolt) connections (Figure 12).

Table 1. Joining methods between parts used in the design

Parts	Joining method
Main chassis-additional profiles	Welded joint
Main chassis-sled	Mechanical (Bolt) joint
Sled-table	Welded joint
Electric motor-Main chassis	Mechanical (Bolt) joint
Electric motor-disc	Wedge and welded joint
Disc-arm (Tie rod)	Mechanical (Pin) joint

According to the obtained data, the parts used in the design were combined. The methods of combining the parts are presented in Table 1. As a result of combining the parts, the mechanical processes of the shaking table were completed. The shaking table parts, whose mechanical processes were completed, were cleaned by grinding (Figure 12). The cleaned shaking table parts were painted in anthracite color with spray paint as seen in Figure 12.

Figure 12. Revision stages, assembly and painting of shaking table

2.2.3 Shaking Table Electrical Installation

In the mechanically designed shaking table, the linear movement of the table was provided by the 1.5 kW electric motor (Figure 13). A variable frequency drive was used to adjust the table speed. Thanks to the inverter and electric motor used, the table could be moved at the desired speed and dynamic examination of the samples on the table could be performed.

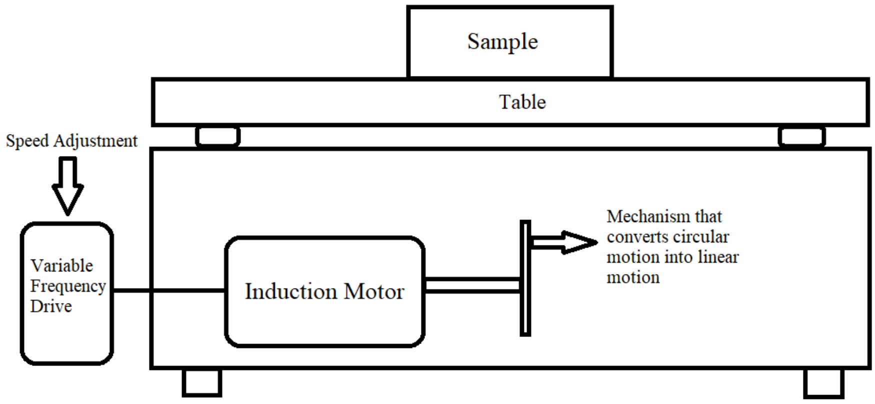

Figure 13. Electrical installation used in shaking table design

In the study, it was assumed that the table had a fixed single axis speed during operation. Therefore, the table speed could be adjusted to the desired fixed speed by adjusting the frequency of the speed variable frequency drive obtained from the motor. Within the scope of the study, the speed adjustment equations for the inverter system were also presented between Equations 1-6. With the help of the presented equations, the table could be adjusted to the desired speed by adjusting the frequency in the variable frequency drive.

Stator and rotor voltage equations study the electrical behavior of stator and rotor circuits. They are usually written in a rotating reference frame [17,18].

$$V_s = R_s I_s + \frac{d\psi_s}{dt} \tag{1}$$

$$0 = R_r I_r + \frac{d\psi_r}{dt} + j\omega_r \psi_r \tag{2}$$

In this equation, V_s is the stator voltage, I_s and I_r are the stator and rotor currents, R_s and R_r are the stator and rotor resistances, ψ_s and ψ_r are the stator and rotor magnetic fluxes, and ω_r is the rotor angular speed [17,18].

Magnetic flux equations determine the relationship between stator and rotor currents and magnetic fluxes [17,18].

$$\psi_s = L_s I_s + L_m I_r \tag{3}$$

$$\psi_r = L_m I_s + L_r I_r \tag{4}$$

In this equation; L_s, L_r are the stator and rotor inductances and L_m is the mutual inductance [17,18].

The mechanical equation of motion relates the angular velocity change of the rotor to the electromagnetic torque T_e, the load torque T_L and the frictional effect. J is the inertial moment and B is the coefficient of friction [17,18].

$$J\frac{d\omega_r}{dt} = T_e - T_L - B\omega_r \tag{5}$$

Slip (s) is defined as the ratio of the difference between the synchronous speed ω_s and the rotor speed ω_r [17,18].

$$s = \frac{\omega_s - \omega_r}{\omega_s} \tag{6}$$

3 RESULTS AND DISCUSSION

3.1 Review Of Shaking Table Design

The majority of the shaking table seen in Figure 14 is made of scrap/used parts. With the design in Figure 14 where the scrap/used parts used can work in harmony, a shaking table with a size of 500x500 mm^2 and a maximum sample carrying capacity of 100 kg was obtained. In the obtained design, the outcome was an environmentally friendly and low-cost design by revising and reusing the scrap/used parts. All parts of the obtained design were painted in anthracite color at the final stage. In addition, yellow lines were added to the table and the mechanism at the end of the motor was painted in yellow to provide visuality.

Figure 14. Final painted version of the shaking table

3.2 Dynamic Investigation of Shaking Table

The shaking table is designed with a ±25 mm linear working limit. Figure 15b shows the zero position of the design. Figure 15a shows the -25 mm movement limit of the table. Figure 15c shows the +25 mm movement limit of the table.

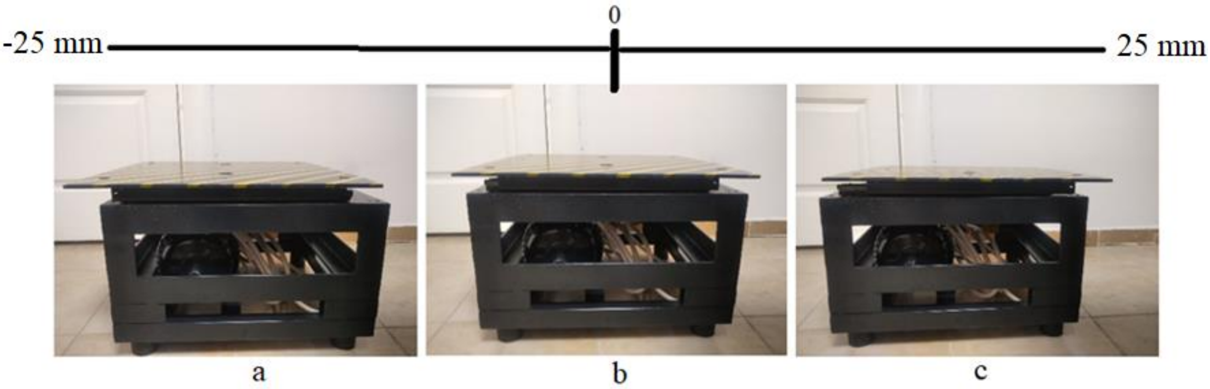

Figure 15. Linear movement limits of the shaking table

The table displacement/disc rotation angle graph is presented in Figure 16. When Figure 16 is examined, it is determined that dynamic examination of the samples can be performed by moving the table between +25 and -25 mm.

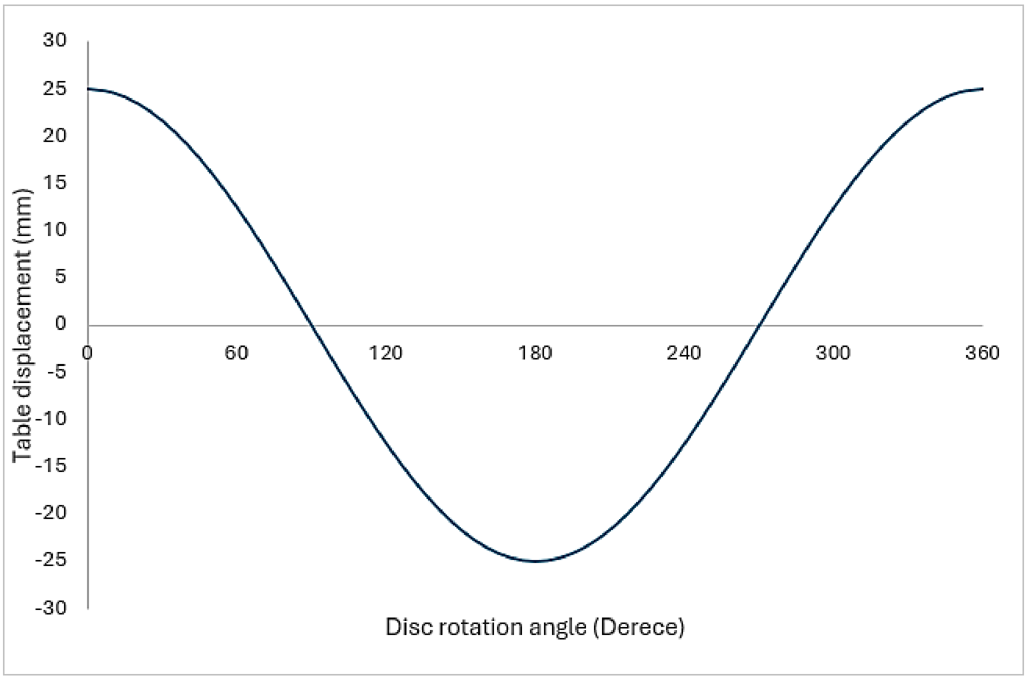

Figure 16. Table displacement/disc rotation angle graph

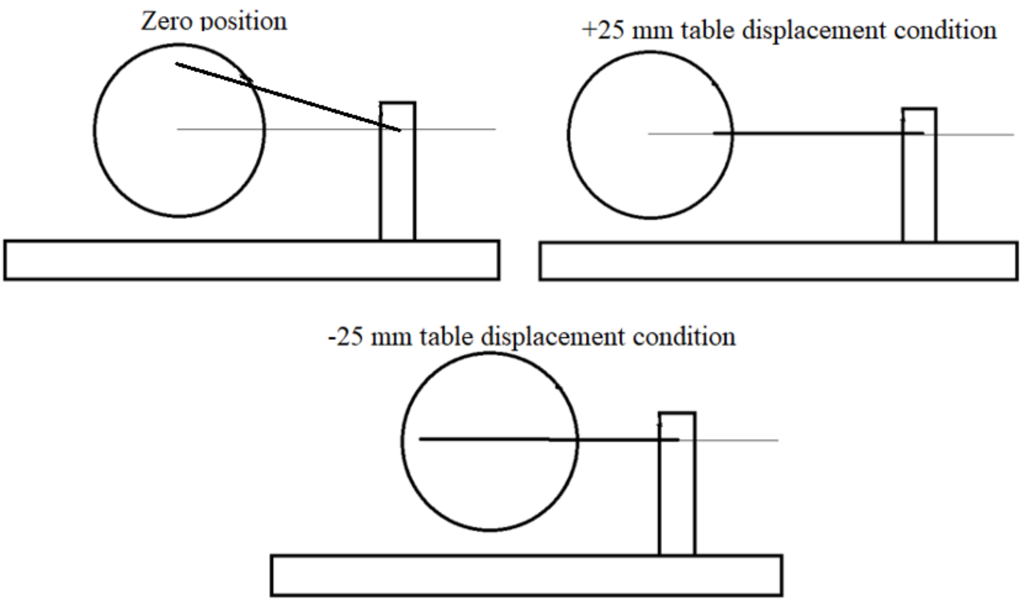

Figure 17. Mechanism shape according to table position

The mechanism shapes at the maximum, minimum and zero positions of the table are presented in Figure 17. In order to determine the table speed during the movement of the mechanism, the visual for the dynamic examination in Figure 18 was prepared and the motion equation in Equation 7 was created. With Equation 7, the speeds of the tie rod and table can be found by placing the motor speed at the desired disk angle into the equation. Simplifying assumptions were used in the derivation of Equation 7. The assumptions used are;

• Because the mechanism used has two axes of motion, the third axis is not included in the equation.

• Due to the sufficient lubrication of the moving parts in the mechanism, the effect of friction is considered to be minimal, so it is neglected.

• Due to the low inertial resistance of the disc and arm used, the table's inertia effects on the velocity equation are considered to be minimal, so the inertia effects of the parts are neglected.

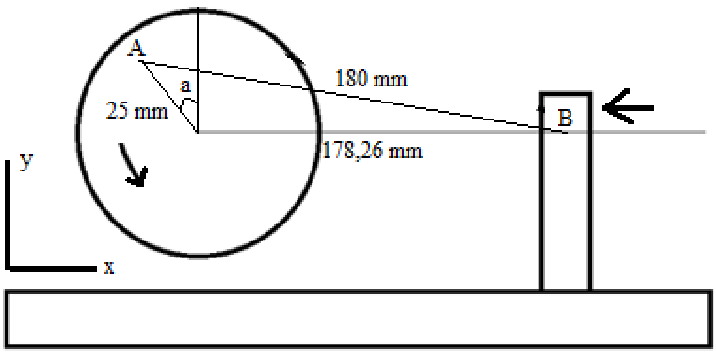

Figure 18. Dynamic motion equations of the table

$$-V_B = W_d k(-25cos(a)i + 25sin(a)j) + W_{tr} k((178{,}26 + 2525cos(a))i - 25sin(a)j) \quad (7)$$

3.3 Cost Analysis of Shaking Table

Table 2 presents the manufacturing costs and comparison of the shaking table from scrap material and new parts. While making cost analysis as a new part, raw material and processing costs were taken into consideration for a part that needs to be processed (Main chassis, Table, Connecting rod, Connecting rod and main chassis connection pole, Disc at motor end). If there is no need for any processing for the part used in production (Electric motor, Inverter, Sled, Square profiles), the procurement cost was used.

For the shaking table, mostly scrap/used parts were used to contribute to recycling. By evaluating the scrap/used parts for redesign, both a contribution to nature was made through recycling and a low-cost design was obtained. Table 2 presents the cost of the design obtained from scrap/used parts and the cost schedule of the design obtained from zero parts.

As a result of the study, a shaking table with a very low cost compared to its peers in the literature [2,3] and an environmentally friendly shaking table was obtained. According to the data obtained, it was determined that 85.15% savings were achieved in the design by using mostly scrap/used parts.

Table 2. Cost comparison of design for scrap/used and new part usage cases

	Cost analysis in case of using scrap/used parts (TL)	**Cost analysis in case of using new parts (TL)**
Main chassis	1000	15000
Table	500	5000
Electric motor	1000	7000
Sled	250	5000
Inverter	4000	4000
Connecting rod	50	2000
Connecting rod and main chassis connection pole	400	3000
Square profiles	500	3000
Disc at motor end	250	3000
Assembly cost	1000	10000
Painting and grinding	1000	10000
Total cost	9950	67000

4 CONCLUSION

In the study, scrap/used parts were revised again and used in the shaking table design. In the design phase, solid modeling study was carried out by considering the geometry and dimensions of the scrap/used parts. The manufacturing phase of the design determined with solid modeling was started. The scrap/used parts were revised as determined and the parts were assembled. After the mechanical processes were completed, the electrical processes were carried out and the movement of the table was provided. When the data obtained as a result of the study was examined;

• Dynamic examination confirmed that the shaking table design using scrap/used parts was suitable.

• It was determined that the table had a movement limit of 25 mm.

• The maximum safe sample carrying capacity was 100 kg was determined.

• The shaking table can be moved at the desired speed with the variable frequency drive used.

• It was ensured that the table speed could be obtained with the dynamic motion equation of the table depending on the motor speed and the angular position of the disk.

• 85.15% cost savings were achieved with the use of scrap/used parts compared to the design using new parts.

• It has been determined that recycling of scrap/used parts contributes to nature.

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Conflict of Interest Statement

There is no conflict of interest between the authors.

Statement of Research and Publication Ethics

The study is complied with research and publication ethics.

Artificial Intelligence (AI) Contribution Statement

This manuscript was entirely written, edited, analyzed, and prepared without the assistance of any artificial intelligence (AI) tools. All content, including text, data analysis, and figures, was solely generated by the authors.

Contributions of the Authors

Conceptualization E.K., M.Ş.Y. and C.A.; methodology E.K., M.Ş.Y. and C.A.; investigation E.K. and M.Ş.Y.; writing—original draft preparation E.K., M.Ş.Y. and C.A.; All authors have read and agreed to the published version of the manuscript.

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