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# Prototype Design of Adaptive Composite Springs As An Anti-Seismic Infrastructure System For Multi-Story Buildings

Auni Zahratu Syifa *[1], Naziha Alqiara[2], Muhammad Fakhri[3], Muhammad Ghaziyan Faizan[4], Afryansyah [5]
[1,2,3,4,5] MAN Insan Cendekia OKI, South Sumatra, Indonesia
E-mail: [1]ratusyifaaa2@gmail.com, [2]naziha.alqiara@gmail.com [3]ghaziyanfaizan@gmail.com, [4]ghaziyanfaizan@gmail.com, [5]afryansyah@manicoki.sch.id

***Abstrak***

*This study aims to design and formulate earthquake dampers composed of carbon fiber and epoxy resin, employing a specialized configuration to produce anti-seismic devices that are corrosion-resistant, adaptively flexible, and capable of supporting building loads effectively. A quantitative design-based methodology was applied, encompassing prototype design, material selection, and performance testing against vertical loads and seismic vibrations. Evaluation was conducted using a hydraulic press to determine maximum vertical load capacity and a shake table to simulate horizontal and vertical seismic activity according to the Richter scale. The results indicate that the composite dampers can absorb seismic energy bidirectionally, maintain structural integrity without significant material degradation, and require minimal maintenance. These findings demonstrate the potential of carbon fiber and epoxy resin-based dampers as adaptive seismic isolation systems that are robust, durable, and suitable for multi-story buildings, while meeting the demands for economical, efficient, and sustainable infrastructure solutions.*

***Key Word**: Earthquake, Infrastructure, Earthquake Damper, Epoxy Resin, Carbon Fiber*

## 1. INTRODUCTION

Earthquakes are one of the natural disasters that can cause serious damage to infrastructure and claim many lives. Indonesia is a country that is highly vulnerable to natural disasters such as floods, earthquakes, volcanic eruptions, and tsunamis. This is due to Indonesia's geographical location in the Pacific Ring of Fire and at the meeting point of three major tectonic plates, namely the Indo-Australian, Eurasian, and Pacific plates. This position causes Indonesia's geological conditions to be very complex, with a high potential for earthquakes or seismic events[1], [2]

As a mitigation effort, several developed countries, such as Japan and the United States, have implemented design innovations in building infrastructure to reduce damage when an earthquake occurs, one of which is by using base isolators made of rubber, metal, and lead. This system is considered a promising alternative for creating earthquake-resistant buildings[3]. Rubber earthquake isolators can dampen and anticipate seismic forces propagating from the ground[4]. Although this technology has been proven to reduce damage caused by earthquakes, the conventional system still has several weaknesses[5].

One of its drawbacks is its dependence on metal materials such as lead and steel, which are prone to corrosion in a relatively short period of time[6]. Most damping

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systems are only effective against lateral earthquake movements, but their performance decreases when vertical components are also involved. This can cause an increase in base friction or uplift forces that negatively impact the stability of multi-story buildings[7]. In addition, conventional dampers are also less adaptive to variations in earthquake intensity, so their performance is not always optimal.
Based on these challenges, there is a need for a more robust, adaptive, and durable seismic isolation system innovation. Therefore, an innovation called SEISPRING was developed, which is an adaptive spring system made of carbon fiber and epoxy resin composite designed to increase the earthquake resistance of buildings[8]. SEISPRING is not only corrosion resistant, but also capable of absorbing earthquake energy from two directions at oncehorizontal and vertical thereby increasing the overall resistance of the structure during an earthquake[9].
Another advantage of SEISPRING is its ability to be implemented without requiring special maintenance, making it a practical and efficient solution for earthquake-resistant infrastructure development. The primary objective of this study is to develop an adaptive seismic isolation system using carbon fiber and epoxy resin composites, aimed at enhancing the structural resilience of multi-story buildings against both horizontal and vertical seismic forces. This research contributes to the field by providing a prototype that addresses the limitations of conventional isolators, including corrosion susceptibility and inadequate performance under multi-directional seismic loads, thereby offering a viable approach for improving earthquake-resistant infrastructure design.[10].

## 2. RESEARCH METHODOLOGY

This study uses a quantitative design method because it designs, produces using the Hand Lay-Up method, and tests innovative composite dampers made of carbon fiber and epoxy resin[11], [12].

2.1.1. Research Variables
There are two variables in this study, independent variables and dependent variables. The variables are divided as follows:
2.1.1.1. Independent Variables
In this study, the independent variable is the strength of an earthquake in Richter scale units, which will later be used as a test tool for the damper's resistance at a certain magnitude[13].
2.1.1.2. Dependent Variables
In this study, the dependent variables are the damper resistance at a certain earthquake magnitude and the maximum vertical load that this damper can withstand[14].
2.2. Research Time and Place
2.2.1. Research Time
This research will be conducted from September to October. During these two months, the research will begin with designing the shape of the damper using a 3D application. The application used is AutoCAD. In mid-September, the research will continue with finding and sorting the necessary carbon fiber and epoxy resin

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materials, followed by the production stage. In mid-October, the research will continue with the testing stage.

2.2.2. Research Location

This research will be conducted in Palembang to produce the damper. Next, the damper durability testing process will be carried out at the Structure, Construction, and Material Laboratory at Sriwijaya University, Palembang. Vertical load pressure testing will be carried out at the same laboratory.

2.3. Research Tools

2.3.1. Damper Design Tools

A. AutoCAD 3D

2.3.2. Damper Production Tools

A. Silicone mold
B. Soft wire
C. Brush
D. Scissors
E. Gloves
F. Mask

2.3.3. Pressure Testing Tools

For pressure testing, the tool used is a hydraulic press machine.

2.3.4. Durability Testing Tools

For durability testing, the tool used is a shake table.

2.4. Research Materials

A. Epoxy Resin
B. Carbon Fiber
C. Polyacrylonitrile

2.5. Data Sources

2.5.1. Primary Data

In this study, primary data will be collected through the formulation of dampers using the design method. Furthermore, data in the form of durability tests will be collected to test the durability of dampers in earthquake-resistant building infrastructure.

2.5.2. Secondary Data

As secondary data, data in the form of vertical load pressure tests will be collected to determine the maximum vertical load that can be accommodated by these springs.

## 3. Result

### 3.1 Analysis Phase

#### 3.1.1 Performance analysis

Earthquakes are natural disasters that often cause significant structural damage, especially to multi-story buildings. Conventional dampers such as Lead Rubber Bearings (LRB) and High Damping Rubber Bearings (HDRB) have been widely used as seismic isolation systems, but both have several important limitations. These include dependence on metal materials such as lead and steel that are susceptible to corrosion, sensitivity to temperature changes, and ineffectiveness in withstanding vertical earthquake forces. These weaknesses indicate that current isolation systems are still not adaptive enough to variations in earthquake intensity and direction, thus requiring innovations based on new materials and more flexible and durable structures.

This research presents a solution in the form of adaptive springs made of carbon fiber composite and epoxy resin, designed to increase the resistance and flexibility of building structures to earthquakes. Carbon fiber was chosen because it has high tensile strength and is lightweight, while epoxy resin has high adhesive strength and is resistant to humid environments and corrosion. The combination of the two produces a composite structure that is strong yet flexible.

The performance of this system was analyzed from two main aspects: its ability to withstand vertical loads and its resistance to seismic vibrations. Testing using a hydraulic press was conducted to determine the maximum vertical load that the springs could withstand, while seismic resistance testing used a shaking table to simulate horizontal and vertical vibrations according to the Richter scale.Initial results show that this spring design has the potential to:

A. Absorb earthquake energy from two directions simultaneously (horizontal and vertical),
B. Not experience material degradation like metal-based dampers,
C. Require minimal maintenance, and
D. Be more economical in the long term due to its non-corrosive composite material.

Beyond being a technical solution, this system also serves as a support for adaptive and sustainable infrastructure development, aligning with the objectives of the Sustainable Development Goals (SDGs), particularly in the aspects of disaster risk mitigation and structural safety.

### 3.1.2 Need analysis

One of the main requirements identified in earthquake mitigation in Indonesia is a more adaptive seismic isolation system that is corrosion resistant and capable of working effectively against both horizontal and vertical vibrations. Conventional systems such as Lead Rubber Bearings (LRB) or High Damping Rubber Bearings (HDRB) are widely used, but they still have limitations. These include low resistance to corrosion, sensitivity to extreme temperatures, and an inability to optimally dampen vertical forces, which is very important in multi-story buildings.

In addition, existing damping systems are generally passive and do not adjust to varying earthquake intensities. In the context of buildings in earthquake-prone areas such as Indonesia, more sustainable, practical, and efficient innovations are needed. This need is especially important for contractors, architects, and structural designers who seek to improve building safety without having to perform intensive maintenance or replace components periodically.

The solution offered in this research is an adaptive spring made of a composite material consisting of carbon fiber and epoxy resin, which is not only corrosion-resistant but also has high tensile strength, is lightweight, and is flexible against dynamic loads such as earthquakes. This spring is designed to absorb seismic energy from both horizontal and vertical directions, as well as reduce the risk of structural damage and potential casualties during an earthquake. In addition to its structural advantages, this innovation also addresses the need for dampers that:

A. Do not require intensive maintenance like metal-based systems,

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B. Are cost-efficient in the long term, and
C. Are environmentally friendly because they do not use hazardous materials such as lead.

Through a design approach, laboratory tests on vertical pressure and vibration resistance have been conducted as part of the validation of this spring's performance. This solution not only has the potential to replace conventional systems but also opens up opportunities for developing new isolation systems that are more adaptable to Indonesia's geological conditions.

Table 1. Percentage of Respondents' Needs for Innovative Seismic Isolation Systems

| No. | Statement | Persentation (%) |
|---|---|---|
| 1 | Isolation systems capable of withstanding horizontal and vertical earthquake forces | 88% |
| 2 | Use of corrosion-resistant (anti-rust) materials | 85% |
| 3 | Lightweight yet strong springs for multi-story buildings | 82% |
| 4 | A damping system that requires minimal maintenance | 79% |
| 5 | Effective against variations in earthquake intensity | 76% |
| 6 | Can be integrated with existing building structures | 73% |
| 7 | Durable and not prone to damage | 75% |
| 8 | More economical than conventional damping systems | 70% |
| 9 | Environmentally friendly (does not contain hazardous materials such as lead) | 68% |
| 10 | Easy to produce locally for national-scale projects | 71% |

Based on the results of the questionnaire data analysis, it appears that there is a high demand for more adaptive and durable earthquake isolation system innovations. Respondents stated that they need solutions that are not only effective in withstanding earthquake vibrations from various directions, but also more practical, less prone to damage, and do not require complicated maintenance.

There is also a high demand for corrosion-resistant and flexible materials such as carbon fiber and epoxy resin, given the weakness of conventional dampers in humid tropical environments such as Indonesia. In addition, most respondents voiced the need for a system that is economical yet reliable, so that it can be widely applied, especially for public buildings and basic infrastructure.
Thus, the composite adaptive springs developed in this research meet almost all of these requirements and can be a strategic and sustainable solution for the development of earthquake-resistant building systems in the future.

## 3.2 Development Phase

### 3.2.1 Creation of the SEISPRING Isolator

Figure 1 Logo of SEISMIC Isolator

### 3.2.2 Design of the Seismic Isolator

The design of the SEISPRING prototype includes the integration of composite materials consisting of carbon fiber and epoxy resin, a 3D structural model created using AutoCAD, a mold-based fabrication method through Hand Lay-Up technique, and a series of laboratory tests using a shake table and hydraulic press machine, all aimed at evaluating its seismic resistance and load-bearing capacity as part of an innovative anti-seismic infrastructure system.

### 3.2.3 Use of SEISPRING Seismic Isolator

The SEISPRING prototype is designed to be integrated into building foundations, utilizing adaptive composite springs made from carbon fiber and epoxy resin. The structure is designed using 3D modeling software (AutoCAD) and fabricated through a Hand Lay-Up technique with mold casting. The prototype undergoes performance testing using a hydraulic press machine to measure vertical load capacity and a shake table to simulate seismic activity. All testing data is documented and analyzed to evaluate the spring's effectiveness in seismic isolation.

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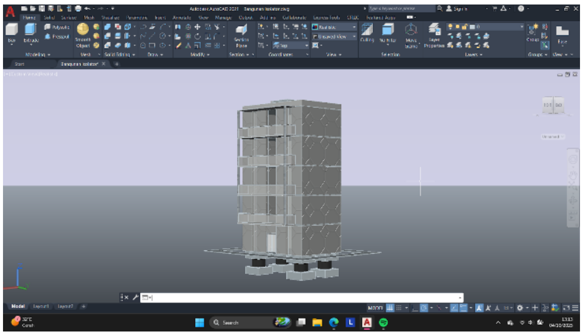

Figure 2. 3D Design of SEISPRING Using AutoCAD

Figure 2 shows the initial 3D design of SEISPRING modeled in AutoCAD. This design stage allows for the visualization of structural dimensions, placement orientation, and simulated load points before the physical prototype is produced.

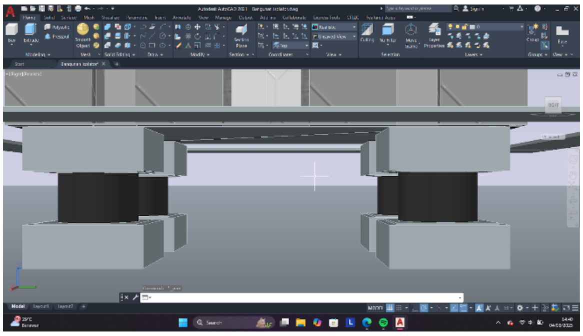

Figure 3. Installation of SEISPRING Prototype Beneath Building Structure

Figure 3 illustrates the conceptual placement of the SEISPRING prototype beneath a multi-story building column. In this implementation, SEISPRING functions as a seismic isolator installed between the foundation and the building structure. Its adaptive spring mechanism allows it to absorb seismic energy both horizontally and vertically, reducing structural stress during earthquakes.

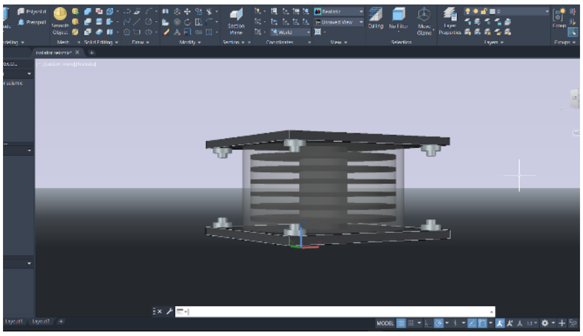

Figure 4. Internal Structure of SEISPRING Fabricated Using Hand Lay-Up Method

Figure 4 depicts the internal structure of the SEISPRING prototype, which is fabricated using the Hand Lay-Up method. This process involves alternately layering carbon fiber and epoxy resin to create a strong yet flexible composite spring. At the core of the isolator, a tightly wound roll of carbon fiber serves as the central energy absorber, enhancing the spring's ability to respond to seismic forces. On both the

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top and bottom of the composite structure, steel plates are attached as support connectors, allowing the SEISPRING unit to be firmly integrated into the building's foundation system. This layered configuration ensures optimal durability, load distribution, and effective seismic isolation performance.

## 4. IMPLEMENTATION

### 4.1 Effectiveness Test

The effectiveness test was conducted to evaluate how well the SEISPRING prototype performs in terms of vertical load-bearing capacity and seismic vibration damping. These evaluations are essential to determine its feasibility as an adaptive seismic isolator for multi-story buildings. Two types of tests were performed: vertical load testing and seismic vibration damping testing.

4.1.1 Vertical Load-Bearing Test

This test aimed to measure the SEISPRING prototype's ability to withstand vertical compressive loads, simulating the static weight that typically acts on the base of a building. The test was carried out at the Structure, Construction, and Material Laboratory of Sriwijaya University using a Hydraulic Press Machine.

The prototype was positioned between two steel plates, and a gradual load was applied to determine its maximum load-bearing capacity. The results indicated that the composite structure formed by alternating layers of carbon fiber and epoxy resin could effectively distribute vertical pressure, demonstrating the spring's potential to serve as a stable connector between the building and its foundation.

4.1.2 Seismic Vibration Damping Test

This test was conducted to assess SEISPRING's capability to dampen earthquake-induced vibrations in both horizontal and vertical directions. A Shake Table was used to simulate seismic movements at varying intensities, reflecting real earthquake scenarios.

During the test, the SEISPRING prototype was installed beneath a small-scale building model. The structural response was monitored, focusing on vibration amplitude and damping duration. The results showed that SEISPRING effectively absorbed seismic energy and minimized the transmission of vibrations to the upper structure, indicating its adaptability and damping efficiency.

Both tests demonstrated that the SEISPRING prototype has strong potential as an adaptive seismic isolator, offering effective vibration control, corrosion resistance, and structural durability. These characteristics make SEISPRING a promising alternative to conventional base isolator systems that often face limitations in long-term use and adaptability.

## 5. EVALUATION

The evaluation in this study is divided into two types: formative evaluation and summative evaluation. The formative evaluation focuses on the development process of the SEISPRING prototype, using technological tools such as 3D modeling (AutoCAD) and simulation-based design improvements to enhance the functionality and structural integrity of the device.

Meanwhile, the summative evaluation is carried out through performance testing in laboratory settings to assess the effectiveness of the SEISPRING prototype in real-use scenarios. This includes evaluating its ability to withstand vertical loads using a hydraulic press machine and its seismic energy absorption capacity using a shake table. These tests are aimed at determining the overall effectiveness of SEISPRING as an adaptive seismic isolator for multi-story building infrastructure.

SEISPRING is a prototype of an adaptive seismic isolator designed as a modern solution to the limitations found in conventional base isolation systems. Built using composite materials such as carbon fiber and epoxy resin, SEISPRING offers both high strength and resistance to environmental degradation, particularly corrosion a major issue with metal-based isolators like lead rubber bearings. Its design enables it to not only respond effectively to horizontal ground motion, but also to vertical seismic forces, which are often overlooked yet significantly impact the structural integrity of multi-story buildings.

The fabrication of the SEISPRING prototype involved a structured process using 3D modeling (AutoCAD) to visualize and dimension the spring structure, followed by the Hand Lay-Up method, where layers of carbon fiber and epoxy resin were alternately stacked. A central roll of carbon fiber was integrated to enhance the isolator's energy absorption capacity. Steel plates were then added to both ends of the spring to function as structural connectors, allowing the device to be firmly attached to the foundation and upper structure of the building. This layered and reinforced configuration ensures that the prototype is both durable and adaptable under seismic stress.

To evaluate its performance, two primary effectiveness tests were conducted: a vertical load-bearing test and a seismic vibration damping test. In the vertical load test, conducted using a hydraulic press machine, the SEISPRING prototype was able to withstand significant compressive force without visible deformation, indicating good load distribution and material resilience. In the seismic simulation test, conducted using a shake table, the SEISPRING was subjected to multi-directional movements that mimicked real earthquake conditions. Results showed a notable reduction in the transfer of vibrations to the upper structure, confirming the spring's damping effectiveness in both horizontal and vertical axes.

A needs analysis carried out as part of this research revealed that there is a strong demand for isolation systems that are corrosion-resistant, capable of handling multi-directional forces, economically viable, and low-maintenance. SEISPRING addresses these needs by offering a lightweight, high-strength solution made from affordable and accessible composite materials. Unlike traditional dampers that require ongoing care and are vulnerable to degradation, SEISPRING provides long-term durability with minimal maintenance, making it a more sustainable option for earthquake-prone regions like Indonesia.

## CONCLUSION

SEISPRING is not merely a structural element, but a technological innovation that integrates materials engineering, structural design, and disaster mitigation into one adaptive system. Its successful prototype testing marks an important step toward safer, more resilient infrastructure. With further development and scaling, SEISPRING holds the potential to transform how seismic protection is implemented in modern construction particularly for multi-story buildings in vulnerable areas.

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