Analysis of Damping Ratio in Passive Control Devices with Graded Sand as Fillers in the Shaft Section

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Abstract. Earthquake resistant design of structures has become a necessity in the present. Various kinds of innovations have been found in making earthquake dampers which are attached to the building structure. This innovation is one of passive control systems that modify the mass and stiffness as well as by adding damping materials to control the dynamic response of the structure due to the influence of lateral forces, one of which is the seismic force. This study focuses on a passive control device that can be added to the structure, which is a composition of rubber layers and steel plates with graded sand as the centre filler. Several previous studies have proved that the rubber has the ability to reduce vibration because of its elasticity. While the sand as choice for additive material based on a grain of sand forms a uniform that cause internal friction between the sand and can produce damping. Research conducted on a passive control device without graded sand as the centre filler and a passive control device with graded sand as the centre filler by using the half power bandwidth method to produce a damping ratio value (ξ). The experimental results showed that the value of the damping ratio of the passive control device with graded sand as the centre filler increased up to 43.94% instead of the passive control device without graded sand as the centre filler.

Keywords: passive control device, sand, graded sand, damping ratio, the increasing value of damping ratio.

1. INTRODUCTION

An earthquake is a vibration or shock that occurs on the surface of the earth due to the sudden release of energy that creates seismic waves.

Indonesia's geographical location between three active earth plates, namely the Pacific plate, Indo-Australian plate, and Eurasian plate causes Indonesia to be very vulnerable to earthquake disasters. The earthquake-prone areas include the western region of Sumatra Island, the southern region of Java, Nusa Tenggara, Maluku and Papua. Generally, earthquakes that occur in these areas
always cause fatalities. And most of the causes are not due to the direct effects of the earthquake, but because of the collapse of buildings during an earthquake.

In general, a building structure will withstand earthquake forces that occur by forming plastic joints on the beam due to energy absorption through the strength of the building itself. The formation of a plastic joint allows building occupants to save themselves during an earthquake. However, the plastic joints cause significant damage to the building and a substantial cost is needed to make improvements to the building structure after the earthquake.

Therefore, the researchers tried to develop an earthquake resistant building planning system to reduce damage that occurred after the earthquake. This system has the principle to control the earthquake force received by the structure of the building by reducing earthquake force. Basically this control system can be divided into two categories, namely a passive control system and an active control system.

Judging from the way it works, passive control devices are more beneficial when compared to active control device systems. In addition to its easier installation, passive control devices can also work well even without electricity, unlike active control devices that use electricity as their energy source, given the possibility of power outages during an earthquake. In addition, passive control devices can also be easily replaced with new devices if they are damaged after being affected by the earthquake.

Passive control system consists of two main functions that become the basic system of building structure control. The first function is to shift the natural frequency of the structure by modifying the mass and stiffness. While the second function is to reduce earthquake force by providing additional damping to the structure.

At the time of an earthquake, the earthquake force from the structure of the building will be transferred to the device first, so that the earthquake force can be reduced and only a small part of the earthquake force will be transmitted to the building structure.

2. PASSIVE CONTROL STRUCTURE SYSTEM

Passive control system is a system that uses enhancements to the structure with the aim of increasing locally the capacity of the structure to absorb earthquake energy, namely at the installation locations of the device. In this system, no additional energy sources or special electronic devices are needed to form a control system for the structure.

Based on its location, the type of passive control system used can be grouped into three, namely:

1) An additional passive damping system that is placed between floors of the building structure. Some examples of this type are viscous dampers, viscoelastic dampers, hysteretic dampers, and others.

2) A device system that is placed at the top of the building structure, namely Tuned Mass Damper (TMD).

3) A device system that is placed at the bottom of the building structure, namely the base isolation system.

This research is more focused on one type of passive control system, namely the base isolation system. The main concept of this base isolation system is to shift the natural frequency of the structure out of the frequency range which has a dominant influence due to the acceleration of the ground caused by the earthquake. In addition, base isolation is also expected to improve the ability of the structure to absorb earthquake energy, so that the earthquake force received by the building structure becomes smaller compared to ordinary building structures with pinch placement.
In this study used calculation of damping ratio by using the Half Power Bandwidth method. Half Power Bandwidth is the difference between two frequencies with respect to the same amplitude response, which is associated with damping in a system. A shape of the amplitude curve from a frequency obtained experimentally for a muffled structure, can be seen as in Figure 2. According to the picture, the bandwidth is located at $1/\sqrt{2}$ times the resonance amplitude. The equation used to find the damping ratio with this method, can be expressed by the following equation:

$$\xi = \frac{\omega_b - \omega_a}{2\omega_n} = \frac{f_b - f_a}{2f_n} = \frac{f_b - f_a}{f_a + f_b}$$

Figure 1. Main Concept of Base Isolation System

(Christianto, 2013:16)

Figure 2. Half Power Bandwidth (Chopra, 2007:83)
3. SAND AS DAMPER

Sand is one kind of granular material. Sand granules are generally between 0.0625 - 2 millimetres. Sand is a non cohesive soil because it has no or little particle adhesion between its granules, formed due to weathering of rocks. The weak bond between the soil particles is caused by the influence of carbonate or oxide compounded between the particles.

Grain size of sand

In Figure 3, it can be seen that the size of the sand grains are reclassified into 3 parts, namely coarse-grained sand, medium-grained sand, and fine-grained sand.

Sand can absorb an energy in two ways, through plastic deformation between grains of sand and friction between the sand grains. Through grain inter plastic deformation can occur in sand that gets a large pressure, the style is relatively lower, so that the grain between the sand does not change position. Through friction between the sand grains can occur if the sand grains get a pressure that causes a change in the position between the sand because of the frictional force between the grains, so that sand can absorb energy by converting mechanical energy into heat energy. Changes in position that occur in sand grains causes plastic strain through dynamic loading and then plastic strain turns into a hysteresis event. This hysteresis event forms a closed curve of the strain stress relationship in a dynamic loading in a cycle which is usually called a hysteresis loop.

Shear modulus and sand damping ratio are important parameters in soil dynamics, here is an explanation of shear modulus and damping ratio by sand. Shear modulus is one of the properties in soil dynamics. In general, land has a strain and stress relationship as shown in Figure 4. Shear modulus is shown from the cutting line as the highest value indicator on a hysteresis curve.
Figure 4. Sand Hysteresis Curve with Different Amplitude [12]

Damping is the release of strain energy in cyclic loading. The damping ratio is influenced by the grain size of the sand, moisture content, pore number, density level, number of loading cycles, strain levels, and pressure. Proportional damping of the area on the hysteresis curve. The damping ratio of the sand is influenced by the grain size of the sand, moisture content, pore number, density level, number of loading cycles, strain level, and the pressure applied to the surface of the sand layer.

4. MODELING OF TEST OBJECTS

The parameters of the test object model are obtained from the results of the analysis using formulas that are adapted to the conditions of the testing equipment in the laboratory.

a) Horizontal rigidity (K_H)
   \[ K_H = 1.250.000 \, \text{N/m} \]

b) Cross-sectional area (A)
   \[ A = 0.294118 \, \text{m}^2 \]
c) Dimensions of holes in the shaft of the test object model

![Diagram of a cross-section testing showing D1 and D2 dimensions](image)

Figure 6. Cross-section Testing

\[ \begin{align*}
D1 &= 0.7065 \text{ m} \\
D2 &= 0.3532 \text{ m}
\end{align*} \]

d) Number of rubber layers

Number of rubber layers = 10 layers

The force produced by the actuator machine has the following functions:

\[ F = F_0 \sin(2\pi ft) \]

In this test, frequency \( f \) is varied from 2.2 Hz to 5.2 Hz with an increase of 0.2 Hz.

The response obtained from this test is:

- \( U_1 \) = displacement measured by the sensor on the surface of the test object
- \( U_2 \) = displacement measured by the sensor at the bottom of the test object

![Diagram of testing models in the laboratory](image)

Figure 7. Testing Models in the Laboratory

As a filler in the shaft, a graded sand composition adjusted to the large arrangement of sand grains found in SNI 03-2834-2000, can be seen in table 1 below.
Table 1 Requirements for Sand Gradient Limits [2]

| Sieve (mm) | Zone 1 (%) | Zone 2 (%) | Zone 3 (%) | Zone 4 (%) |
|------------|------------|------------|------------|------------|
| 9.6        | 100        | 100        | 100        | 100        |
| 4.8        | 90-100     | 90-100     | 90-100     | 95-100     |
| 2.4        | 60-95      | 75-100     | 85-100     | 95-100     |
| 1.2        | 30-70      | 55-90      | 75-100     | 90-100     |
| 0.6        | 15-34      | 35-59      | 60-79      | 80-100     |
| 0.3        | 5-20       | 8-30       | 12-40      | 15-50      |
| 0.15       | 0-10       | 0-10       | 0-10       | 0-15       |

The chosen zone is zone 3 sand gradation, which is fine sand. The filter retained size used in this study was 9.6 mm; 4.8 mm; 2.4 mm; 1.2 mm; and 0.6 mm. Calculation of graded sand composition is carried out by the following steps:

1. The calculation of the percentage of the amount held from each of the retained filter sizes can be seen in Figure 8. and table 2. below.

![Figure 8. Percentage Graph Passing the Filter (Zone 3)](image)

Table 2. Percentage of Amounts Detained from Each Size of Hold Filter

| S. No. | Size (mm) | Amount Retained (%) | Cumulative Retained (%) | Percent Passing (%) |
|--------|-----------|---------------------|-------------------------|---------------------|
| 1/8    | 9.6       | 0                   | 0                       | 100                 |
| 4      | 4.8       | 7                   | 7                       | 93                  |
| 8      | 2.4       | 3                   | 10                      | 90                  |
| 16     | 1.2       | 7                   | 17                      | 83                  |
| 30     | 0.6       | 13                  | 30                      | 70                  |
| 50     | 0.3       | 70                  | 100                     | 0                   |

2. Calculation of the volume value rather than the axis of the test object model. Shaft diameter is taken 35 cm and shaft height 40 cm.
The volume of the shaft cylinder obtained is 0.03848451001 m³.
3. Calculation of the amount of sand needed for each size of the filter. The value of the weight of the sand taken is 1600 kg / m³. The calculation results can be seen in table 3.

\[ \text{Requirements} = \% \text{Amount of Retained} \times 1600 \times \text{Poros volume}. \]

Table 3. Sand Requirements for Each Size of Filter

| Sieve Number | Size (mm) | Requirements (kg) |
|--------------|-----------|-------------------|
| 4            | 4.8       | 4.31              |
| 8            | 2.4       | 1.85              |
| 16           | 1.2       | 4.31              |
| 30           | 0.6       | 8.00              |
| 50           | 0.3       | 43.10             |

5. TESTING RESULTS

The results of measurement data on the specimens carried out in the laboratory are as follows:
- mass of specimen \( (M_1) = 682 \) kg
- mass of specimen + sand \( (M_2) = 743.57 \) kg
- additional mass \( (M_3) = 1024 \) kg
- the stiffness of the specimen \( (k) = 146666.667 \) kg/m

\[ y = -10.43043288x^6 + 175.79182859x^5 - 1.188,72457532x^4 + 4.062,50199147x^3 - 7.171,60049119x^2 + 5.740,10784360x - 1.187,63595021 \]

Figure 9. Graph of Maximum Transfer Relations with Actuator Frequency in Graded Sandless Test Objects as Fillers in Shaft Parts
Based on the relationship of the maximum displacement graph with the frequency obtained the damping ratio as follows by using the Half Power Bandwidth method:

1. For graded sand-free specimens as fillers on the shaft, the calculation is as follows:
   From graph 5.1, the $f_a$ value is 3.00 Hz and $f_b$ is 3.90 Hz.
   Then we calculate the value of the damping ratio ($\xi$) :
   $$\xi = \frac{f_b - f_a}{f_a + f_b} = \frac{3.90 - 3.00}{3.00 + 3.90} = 13.04 \%$$
   The damping ratio ($\xi$) of the specimen without graded sand as a filler on the shaft section is 13.04 %.

2. For specimens with graded sand as fillers on the shaft, the calculation is as follows:
   From graph 5.2, the $f_a$ value is 2.77 Hz and $f_b$ is 4.05 Hz.
   Then we calculate the value of the damping ratio ($\xi$) :
   $$\xi = \frac{f_b - f_a}{f_a + f_b} = \frac{4.05 - 2.77}{2.77 + 4.05} = 18.77 \%$$
   The damping ratio ($\xi$) of the specimen with graded sand as a filler on the shaft section is 18.77 %.

6. CONCLUSION
Based on analysis data, the following conclusions are drawn:
- The damping ratio ($\xi$) of the specimen without graded sand as a filler on the shaft section is 13.04 %.
- The damping ratio ($\xi$) of the specimen with graded sand as a filler on the shaft section is 18.77 %.
- Increased damping ratio with graded sand addition as filler on the shaft part is 43.94 %.
- The damping ratio ($\xi$) generated by the test object with a large scale is relatively the same as the damping ratio ($\xi$) generated by a small scale test object.
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