

The Development of Earthquake Simulator

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Abstract

An earthquake is an event that vibrates or shakes the earth due to the sudden movement or shift of rock layers on the earth's crust due to the movement of tectonic plates. Earthquakes that occur cause damage to buildings and loss of life and can trigger other natural disasters such as tsunamis and even liquefaction. To anticipate this, it is necessary to study the structure of the building and tools to test the strength of the building, so that it becomes an effective tool and is needed to anticipate the occurrence of large losses. The earthquake simulator was built in the form of a shaking table driven by a hydraulic actuator. The earthquake simulator is equipped with a proximity sensor to determine the cylinder motion distance which is controlled using proportional and integral using the Arduino Mega2560 controller. The results showed that the shaking table can work ideally with a value of $P(kc) = 0.066195$ and a value of $I(ki) = 2.009974$ which can produce acceleration data in actual (real-time) which is displayed in graphical form on the LabVIEW front panel.

Keywords: Arduino; earthquake, electro-hydraulic; simulator

1. Introduction

An earthquake is an event that occurs due to the movement and collision of rock layers on the earth's crust or tectonic plates. These collisions or shifts produce energy that propagates to the earth's surface as seismic waves [1]. Earthquakes can be caused by several factors such as volcanic eruptions, shifting of the earth's plates, and dynamite explosions [2].

Earthquakes for the territory of Indonesia are one of the sources of natural disasters that often appear. The Meteorology, Climatology, and Geophysics Agency (BMKG) recorded 18 significant earthquakes in Indonesia in 2018. Significant earthquakes are earthquakes with a magnitude of $M \geq 6$ and earthquakes that cause damage even though the magnitude of the earthquake is $M \leq 6$. One of the significant earthquakes recorded was an earthquake that occurred in Central Sulawesi with a magnitude of 7.4 on the Richter Scale which caused a tsunami and liquefaction [3]. This certainly makes earthquakes one of the concerns in the field of research.

In this case, theory, practice, and application are needed so that they need to be supported by practical means to improve learning that is good and can be understood easily and can be practiced directly. Through the learning model, the help of simulation tools will make it easier to find out building structures that are resistant to earthquake loads.

Earthquakes are catastrophic and widespread natural disasters, causing damage and causing casualties [4]. In addition, earthquakes can also trigger other natural disasters, such as tsunamis and liquefaction, which have a very large loss impact [5]. Therefore, every building must be designed so that it can withstand earthquakes that can cause a collapse as a form of anticipation [6].

Anticipation of countermeasures or prevention of victims from disasters makes earthquake test equipment a necessary and effective tool. This tool is indispensable for earthquake-prone areas and areas where earthquakes rarely occur.

Earthquake simulator tool is an experimental method that has an important role in conducting experimental earthquake simulations as well as for evaluating structural performance in earthquake engineering. Earthquake simulator systems provide an effective way of subjecting structural components, substructures, or the entire structural system to dynamic excitation, which is like earthquake induction. In general, an earthquake simulator system consists of mechanical, hydraulic, and electronic components (controllers and sensors) [7].

The earthquake simulator system is given parameters to represent the actual earthquake. The earthquake wave vibration parameters recorded by the seismograph are velocity (cm/s), deviation in units (μm), and deviation (gal or cm/s^2). One of the important things in seismological research is knowing the damage caused by earthquakes, where the source of damage is expressed in-ground acceleration so that Peak Ground Acceleration (PGA) due

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to earthquake vibrations is important to describe the level of risk [8].

Parameter testing is generally modeled in two categories, namely testing under earth acceleration (test with a vibrating table) and testing under conditions above earth acceleration (centrifuge test). In testing the shaking table can be conditioned to different amplitude conditions, one direction or many directions and it is easy to make experimental observations. The shaking table tool works by using the power that comes from the driving motor, which is then converted into a horizontal movement [9].

The shaking table earthquake simulator has an important role in earthquake engineering. This is because the shaking table is the only experimental device that can mimic the nature of an earthquake. The principle is a test plate/table which is driven by an actuator to produce ground acceleration replication [10]. With the earthquake simulator capabilities, it can be used to analyze the influence of earthquake strength on buildings and help develop about the influence of earthquake strength.

Based on these problems, the purpose of this research is to design and build a simulator that can represent earthquakes.

2. Research Method

2.1. Earthquake simulator (shaking table)

An earthquake simulator is a tool used to replicate or create an acceleration that resembles an earthquake. The acceleration is generated from the actuator which is driven by a controller that gives a command to the valve to reach a certain position so that the platform will follow the target movement that has been determined [11]. Figure 1 is an example of an earthquake simulator.

Figure 1 shows an earthquake simulator that resembles a table commonly called a shaking table. Earthquake simulators are grouped according to their actuator power, frequency range, and the maximum load they can handle. However, it is usually classified within small scale with a load of 0 to 1000 kg, medium scale ranges from 1000 to 5000 kg, and large-scale ranges more than 5000 kg [12].

Earthquake simulator testing is carried out by placing the test object on a table-mounted with binders or compacted artificial soil. The test object will undergo a shaking process at a certain frequency value and time limit.

In this research, an earthquake simulator tool in the form of a shaking table was built using st-37 material. However, in this study, the use of material types and the calculation of material loading were not considered.

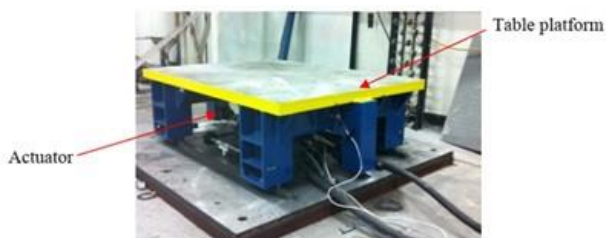


Figure 1. Earthquake simulator



Figure 2. Arduino Mega2560 [13]

2.2. Microcontroller

The Microcontroller is a device that functions as an input and output controller on an earthquake simulator. The microcontroller has pins for external connection of input and output, power, time, and control signals. The pins for input and output are grouped in units called input/output ports [14].

In this study, Arduino Mega2560 was used to control the movement of the hydraulic actuator by adjusting the valve opening and closing [15]. Arduino mega2560 is shown in Fig. 2. In this figure, a total of 54 digital pins and 16 analog pins, the Arduino mega2560 is a versatile, inexpensive, and easy to use option. In addition to being open-source, Arduino also has other advantages compared to other microcontroller boards, namely Arduino has its own programming language in the form of C language. Besides that, the Arduino board already has a USB loader, making it easier for us when programming the Arduino microcontroller.

2.3. Actuator

An actuator is an element of a mechatronic system that receives a command from a control (in the form of a power supply) and produces changes in the physical system by generating force, motion, flow, etc. [16]. Figure 3 shows a typical actuator unit.

In this research, an actuator or hydraulic drive is used. The hydraulic system functions as a power transfer system or as a control system. Hydraulic actuators are widely applied to large power requirements. So in this study, a hydraulic actuator was used. In Nakata's study, hydraulics were used as actuators for earthquake simulators [17].

2.4. Accelerometer

An accelerometer is an instrument used to measure acceleration, detect, and measure vibration, or measure acceleration due to Earth's gravity. This study used the ADXL345 accelerometer. The ADXL345 is a three-axis accelerometer with high-resolution specifications (13 bits), and measurements up to $\pm 16g$. This tool will take the acceleration data and then forward it to the microcontroller (Arduino mega2560). The form of the ADXL345 sensor can be seen in Fig. 4.

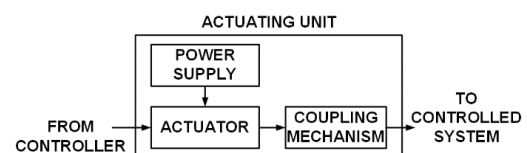


Figure 3. Actuating unit

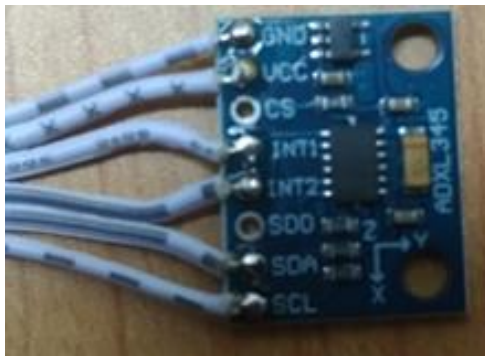


Figure 4. ADXL345

In addition, the adxl345 accelerometer sensor can also be used to measure the frequency of a system [18].

2.5. LabVIEW

LabVIEW is software that is used to process and visualize data, control and instrumentation, and automation. LabVIEW stands for Laboratory Virtual Instrument Engineering Workbench [19]. LabVIEW can perform real-time data acquisition and display the results in graphical form [20].

This study uses LabVIEW to control the output, acquire input from the sensor, and regulate the work of the system to the Arduino Mega2560.

2.6. Stages of research

The preliminary study includes a literature study that is collecting information, theory, and literature that can assist in the process of making the system. The literature sought is related to earthquake information, the working system of earthquake simulators, testing methods for simulators, measuring instruments, controllers, and propulsion devices.

The design stage includes the design of hardware and software. The hardware design includes the manufacture of mechanical shaking tables and electronic circuits. While the software is making the system work and making an earthquake simulator control program.

The testing phase includes giving the program to the tool that has been made to see the response of the system in the form of step units, sinusoidal waves, and can generate acceleration data. The results of the design of the tool, it is expected to be able to provide solutions to problems and meet or adjust the needs of the users of the tool [21].

Figure 5 is the shaking table simulator design and a block diagram of the working system of the tool.

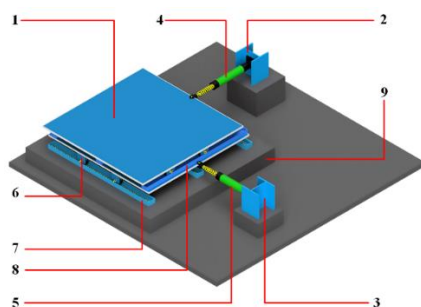


Figure 5. Design of earthquake simulator

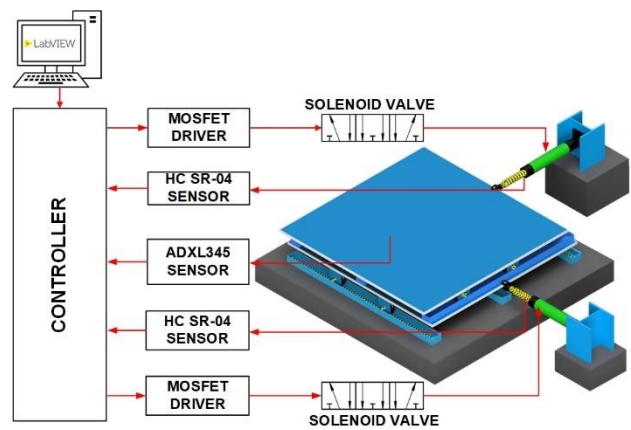


Figure 6. Earthquake simulator block diagram

Figure 5 shows the parts consisting of:

- Testing table (1)
- Y axis cylinder holder (2)
- X axis cylinder holder (3)
- Y-axis cylinder (4)
- X-axis cylinder (5)
- Wheel (6)
- X-axis rail (7)
- Y-axis rail (8)
- Support (9)

Earthquake simulator design was made using Autodesk Inventor software with dimensions of 1.25 m × 1.25 m. The block diagram of the earthquake simulator is shown in Fig. 6.

The test includes the work system of the tool on the simulation software and the hardware system that has been made.

2.7. Operation of shaking table

As it is known, the shaking table system is used to produce seismic motion that is like ground motion (in this case acceleration) so that the examiner can place the product on the test table to evaluate the product and improve response and ability to withstand the seismic motion [22].

In Fig. 7, to produce ground acceleration (seismic motion), the testing table must be driven by an actuator. This testing table is mounted on a platform (support) with rails and wheels, thus producing a linear motion. The input signal generated by the microcontroller is then entered into the actuator so that the linear motion of the testing table is as desired.

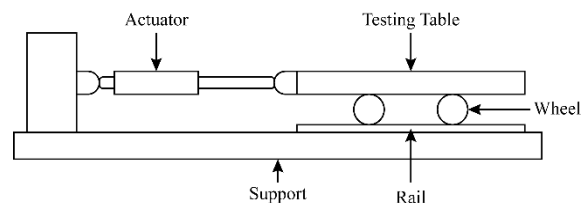


Figure 7. Schematic of an earthquake simulator

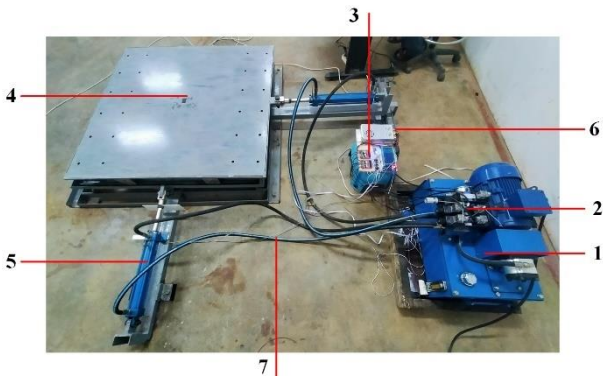


Figure 8. Results of making earthquake simulator

3. Results and Discussion

3.1. Earthquake Simulator

Figure 8 shows the results of making an earthquake simulator in the form of a shaking table.

Figure 8 is an earthquake simulator that was made consisting of 7 parts, namely:

- Hydraulic Power Pack (1) using a 3 Phase AC motor as the hydraulic power supply.
- Solenoid valve 4/3-way (2) used for regulating the opening and closing of fluid flow in the drive system.
- The controller (3) as a means of controlling input and output on the simulator, is regulating the valve opening and closing on the drive system, reading sensor results, and sending data to be displayed on LabVIEW.
- Test table (4) is used to place the test object. This test table will move according to the frequency and amplitude given to the driving tools.
- Hydraulic cylinder (5) is used to drive the test table.
- Power supply (6) used as a source of electrical energy for earthquake simulators.
- hydraulic hose (7) is used to deliver fluid to the system

In addition, the simulator is also equipped with a cylinder movement distance reading system. Cylinder movement distance readings using the PING HC SR-04 sensor. The distance reading data will be processed on the Arduino Mega2560 microcontroller.

Figure 9 shows the form of the HC SR-04 ping sensor.



Figure 9. HC SR-04 Ping Sensor

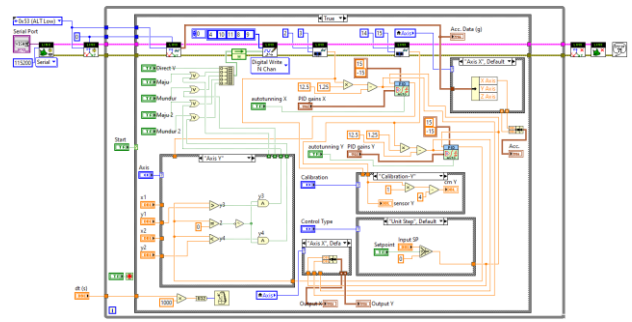


Figure 10. LabVIEW block diagram program display

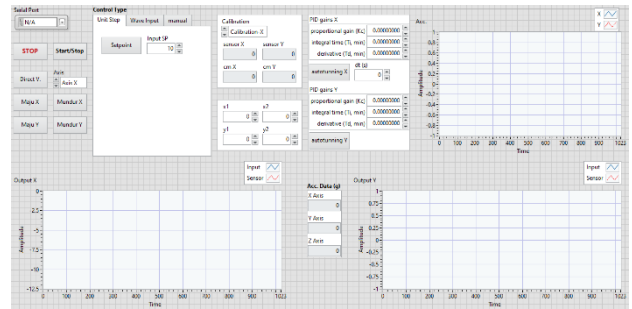


Figure 11. LabVIEW front panel program display results

3.2. Cylinder position control programming

The simulator program is made using LabVIEW. LabVIEW consists of two parts, namely the front panel and block diagram. The front panel functions as a user interface while the block diagram functions to build programs using the GUI (Graphical User Interface) programming language. Figure 10 shows the program built in the form of a block diagram. The program built produces a display on the front panel of Fig. 11.

3.3. Program implementation

The implementation of the program is by connecting the LabVIEW software which contains programs built with hardware (earthquake simulator) that have been made. In building a system, especially a system that has feedback characteristics, it becomes very prone to imprecision. In the instrumentation and control system, there is a control system that can overcome this, namely PID (Proportional-Integral-Derivative controller). In the simulator system made PID is used to control the valve. In this study, the first step was carried out using only one parameter, namely the proportional parameter (P) to determine whether the system built was ideal and stable or still required parameters I and D.

3.3.1. Programming using Proportional (P) controller

The system program using P control begins by giving the gain value. The gain value given is getting bigger until the system reaches a stable condition. Then given a step unit to see the response of the step by giving a gain value = 0.029332.

Figure 12 displays the results of the unit step test performed.

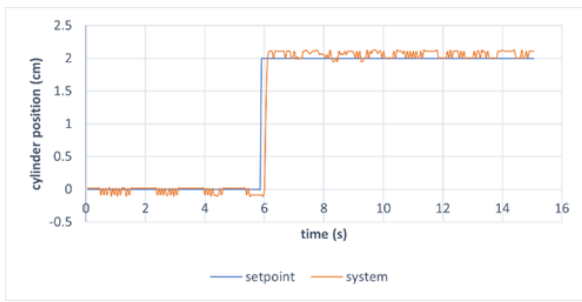


Figure 12. Proportional (P) control test results with a unit step of 2

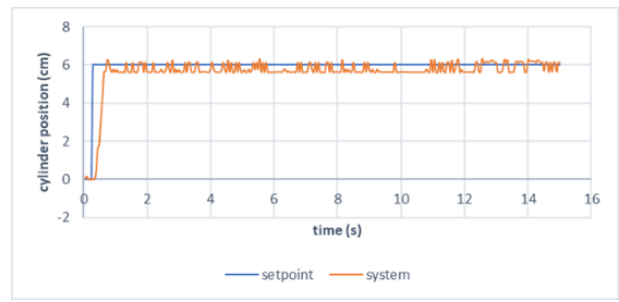


Figure 15. PI control test results with a unit step of 6 cm

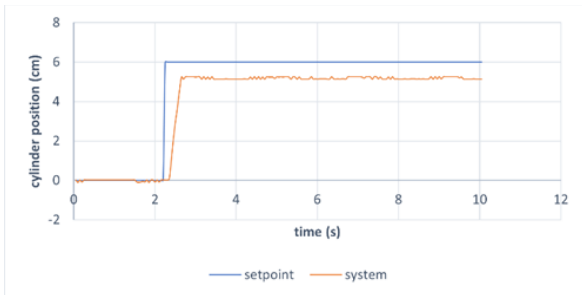


Figure 13. Proportional (P) control test results with a unit step of 6

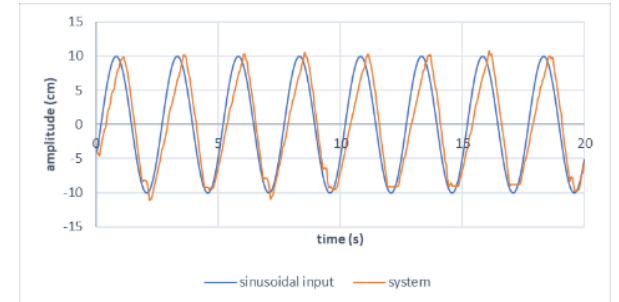


Figure 16. PI control test results with a sinusoidal input

From the results of the step variation test, when the cylinder position is set to a 2 cm stroke position, the cylinder can reach the setpoint without experiencing overshoot with a settling time of about 0.5 seconds and does not experience a steady-state error as shown in Figure 10. However, when given a setpoint with 6 cm, the hydraulic cylinder moves forward but does not reach the setpoint as shown in Fig. 13. In this case the control system using only proportional parameters (P) does not meet the desired design criteria.

3.3.2. Programming using Proportional (P) and Integral (I) controllers

The implementation of programming with PI (proportional-Integral) control begins with increasing the gain value of P (k_c) the same as setting the P value (k_c), then increasing the value of I (integral time = k_i) slowly until the system has reached the setpoint. The value of P (k_c) = 0.066195 and the value of I (k_i) = 2.009974. The PI value is given a unit step to see the response of each step. Figures 14 and 15 show the results of the step test with PI control.

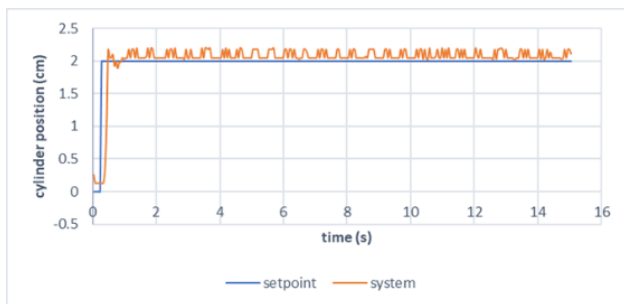


Figure 14. PI control test results with a unit step of 2 cm

The results above show that when the hydraulic cylinder position is set to reach a stroke position of 2 cm, the hydraulic cylinder can reach the setpoint (2 cm) without experiencing overshoot with a settling time of 0.5 seconds and does not experience a steady-state error (Figure 14). When the position of the hydraulic cylinder is given a unit step variation of 6 cm, the hydraulic cylinder moves forward and successfully reaches the setpoint (Figure 15). In this case, the control system using PI has met the desired system design criteria. This shows that the values of k_c and k_i used are appropriate and can be used in an earthquake simulator system.

PI parameter data that has been obtained, then tested using a sinusoidal wave to see the response of the system. The input given is a sinusoidal wave with a frequency of 20 mHz and an amplitude of 10.

Based on the Fig. 16, the system is given a sinusoidal wave input with a frequency of 20 mHz and an amplitude of 10 that can follow stably. The cylinder moves forward 10 cm, then back 10 cm according to the given amplitude value.

3.3.3. Earthquake simulator acceleration sensor data

Based on the results of earthquake simulator programming using PI control which produces ideal and stable performance, acceleration data is obtained. Acceleration data is generated by giving input values to the LabVIEW front panel in the form of frequency and amplitude data. The following are the results of the experiment by giving frequency and amplitude values which produce acceleration data that is displayed on the LabVIEW front panel in graphic form.

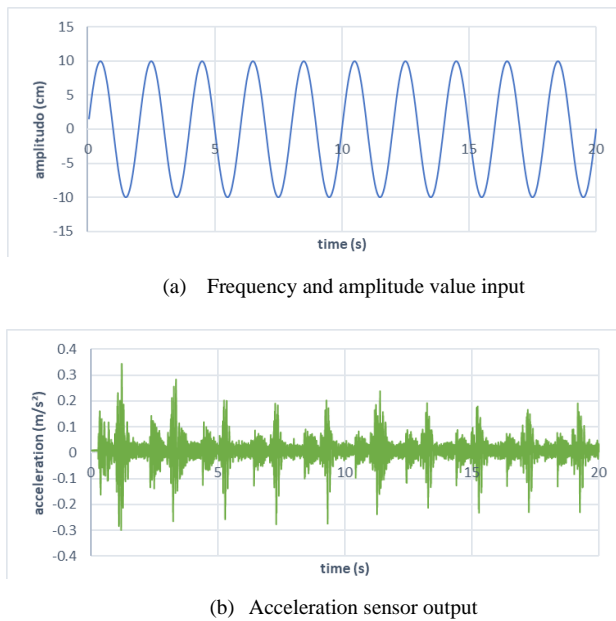


Figure 17. Experimental results the frequency value of 25 mHz and the amplitude of 10 to the acceleration

The experiment above shows that when providing input in the form of a sinusoidal wave with a frequency of 25 mHz and an amplitude of 10 (Fig. 17a), the cylinder can move forward and backward with 10 cm according to the input of the given amplitude. The results of these inputs can be seen in Fig. 17b that the maximum acceleration generated is 0.31 m/s^2 . Acceleration data is displayed in real-time on the LabVIEW front panel.

4. Conclusion

Earthquake simulator tool built using Arduino Mega2560 microcontroller with PI control, namely $P(kc) = 0.066195$ and $I(ki) = 2.009974$. The system response from the given unit step is a settling time of 0.5 s, there is no overshoot, and there is no steady-state error. So that the system complies with the criteria. The earthquake simulator can generate real-time acceleration data that is displayed in the LabVIEW front panel in graphical form.

References

- [1] K. Kaur, "Earthquake : Its Causes, Types & Measurement," *Int. J. Sci. Res.*, vol. 4, no. 7, pp. 260–261, 2015.
- [2] J. O. Oluwafemi, O. M. Ofuyatan, O. M. Sadiq, S. O. Oyebisi, J. S. Abolarin, and K. O. Babaremu, "Review of World Earthquakes," *Int. J. Civ. Eng. Technol.*, vol. 9, no. 9, pp. 440–464, 2018.
- [3] U. Setiyono *et al.*, *Catalog of Significant and Destructive Earthquakes 1821-2018*. Jakarta: Pusat Gempabumi dan Tsunami Kedepujian Bidang Geofisika Badan Meteorologi Klimatologi dan Geofisika, 2019. [in Bahasa]
- [4] W. Guo, Y. Hu, Y. Li, Z. Zhai, and P. Shao, "Seismic Performance Evaluation of Typical Dampers Designed by Chinese Code Subjected to the Main Shock-Aftershocks," *Soil Dyn. Earthq. Eng.*, vol. 126, no. August 2018, p. 105829, Nov. 2019.
- [5] M. Anda, S. Purwanto, E. Suryani, Husnain, and Muchtar, "Pristine Soil Property and Mineralogy as The Strategic Rehabilitation Basis in Post-Earthquake-Induced Liquefaction, Tsunami and Landslide in Palu, Indonesia," *CATENA*, vol. 203, p. 105345, Aug. 2021.
- [6] Y. Zhou, H. Shao, Y. Cao, and E. M. Lui, "Application of Buckling-Restrained Braces to Earthquake-resistant Design of Buildings: A review," *Eng. Struct.*, vol. 246, no. April 2020, p. 112991, Nov. 2021.
- [7] J. E. Luco, O. Ozelik, and J. P. Conte, "Acceleration Tracking Performance of the UCSD-NEES Shake Table," *J. Struct. Eng.*, vol. 136, no. 5, pp. 481–490, 2010.
- [8] Sunarjo, M. T. Gunawan, and S. Pribadi, *Earth Quake*, Populer. Jakarta: Badan Meteorologi Klimatologi dan Geofisika, 2012. [in Bahasa]
- [9] M. Giatman, R. Rahmad, and N. Zuwida, "Development of the Shaking Table as an Interactive Learning Media in Earthquake Engineering Lectures (Case Study in the Department of Civil Engineering, Faculty of Engineering, University of Graha Nusantara)," in *Konvensi Nasional Pendidikan Indonesia (KONASPI) VIII*, 2016, pp. 572–579. [in Bahasa]
- [10] R. T. Severn, "The Development of Shaking Tables—A Historical Note," *Earthq. Eng. Struct. Dyn.*, vol. 40, pp. 195–213, 2011.
- [11] G. Maddoni, K. P. Ryu, and A. M. Reinhorn, "Simulation of Floor Response Spectra in Shake Table Experiments," *Earthq. Eng. Struct. Dyn.*, vol. 40, pp. 591–604, 2010.
- [12] K. Bin Ngadimon, "Design and Simulation of Hydraulic Shaking Table," University of Technology Malaysia, 2006.
- [13] "Arduino-Home."
- [14] W. Bolton, *Mechatronics, Electronic Control Systems in Mechanical and Electrical Engineering*, Sixth. United Kingdom: Pearson Education Limited, 2015.
- [15] E. Damci and Sekerci, "Development of a Low-Cost Single-Axis Shake Table Based on Arduino," *Exp. Tech.*, vol. 43, no. 2, pp. 179–198, 2018.
- [16] R. H. Bishop, *The Mechatronics Handbook*. New York: CRC Press, 2002.
- [17] N. Nakata, "Acceleration Trajectory Tracking Control for Earthquake Simulators," *Eng. Struct.*, vol. 32, no. 8, pp. 2229–2236, 2010.
- [18] M. S. D. P. Rahman, S. Zahara, and M. Nurjanah, "Design and Build of Shaking Table Prototype as Short-period Seismometer Calibrator Based on Microcontroller," *J. Phys. Conf. Ser.*, vol. 1434, no. 1, 2020.
- [19] D. Artanto, *Interaksi Arduino dan LabVIEW*. Jakarta: PT. Elex Media Komputindo, 2012.
- [20] N. R. Wibowo, "Design and Build of a DC Motor Speed Control System as a Control System Practicum Learning Media using Labview," *JST (Jurnal Sains Terapan)*, vol. 6, no. 2, 2020. [in Bahasa]
- [21] H. M. Haines and J. R. Wilson, *Development of a Framework for Participatory Ergonomic*. Nottingham: HSE Books, 1998.
- [22] A. B. K. Teh and C. Venkatratnam, "Design and Development of a Seismic Shaking Table for Evaluation and Analysis of The Performance of Elastomeric Bearing," *2015 IEEE Student Conf. Res. Dev.*, pp. 111–116, Dec. 2015.