Conversion of Earthquake Vibrations in to Electricity

Ashwini Satyanarayana[1*], Apeksha S. A[2], Geetha L[3]

[1*]*Assistant Professor, Department of Civil Engineering, Dayananda Sagar College of Engineering, Bengaluru -560111*

[2] *PG Student, Department of Civil Engineering, Dayananda Sagar College of Engineering, Bengaluru -560111*

[3]*Assistant Professor, Department of Civil Engineering, Dayananda Sagar College of Engineering, Bengaluru -560111*

Abstract: -Energy is produced by nature, and humans have always sought to manipulate this source for their own gain. Different strategies for reaching this goal have been developed over time. Due to the underutilized yet significant energy that may be acquired from earthquakes,this article investigates a different source of power. By catching this energy and turning it into electricity, a novel sort of generation could be accomplished. It's not widely understood that seismic mechanical waves can be used as a source of energy, and there isn't much literature on the subject either. The focus of this research paper is to convert earthquake vibrations into electrical signals by using vibration sensor in Servo electric shake table apparatus. The model is tested for El Centro earthquake time history data, Chile earthquake data and for random sine waveforms.

Keywords*: seismic waves, Energy harvesting, Vibrations, Earthquake, Electricity, Sensor.*

1. Introduction

Earthquake**,** any sudden shaking of the ground caused by the passage of seismic waves through Earth's rocks. Seismic waves are produced when some form of energy stored in Earth's crust is suddenly released, usually when masses of rock straining against one another suddenly fracture and "slip." Earthquakes occur most often along geologic faults, narrow zones where rock masses move in relation to one another. The major fault lines of the world are located at the fringes of the huge tectonic plates that make up Earth's crust. The total energy from an earthquake required to create new cracks in rocks, energy dissipated as heat through friction and energy elastically radiated through earth. Of these the only quantity that can be measured is that which is radiated through the earth. And this energy could be harnessed given the dedication of enough resources and the proper implementation of the right technologies.Only a few undergraduate articles on this issue can be discovered, and standard databases return zero results when the topic is searched. Among them, the University of Leicester in England [2] featured a student concept in 2016 that involves using a certain type of generator in the basement of buildings to store energy and use it after a seismic event has passed. They suggested that a 7.2 magnitude earthquake in San Francisco, California may create about 770 W if the foundations of a certain structure were constructed utilizing generator blocks.

Overview of earthquake features

An earthquake is what happens when two blocks of the earth suddenly slip past one another. The surface where they slip is called the fault or fault plane. The location below the earth's surface where the earthquake originates is called the hypocentre, and the location directly above it on the surface of the earth is called the epicentre. Sometimes an earthquake has foreshocks, these are smaller

Types of Seismic Waves

There are several different kinds of seismic waves, and they all move in different ways. The two main types of waves are body waves and surface waves. Body waves can travel through the earth's inner layers, but surface waves can only move along the surface of the planet like ripples on water. Earthquakes radiate seismic energy as both body and surface waves. Recordings of seismic waves from earthquakes led to thediscovery of the earth's core and eventuality of the layers of the Earth's inside. Just as the prism below refracts light on its faces, seismic waves bend, reflect and change speed at the boundaries between different materials below the Earth's surface.

Body Waves

Traveling through the interior of the earth, body waves arrive before the surface waves emitted by an earthquake. These waves are of a higher frequency than surface waves.

P Waves

The P wave, or main wave, is the initial type of body wave. Since it travels the fastest, it is the first seismic wave to "arrive" at a seismic station. The P wave can travel through both solid rock and liquids, such as water or the earth's liquid layers. Similar to how sound waves push and pull the air, it pushes and pulls the rock as it passes through it. Because sound waves were pushing and pulling on the window glass in a manner similar to how P waves push and pull-on rock, the windows began to ratchet. Animals occasionally have the ability to hear earthquake P waves. For instance, dogs frequently start howling frantically just prior to an earthquake (or more particularly, prior to the arrival of the surface waves). People typically can only feel the bump and rattle of these waves. Compressional waves, which describe the pushing and pulling that P waves perform, are another name for them. When subjected to a P wave, particles go in the same direction as the wave, which is also known as the "direction of wave propagation" and is where the energy is traveling.

S waves

The S wave, also known as a secondary wave or second wave in an earthquake, is the second type of body wave. An S wave cannot go through any liquid media; it can only pass through solid rock and is slower than a P wave. Seismologists concluded that the Earth's outer core is a liquid because of this characteristic of the S waves. S waves lift rock fragments.

Surface waves travel exclusively through the crust, have a lower frequency than body waves, and may therefore be easily distinguished on a seismogram. Although surface waves arrive after body waves, they are mostly to blame for the havoc and damage brought on by earthquakes. In deeper earthquakes, this damage and the force of the surface waves are lessened.

Love Waves

In honour of A.E.H. Love, a British mathematician who developed the mathematical model for this type of wave in 1911, the first type of surface wave is known as a Love wave. The fastest surface wave, it sways the earth in all directions. Love waves only travel along the crust's surface and only generate horizontal motion.

Rayleigh Waves

The Rayleigh wave, named after John William Strutt, Lord Rayleigh, who theoretically foresaw the existence of this type of wave in 1885, is the other type of surface wave. Similar to how a wave might move across a lake or the ocean, a Rayleigh wave moves along the ground. It rolls, which causes the ground to move in the same direction as the wave up and down and side to side. The Rayleigh wave, which can be much greater than the other waves, is what causes the majority of the shaking experienced during an earthquake.

Geographic statistics indicate that earthquakes are likely to occur across over 54% of India. The seismic jeopardy across the country has been rapidly increasing as a result of recent large earthquakes, which took place even in the stable continental zone. The most recent version of the seismic zoning map of India is included in the earthquake resistant design code of India [BIS 1893 (Part 1) 2002], and it assigns four degrees of seismicity for the totality of India in terms of several zone variables. In other words, as opposed to its earlier iteration, which had five or six seismic zones, the current earthquake zoning map of India splits the country into four seismic zones (Zones II to V). Zone II is connected with the lowest amount of seismicity, whereas Zone V is expected to experience the highest level of seismicity, according to the current zoning map.

• Regions in Jammu, Kashmir, the North East, Uttarakhand, Bihar, etc. are part of the Himalayan Range. These areas, which are on the tectonic plate's edge, are frequently shaken by earthquakes.

• The Western Ghats, which are prone to earthquakes due to their basaltic or trap rock composition and location in zone 3 of the Seismic Zoning Map.

• The volcanic Andaman and Nicobar Islands, which are prone to earthquakes because of volcanism.

• A few coastal and plains cities, including Delhi, Kolkata, Guwahati, Bhuj, Imphal, Amritsar, Srinagar, Port Blair, etc. Earthquake risk is either high or moderate in these cities

Summary of literature review

The provided excerpts summarize various research papers and studies related to the conversion of vibrations into electrical energy and experimental shake table testing. Here's a brief gist of each:

K. H. Nam et al. described capturing energy from road bumps using a linear electric generation system. It focuses on modeling vibration characteristics from road bumps and optimizing magnetic circuit design for electricity generation. Hrishikesh Meshram et al. explores using renewable energy and discusses how vibrations in machinery and vehicles waste energy. It delves into vibration types, mathematical models, and techniques for energy harvesting, including building prototypes. Chaoqing Min et al. introduces a vibration control system called a serial-stiffness-switch system, emphasizing its vibration energy conversion capabilities and control techniques for higher suppression performance. Jamie Goggins et al. presents a self-centering system for concentrically braced frames (CBF) to enhance their durability during earthquakes. Shake table testing is discussed to evaluate the system's performance. Tomomi Suzuki M. EERI et al. presents Shake table tests that are used to investigate seismic displacement requirements for reinforced concrete buildings, focusing on inelastic torsion and structural flaws. V.L. Stevens et al. Researchers discuss mapping surface strain rates using GPS to understand strain generated during earthquakes in the India-Asia collision zone, helping estimate earthquake likelihood. Bo Wang et al. explores vibration energy harvesting using PVDF materials, presenting a novel vibration energy conversion power supply and its simulation results. It demonstrates its use in low-power electronics. Felipe Díaz-Mora et al. investigates sustainable energy production from telluric movement waves, describing earthquake characteristics and a mechanism for energy generation. Guansong Shan et al. focuses on a cost-effective piezo stack energy harvester for capturing energy from railroad track vibrations, discussing its design, testing, and power generation. Horia-Nicolai L. Teodorescu et al. explores an energy harvester's potential use as a power source for emergency gas valves and seismic event alarms, investigating its design and applications. Santosh Yadav et al. outlines procedures for conducting shake table tests on scaled-down structures, emphasizing efficiency and specimen transfer methods. Xin Li et al. focuses on harvesting ultra-low frequency ambient vibrations by using frequency up-conversion techniques. It evaluates different methods for improving energy harvesting from low-frequency sources.

2. Objectives

- To efficiently capture and convert seismic vibrations into electrical energy using vibration sensors
- Create systems that use seismic energy harvesting to power sensors and data collection devices for continuous monitoring of seismic activity

3. Description of the work

Experimental setup consists of

- Servo Electric Shake table apparatus

- Vibration sensor
- Microcontroller
- Multimeter, LED, Resistor etc.

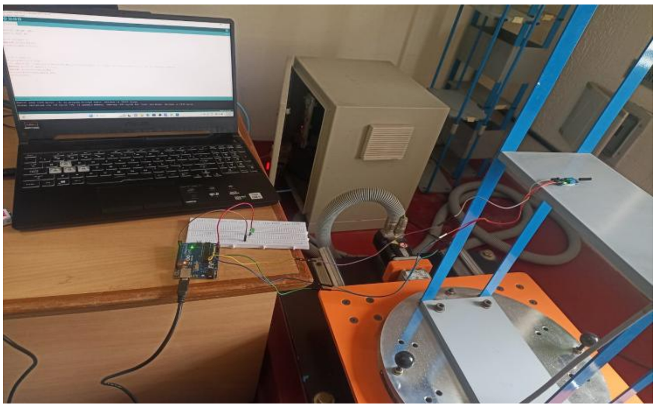


Fig 1. Experimental setup

The shake table model can be subjected to different wave forms/ base motions such as sine, Random, Square, Triangle and saw tooth.For earthquake vibration, Earthquake History/ Time history data has to be fed in servo shake and it will vibrate accordingly. In this work, model is tested for sine form of various frequency, cycles, amplitude and for El Centro and Chile Time history data.

Sequence of procedure follows as below

- Instrument setup
- Connection of vibration sensor and microcontroller board
- Feeding of Vibration .data to the model through servo shake
- Output is recorded in the vibration analyzer software called KAMPANA
- LED is connected in the circuit as an output which shows the intensity of the vibrations
- Voltage is measured using multimeter
- Modelling and analysis of shake table model in SAP2000 software

Instrument setup

For the experiment Servo electric shake table is used. The shake table will be consisting of a Servo Actuator, connecting link, a top table, linear guide ways. The Servo Actuator is controlled through computer. Various base motions such as sine, square, random etc. will be given to the actuator and accordingly the top table will vibrate. Linear guide ways will ensure that the motion of the table is linear. A circular mounting plate will be placed on the vibrating plate through a T-slot, so that, the test structure can be mounted at any desired angle relative to the angle of incidence of the base motion.

A three-storey structure is mounted on the servo shake table; accelerometers are connected to each storey.

Table 1. Geometric data of the structure

Sl No	Part	Dimension in mm		
		Depth (D)	Width (B)	Length (L)
1	Column	3.00	25.11	400.00
2	Slab	12.70	150.00	300.00

Specifications

1) Make: Milenium
2) Type: Servo
3) Frequency: 0-20 Hertz
4) Amplitude/Stroke: 0-1000 mm (+/- 50 mm)
5) Input Power: 230 volts AC
6) Base Motion: Random, sine etc
7) With computer Interface

Connection of vibration sensor and microcontroller board

The vibration sensor used is a SW-420 Vibration sensor module shown in fig.2. It is a closed type vibration sensor which has a driving ability of 15mA and working voltage between 3.3V-5V. Output format is a digital switching output (0 and 1). The vibration sensor and microcontroller board are connected with jumping wires as shown in the fig.3 then microcontroller board is connected to computer through cable. C- programme is uploaded to the board through Arduino IDE software. Resistor used in the circuit is of 220 Ohms.

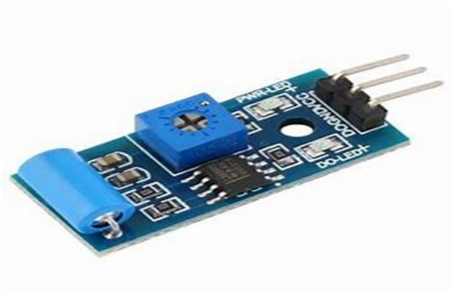


Fig 2. Vibration sensor

C- Programme for vibration sensor

```
#define IN_A0  A0
#define LED 3
void setup()
{
Serial.begin(9600);
pinMode(LED,OUTPUT);
}
void loop() {
digitalWrite(3, LOW);
int value_A0 = analogRead(IN_A0); // reads the analog input from the IR distance sensor
Serial.print(" Analog = ");
Serial.println(value_A0);
if (value_A0>700)
{
```

digitalWrite(LED,value_A0);

}

delay(500);

}

The program is uploaded to the microcontroller board and the vibration sensor is controlled through this board using Arduino software.

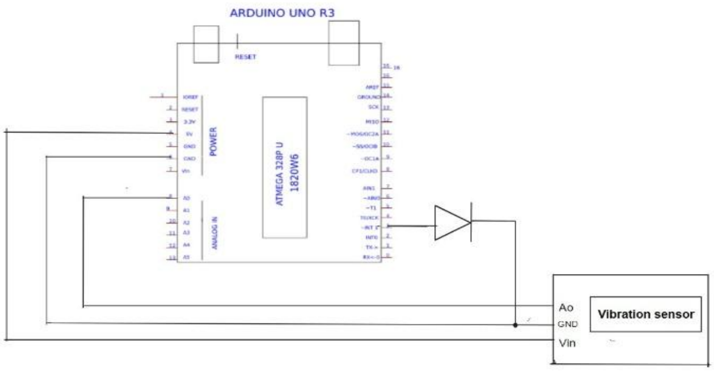


Fig. 3 Circuit diagram

Feeding of Vibration data to the model through servo shake

After connections being done and setup is ready for testing vibration sensor is fixed on the model. Model is tested for sine wave forms and El Centro time history data.

For sine wave forms following data is fed in the servo shake table:

Table 2. Sine wave form data

Constant	Variable
Case 1	Frequency (in Hertz)
Cycles = 5	3
Amplitude = 5mm	5
	7
Case 2	Cycles
Frequency = 3 Hertz	7
Amplitude = 5mm	9
	11
Case 3	Amplitude (in mm)
Cycles = 5	7
Frequency = 3 Hertz	9
	11

For time history data of El Centro, it is obtained from PEER Ground motion database [9].

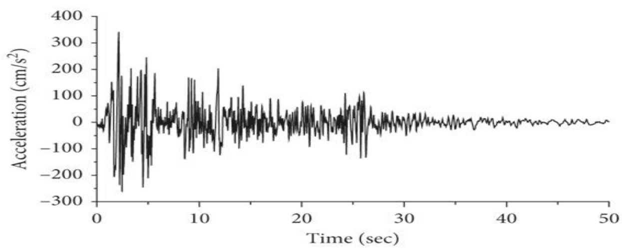


Fig. 4 Acceleration vs Time graph of El Centro earthquake

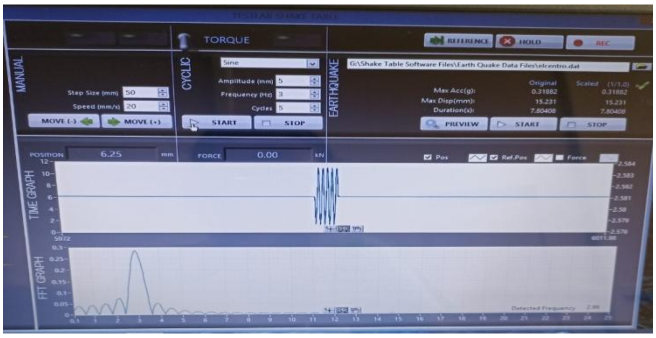


Fig. 5 Feeding of data in servo shake software

When the vibrations are given to the model these vibrations are converted into electrical signals by the vibration sensor. LED is connected as output, based on the intensity of the vibration LED will glow. Through the multimeter voltage is measured. From the vibration analyzer software KAMPANA displacement, velocity, and acceleration at each story in x, y and z direction is obtained.

LED and Resistor

- LED is used as output in the circuit.
- 220 Ohms resistor is used in the circuit.

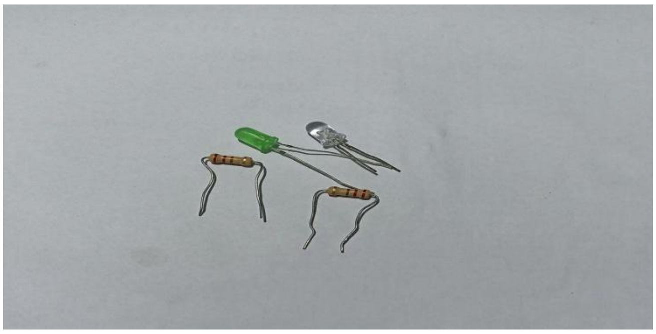


Fig. 6 LED and Resistors

5. Results and Discussion

- Results from shake table test

Results are obtained for sine wave forms, El Centro and Chile earthquake data. Table 3 shows the values of current produced when earthquake vibrations are converted into electrical signals by the vibration sensor for sine wave forms. Similarly, table 4 shows current produced for earthquake data.

The following are the results for sine wave forms with different frequencies, amplitudes, and cycles. The converted electrical signals are measured in volts using multimeter then it is converted into amperes by using the formula given below

Current (I) = Voltage (V) ÷ Resistance (Ω)

Example: Voltage = 1.6 V

Resistance = 220 Ω

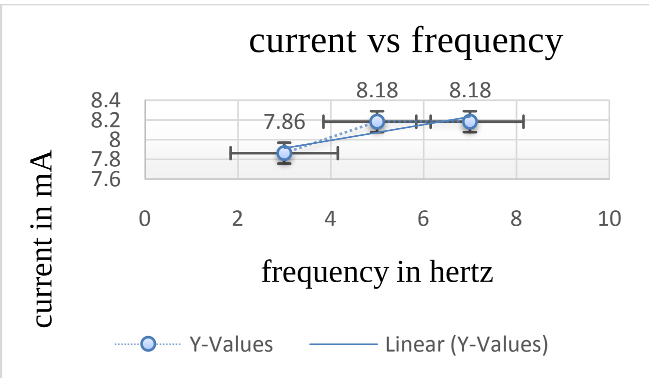
Current = 1.6/220 = 7.27 mA

Results are obtained for the three cases and they are converted into current from the voltage. For the obtained values graphs are being plotted.

Table 3. Current obtained for sine wave forms

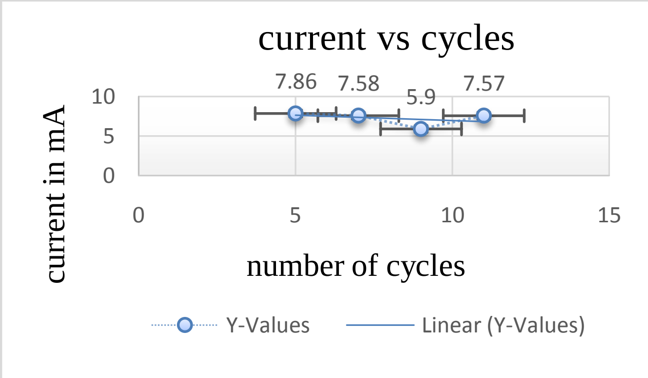
Constant	Variable	Trial 1	Trial 2	Trial 3
Case 1	Frequency (in Hertz)	Current in mA	Current in mA	Current in mA
Cycles = 5	3	8.64	7.27	8.18
Amplitude = 5 mm	5	8.18	8.18	8.18
	7	7.73	8.18	8.64
Case 2	Cycles			
Frequency=3Hertz	7	7.27	7.73	7.73
Amplitude=5mm	9	5.4	5.9	6.4
	11	8.64	8.18	8.18
Case 3	Amplitude (in mm)			
Cycles = 5	7	8.18	8.64	8.18
Frequency =3 Hertz	9	8.18	7.73	7.73
	11	8.18	7.73	8.64

- Graphical representation of case 1



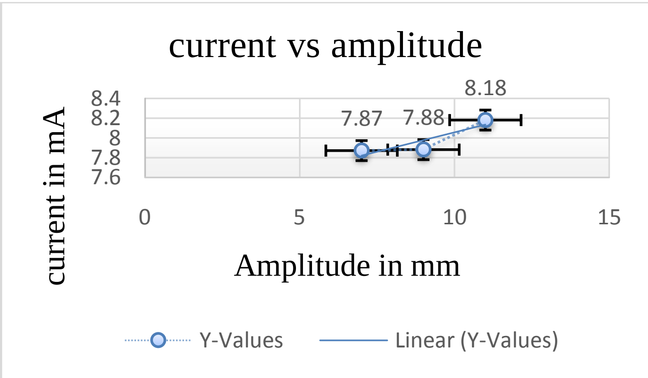
In this case frequency is varied from 3 Hz to 7 Hz for amplitude of 5 mm and 5 cycles. It was observed that the current produced is 7.86 mA for frequency = 3 Hz and it remained same for frequencies 5 Hz and 7 Hz respectively.

- Graphical representation of case 2



The number of cycles in the above instance ranged from 5 to 9. The current generated for the first five cycles was 7.86 mA, and as the number of cycles grew, there was a minor decrease in the current, which was 7.58 mA for the seventh cycle and 5.9 mA for the ninth. Current rose by 7.57 mA as the cycles reached 11.

- Graphical representation of case 3

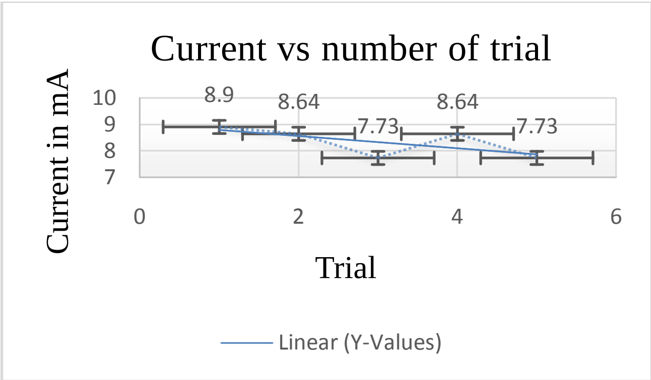


The amplitude in the above-mentioned cases ranged from 5 to 11 mm, and for the amplitude of 5 mm, 7.87 mA of current was obtained. Current likewise rises with an increase in amplitude. Current obtained for amplitude 7 mm measured at 7.88 mA and for amplitude 11 mm at 8.18 mA.

Table 4. Current obtained for earthquake vibrations

Sl. No	Ground motion	Trial 1	Trial 2	Trial 3	Trial 4
		Current in mA	Current in mA	Current in mA	Current in mA
1	El Centro	7.73	8.64	8.64	7.72
2	Chile	0	0	0	0

- Graphical representation for El Centro earthquake data



Testing Context: The model is undergoing a series of tests or trials to evaluate its performance or accuracy.

Number of Trials: There are a total of 5 trials conducted to assess the model's performance.

Consistency of Results: Across all five trials, the results obtained were similar or consistent in terms of the measured current. Specifically, the current values ranged between 7.73 milliamperes (mA) and 8.9 milliamperes (mA).

Chile earthquake

For Chile earthquake, there was no conversion of vibrations into electrical signals since the movement of model was very slow.

- Result from SAP2000 software

The analysis and design sections for the shake table model were examined in accordance with the AA 2015 code, result showed that the analysis and design sections match for all aluminium frames.

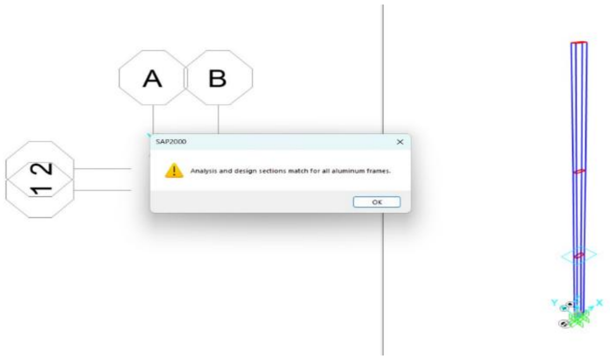


Fig. 7 Analysis and design section match for aluminium frames.

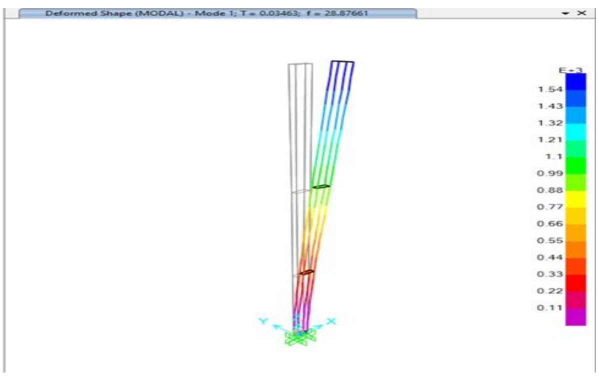


Fig. 8 Deformed shape for modal case

Mode 1: Time period = 0.03463s

Frequency = 28.88 Hertz

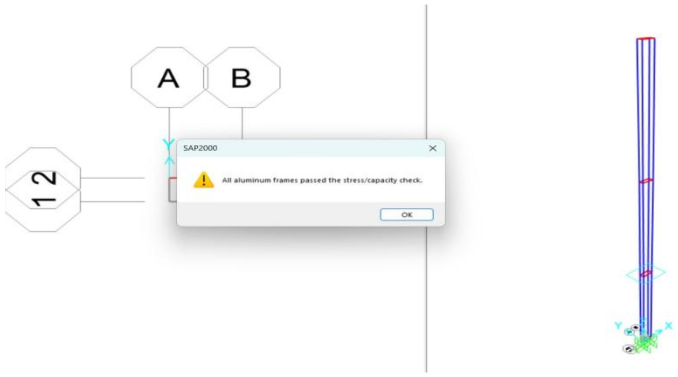


Fig. 9 Frames passed the stress/capacity check.

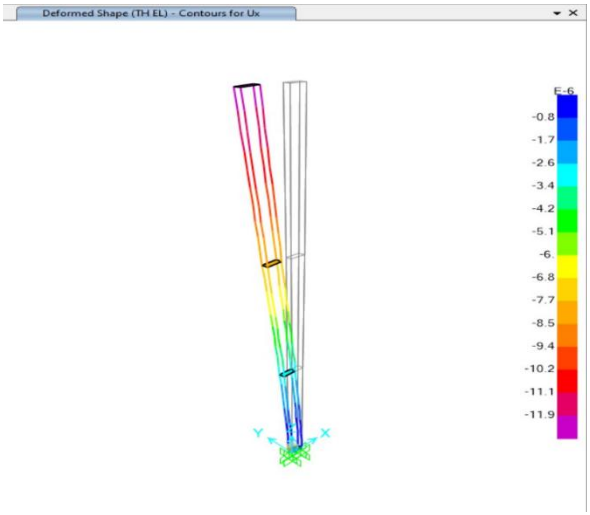


Fig. 10 Deformed shape for EL case

6. Conclusions

The experiments yielded a comprehensive set of results for different combinations of amplitude, frequency, and cycles for sine waveforms. Additionally, random sine waveforms, Chile and El Centro earthquake data were analyzed. Voltage and current data were recorded for each trial.

- For sine wave forms, amplitude varied was between 5 to 11mm, frequency ranged between 3 to 7 Hertz and number of cycles between 5 to 11. Despite systematically altering these parameters, we observed a remarkable consistency in the electrical current output, which ranged from 7.27 mA to 8.64 mA.

Key Findings:

1. Parameter Insensitivity: The most notable observation from our experiments is the insensitivity of our energy harvesting system to changes in amplitude, frequency, and the number of cycles. Even when deliberately varying these parameters over a significant range, the current output remained relatively stable.

2. Consistent Energy Yield: The consistent current output within this narrow range suggests that the system possesses a robust ability to capture and convert mechanical vibrations into electrical energy. This finding highlights the system's reliability and predictability under different vibrational conditions.

- For seismic data, model was tested for El Centro and Chile earthquake data. We sought to assess the system's performance under real seismic conditions and quantify the electrical current generated. For Chile earthquake data vibration sensor did not show any electrical signals since the vibrations in the model was very slow. And for El Centro experiments revealed a consistent and reproducible range of electrical current output, ranging from 7.27 to 8.64 mA across the five trials. This remarkable consistency underscores the system's reliability in capturing and converting seismic energy into usable electricity, even in the face of dynamic and unpredictable seismic forces.
- The results yielded valuable insights into the feasibility and potential of earthquake-induced energy harvesting.
- The experimental setup successfully demonstrated the dynamic behavior of the three-storey structure mounted on the servo electric shake table under various excitations.
- The collected data provided insights into how the structure responds to different types of vibrations, which is crucial for earthquake engineering and structural design.
- The use of SAP2000 software for modelling and analysis enhanced the understanding of the structural response, allowing for further refinements in design and analysis.
- The results, including voltage and current measurements, serve as a valuable data for future research and development of new source for generation of electricity.

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