International Journal of GEOMATE, Aug. 2023, Vol. 25, Issue 108, pp.11-20
ISSN: 2186-2982 (P), 2186-2990 (O), Japan, DOI: https://doi.org/10.21660/2023.108.3725
Geotechnique, Construction Materials and Environment

PROPERTIES AND DESIGN OF ENGINE MOUNTING RUBBER AUTOMOTIVE AS DAMPER FOR BUILDING RETROFITTING

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*Corresponding Author, Received: 29 Nov. 2022, Revised: 09 April 2023, Accepted: 23 April 2023

ABSTRACT: Characterization rubber tests were conducted for rubber materials of engine mounting rubber (EMR), to measure the parameters density (ρ), ultimate tensile strength (σ), elongation at break, and hardness (Shore A). Static and dynamic tests were carried out with several experimental methods for EMR as a damper system, from two brands, namely V-M and V-H. All rubber specimens had average tensile strengths between 16 and 17 MPa. The rubber can expand by 358.33 to 480 percent during the elongation break test, and the V-M rubber shows greater than the V-H, indicating that it is the softest and most elastic rubber. Seven variants of EMR and fifteen designs of damper developed from variety brands, dimensions, and the amount of EMR rubber. The V6 single rubber (V6-S) variant was selected from the most optimal previous stages test with 201.91 N/mm of stiffness and 9.237% of damping ratio at shaking table test. The hysteretic curve generated by experimental modeling on the proposed damper, both on the scaled model and on the prototype, can be represented in constitutive behavior on a numerical model with the appropriate elastoplastic damper parameters.

Keywords: Engine mounting rubber, Damper, Passive control device, Retrofitting

1. INTRODUCTION

Three mechanisms, namely isolation, energy absorption in plastic hinges, and the application of mechanical devices as structural controls, can be effectively and practically used to ensure a sufficient earthquake response from a structure. Two types of structural control that can be applied as mechanical devices are active control and passive control. The disadvantage of active control is that it requires an electric current to activate the damper so it is not reliable during seismic events where the electric current usually occurs. In the passive energy dissipation system, a special device is applied in the structure to absorb some of the seismic energy, so that the energy dissipation in the main structural elements is greatly reduced along with the reduced potential for damage to the structure.

Currently, the most widely used devices to control the vibration response of buildings during seismic events are passive control damper devices for the absorption of earthquake energy. Many materials and designs are utilized in the various types of dampers that are currently on the market to produce differing levels of stiffness and dampening. Some of them are friction dampers, viscous dampers and viscous elastic dampers. For a newly constructed building, dampers are often fitted in the space between two structural components (such as walls or columns). For high-rise existing structures, one possibility for installing the damper is between shear walls. A good damping system may result in increased comfort and safety as well as financial savings.

Most earthquake fatalities occur in low-rise homes and low-level public structures, which are not given much consideration in seismic load planning. When we properly plan high-rise buildings, the situation is totally different. In other occasions, there are several public structures that were built in accordance with previous regulations but are still in service today. To improve the performance of buildings against earthquake loads, especially for low-rise buildings or simple houses, Tanjung [1] has researched the strengthening of concrete frame structures in simple brick wall houses by applying the wire mesh material method to the diagonal wall area. This method is able to increase the lateral strength by 22.6% and delay the collapse time of reinforced concrete. The advantages of this method are easy to apply without the need for experts, and the materials are very cheap and easy to obtain. Especially in developing countries like Southeast Asia, which are prone to earthquakes, easy and cheap damper devices are needed. Cities in Indonesia, in particular, also have a high probability of the occurrence of giant earthquakes and a high level of seismic risk for earthquakes [2].

Houses, simple buildings, and low-rise public buildings are buildings that are generally built at low cost and owned by individuals. So, to do retrofitting as an effort to improve performance, it is better to do it at a low cost and make it easy to manufacture and install. For the purpose of easy application and being cheap and easy to obtain, in the automotive area, there are also spare parts that have the potential to be used to improve building performance, especially in low-rise buildings. Engine mounting rubber (EMR) is one of the vehicle components that is composed of high-damping rubber material, which is the holder component, and at the same time dampens the engine vibration so that the vibration does not propagate to the car frame, which then spreads to the passenger cabin. In this study, the existing component will be equipped with a device holder to facilitate installation in the existing building, which will also play a role in the stiffness test and damping test processes.

2. RESEARCH SIGNIFICANCE

Many existing buildings were built based on the old regulations, which are still standing and operated to serve the public. To ensure the safety and proper functioning of existing buildings, their performance needs to be improved in order to meet the demands of the latest regulations without demolish them down. One alternative potential practical solution is to add passive energy dissipation devices to the existing structure. Since the majority of the problems are in existing low-rise buildings, ideally the selected energy dissipation device should be simple, easy to install, relatively inexpensive but function reliably during an earthquake. Research has been carried out to assess the performance of several alternative simple passive energy dissipation devices, and to apply the best alternative to a scalable model of typical low-rise buildings for performance improvement studies during an earthquake.

3. DAMPING SYSTEM

Two types of structural control that can be applied as mechanical devices are active control and passive control. The disadvantage of active control is that it requires an electric current to activate the damper so it is not reliable during seismic events where electric current normally occurs. In the passive energy dissipation system, the structural elements are applied with a special element system to absorb some of the seismic energy, so that the energy dissipation in the main structural elements is greatly reduced along with the reduced potential for damage to the structure [3-4]. Fig.1 show several concepts of passive energy dissipation systems along with hysteresis loops and physical models.

4. VISCOELASTIC DAMPER

In the early 1990s, viscoelastic dampers (VED) became the subject of research and development for earthquake applications. The damper has been developed and applied to steel frames and reinforced concrete frames through experimental research over the past few years. VEDs are mostly used in structures that have the potential to undergo shear deformation.

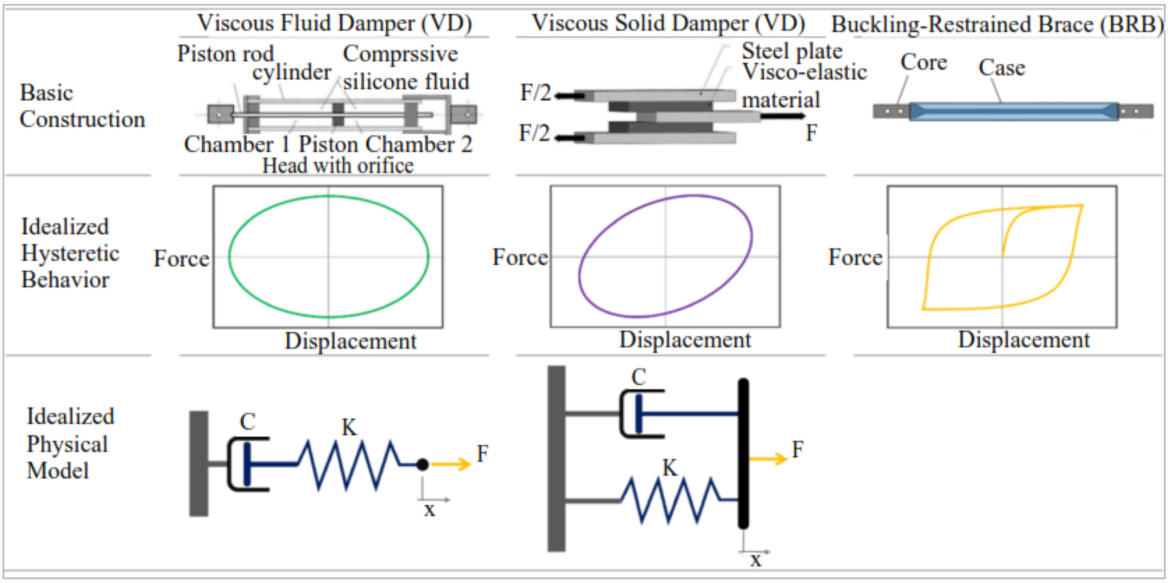

Fig.1 Damper devices design concept of Viscous Fluid Damper, Viscoelastic Solid Damper, and Buckling-Restrained Brace, hysteresis loop curves, and physical models [3]

Viscoelastic solid dampers generally have a design concept that one end of the damper element will slide over one another. By their nature, viscoelastic solids exhibit elasticity and viscosity, i.e., their behavior depends on velocity and displacement [6]. Shanmuga [7] has reviewed several structural behavior with viscoelastic damper installation. The viscoelastic damper material installed in the Stocton hotel is able to reduce deflection up to 17.47%.

Nakamura [8] configured the VED design and placement in buildings. In general, there are three configurations, namely braced type, wall type and column type. The VED material will provide a viscous shear in response to the presence of inter-story drift, resulting in energy dissipation, and therefore, the properties of the VE material will determine the performance and characteristics of the VED. The mechanical properties of the VED generally show a significant dependent on the amplitude and frequency of excitation as well as the temperature at which the material develops.

Chen [9] investigated the Viscoelastic damper material made of high damping rubber (HDR) produced in China. Conducting a series of tests, starting with investigating the material properties of HDR by applying nonlinear analysis with ABAQUS software. Three different geometry variables were tested with cyclic loading. The results of the analysis show that the Viscoelastic damper has a large deformation capability. The effect of strain amplitude is more significant than load frequency. The specimen configuration of the Viscoelastic Chen 2019 material is shown in Fig.2, in the red part is HDR and in the gray part is steel plate. The HDR length, width and thickness are 25 mm, 12 mm and 6 mm respectively. HDR is attached with three steel plates. The length, width and thickness of the three steel plates are 100 mm, 25 mm and 6 mm, respectively. The specimen loading is displacement control. With three variables the displacement amplitude is 6 mm, 12 mm, and 18 mm, respectively. At each amplitude, the specimen was loaded with four cycles. The damping force of the rubber at each displacement level is recorded by the computer system.

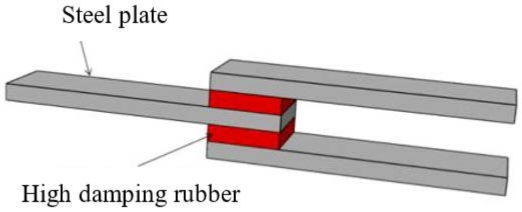

Fig.2 Chen's viscoelastic damper specimen configurations [9]

Table 1 is the mechanical index of the HDR material [9] it can be seen that HDR has a high shear deformation capacity and a high damping ratio, so that the material properties meet the requirements for application as a damper. The hysteresis curve of the experimental results is shown in Fig.3.

Table 1 Mechanical index of HDR materials [9]

Performance Index	Test Value
Hardness	75.00
Tensile strength (MPa)	17.22
Elongation after fracture (%)	436.00
Tearing strength (N/mm)	80.00
Shear modulus (MPa)	1.33
Adhesion strength between rubber and steel plates (MPa)	6.95
Equivalent damping ratio (%)	15.10

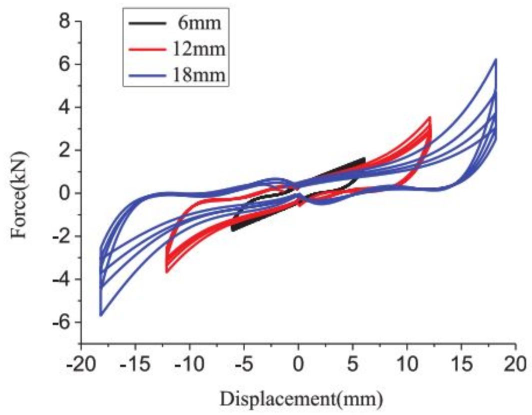

Fig.3 Hysteresis curve of high damping rubber material [9].

The shape of the hysteresis curve is an ellipse with deformation amplitude of 6 mm. When the shear deformation reaches 12 mm, the pinching effect becomes noticeable due to the hardening of the viscoelastic material under the larger deformation.

5. HIGH DAMPING RUBBER

Nakamura [8] has made a design for a viscoelastic damper using high damping rubber (HDR) material which is inserted between 3 layers of iron (inner plate and outer plate) and this design will lead to shear deformation behavior, as shown in Fig.4.

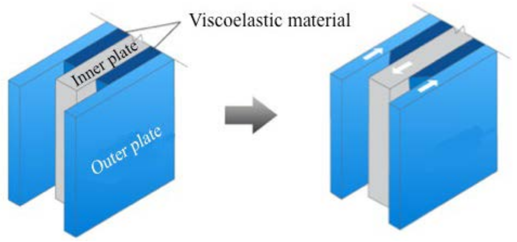

Fig.4 Nakamura's viscoelastic damper design concept [8]

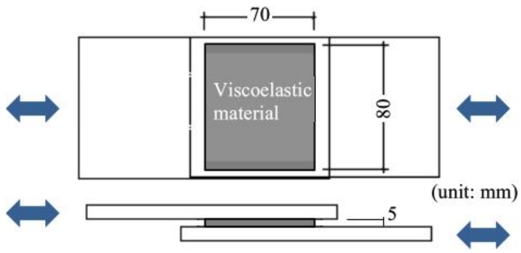

Fig.5 Nakamura's Design of Viscoelastic material specimens [8]

Mechanical characteristics for the new viscoelastic (VE) material developed by Nakamura [8] made from thermoplastic elastomers of the olefin-styrene series. A series of dynamic loading tests were carried out on the specimen consisting of sheets of 70mm x 80mm viscoelastic material per sheet (thickness d 5 mm, total shear area A_s 5,600 mm^2), as shown in Fig.5, with air temperature is 20°C. Fig.6 shows the hysteresis loop of Viscoelastic material at 0.33Hz sine wave [8]. The hysteresis loop measured under sinusoidal load show in Fig.7.

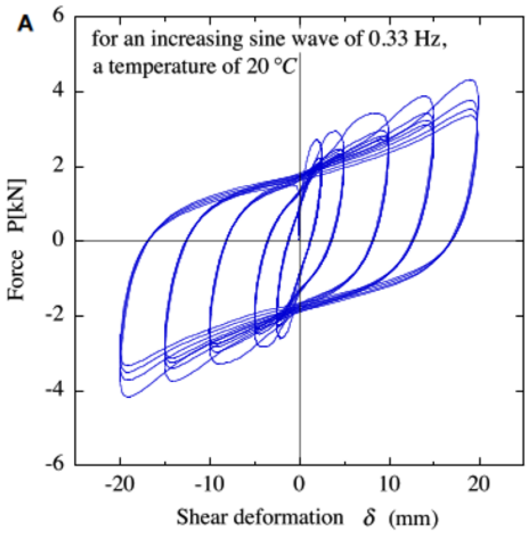

Fig.6 Characteristics of resisting force on Viscoelastic materials [8]

Nakamura and Okada [10] made a damper design using high-damping rubber (HDR) material. As shown in Fig.8, the HDR material is inserted between the metal plates. When the building experiences an earthquake, the HDR which is in a position between the iron plates will experience shear deformation and can absorb vibration energy due to the earthquake. Nakamura also reviewed the temperature conditions of the HDR material, the temperature conditions in HDR will increase by several degrees during earthquake excitation because the absorbed earthquake energy will turn into heat energy.

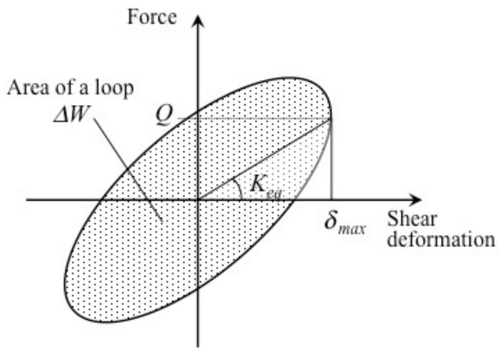

Fig.7 Analysis of equivalent stiffness and area of hysteresis loop [8]

(a) Viscoelastic damper design concept (b) Viscoelastic damper prototype

Fig.8 Okada's viscoelastic damper using high-damping rubber material [10]

6. EXPERIMENTAL METHOD

The materials and systems of passive energy dissipation devices used are selected from existing systems in the automotive spare parts. From previous research, two alternative devices that can be viewed from automotive components where in the system itself the component acts as a damper are Shock Absorber (SA) and Engine Mounting Rubber (EMR). Henceforth, the two types of devices are assumed to be dampers with the type of Viscous fluid damper and the type of Viscoelastic damper. One of the variables in choosing is the type of transportation vehicle from the lightest vehicle to a vehicle that is quite large in tonnage. In this research, the EMR system has been selected as a device that will be proposed as a damper.

6.1 Rubber Characterization

Several tests were conducted as part of the research on rubber materials, namely the ultimate tensile strength test (σ), axial elongation test, hardness test (Shore A), and density test (ρ) were among the tests performed on the physical and mechanical properties. The experiment was carried out in the testing laboratory of Center for Leather, Rubber, and Plastics Yogyakarta, Indonesia. The test was carried out on two types of EMR rubber from two types of manufacturers with different brands of automotive spare parts manufacturers, namely V-H and V-M, brand from automotive companies HINO and Mitsubishi.

6.1.1 Tensile strength test

The test method in accordance with ISO 37: 2015 (IDT-2011) (Rubber, vulcanized or thermoplastic - determination of tensile stress-strain properties) [11]. The specimens shaped as dumbbell from EMR rubber. Its measuring length is 20 ± 0.5 mm, and its narrow section's thickness is 2 ± 0.2 mm, pull until the specimen breaks, the testing machine operates at a grip speed of 500 mm per minute.

6.1.2 Break elongation

The maximal extension expressed as a percentage of the original length before the sample was broken is called elongation at break (%), also possible to determine a specimen's modulus of elasticity by examining the strength-strain relationship curve generated by an automatic machine output.

6.1.3 Hardness test

A material's elasticity can be determined by its hardness. The more elastic material is indicated by a lower hardness. According to ISO 7619-1: 2010 (Rubber, vulcanized or thermoplastic Standard - measurement of identifying hardness - durometer method/Shore Hardness) [12]. According to a scale of penetration depth from 0 to 100 throughout the duration of 3 to 15 seconds, the pressure load of the durometer (Shore A) is 1 ± 0.1 kg or 12.5 ± 0.5 N. The specimens have a surface area to get at least three test points and a thickness of about 6 mm. A minimum of 5 mm must distinguish the points, and a minimum of 13 mm must separate the points from the edge. The machine's digital monitor automatically provided the hardness value [13].

6.1.4 Density test

The density test uses an electronic densimeter with a resolution of 0.01 and follows ISO 2781: 2008 (Rubber, Vulcanized or Thermoplastic - Determination of Density) [14]. The densimeter's beaker has a 250 cm^3 capacity. The sample is a fragment of rubber tire weighing at least 2.5 gr.

6.2 Engine Mounting Rubber Damper Testing

Static and dynamic tests were carried out with several experimental methods. The research for EMR was conducted on two objects, the rubber material itself contained in the EMR system, and the EMR rubber that is already in the damper system.

Several stages of testing, including static and dynamic tests, were conducted as part of the research for EMR rubber as a damper system. Carried out in the structural laboratory of the Department of Civil Engineering and Environmental Sciences, Gadjah Mada University, Yogyakarta, Indonesia. The lab serves as the primary location for the equipment applied in this study. The Dewesoft data acquisition system, a datalogger, a loading frame, a hydraulic jack, a dial gauge, and an LVDT are some of the main equipment.

Variants of high damping rubber engine mounting material are presented in Table 2. There are several designs of dampers with single rubber (V3-S, V4-S, V6-S, V7-S). Small and medium size in dimension will be used as dampers in laboratory scale models, and the larger ones that are potential to be used as prototype dampers in existing buildings. As a comparison, we also tried the damper material from the elastomeric bearing pad of the bridge pedestal (V-BP).

Table 2 Variations of damper design specimens

Varian	Damper Design
V-BP	
V3-S	
V4-S	
V6-S	
V7-S	

6.2.1 Static test

The static test carried out 3 laboratory testing methods (hereinafter referred to as experiments A, C, D). Experiment A is testing the value of the stiffness of the material on 5 types of test objects in Table 2 using the Spring Tester Machine instrument at PT Kayaba Astra Bekasi Indonesia.

The damper device is clamped on both sides of the holder, one of the holders (upper side) is pulled in line with the damper device by controlling a certain displacement according to the plan. By pulling the damper device it will be known how the material reacts to the pulling force and knowing how far the material has increased in length. Load levels and displacement values are variables that can be measured which are read digitally via computer and will get a tensile profile in the form of a curve that shows the relationship between the tensile force and the change in length.

Experiments C, D, E and F were carried out completely at Gadjah Mada Structure Laboratory. Experiment C as shown in the setting up of Fig.9. Tests were carried out on variant 3 single rubber (V3-S), variant 4 single rubber (V4-S), variant 6 single rubber (V6-S), and variant 7 rubber single (V7-S). Static tests are carried out by using the system and instrumentation on loading frame with loading and unloading method. Two LDVTs are installed above and below the damper device, respectively, to control and read displacement data on the data logger. Loading and unloading data is assisted by a load cell measuring instrument, which is also read on the data logger.

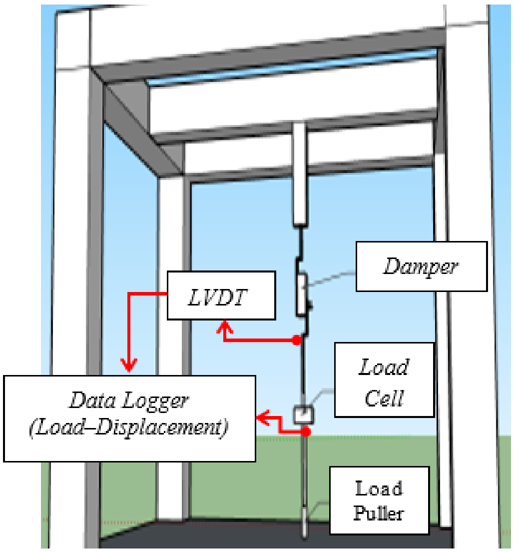

Fig.9 Setting up of static test of damper

Experiment D is a static test activity, using a higher loading frame that is different from experiments C as a requirement to obtain sufficient clearance. The loading method using a hydraulic jack will require a larger space. Further, a test will be conducted on rubber samples in group formation. One rubber group consists of four rubbers of the same variant arranged in two rows, so that the damper device model will be larger than the single-design rubber damper (Fig.12). The variant of rubber dampers tested are variant 3 single (V3-S), variant 4 single (V4-S), variant 6 single (V6-S), variant 3 group (V3-4R), variant 4 group (V4-4R), variant 6 group (V6-4R). Giving load and unload by pulling manually with a hydraulic jack. All LVDT measuring instruments and load cells are computerized using Dewesoft X3 software so that data on load values and displacement values can be obtained.

At experimental stage D, the development of rubber variations from automotive spare parts was also carried out for vehicles with a larger tonnage. These variants also have larger rubber dimensions (t x p x l), namely the V8 variant (3.7 x 4 x 4.4 cm), the V9 variant (4.9 x 6.5 x 5.5 cm), the V10 variant (5.3 x 7.5 x 7.5 cm), the V9 variant (4.9 x 6.5 x 5.5 cm), the V10 variant (5.3 x 7.5 x 7.5 cm), and the V11 (5.2 x 7.5 x 6.3 cm). At this stage, the damper design was also developed from one rubber, two rubbers and four rubbers (Fig.10).

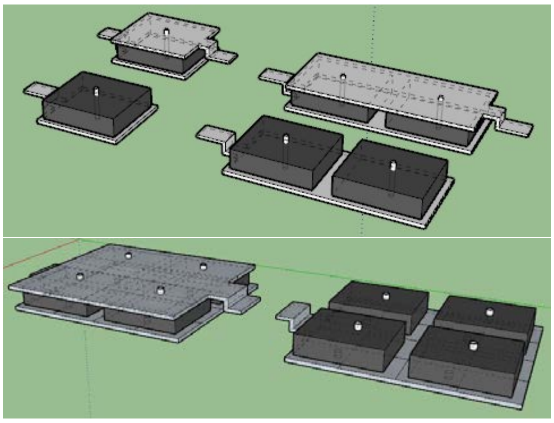

Fig.10 Damper design with 1, 2, and 4 rubber

6.2.2 Dynamic test

The dynamic test carried out 2 laboratory testing methods (hereinafter referred to as experiments E and F). Experiment E is a free vibration test, this activity is carried out to obtain decay behavior on the damper. Examples of free vibration test responses are shown in Fig.11.

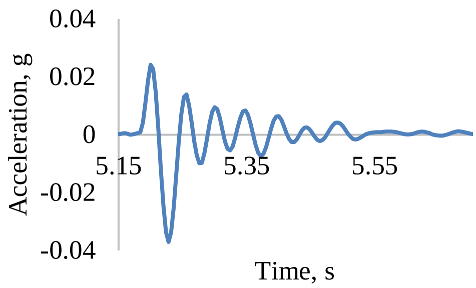

Fig.11 Time response to acceleration and frequency response to the free vibration test.

In the set-up shown in Fig.12, the damper test object is hung on the loading frame with one of the upper damper handles clamped and the other side of the bottom handle free. The load will be hung on the free side of the handle as planned, with a rope serving as the connecting medium between the handle and the load. The rope will be cut to get a free vibration response. The accelerometer is placed on the side of the damper that is not clamped to obtain an acceleration response over time, the decay behavior is obtained due to the material's role as a damper, and the frequency response is obtained by the Fast Fourier Transform (FFT). The types of rubber dampers tested are type 3 single (3-S), type 4 single (4-S), type 6 single (6-S), type 3 group (3-4R), type 4 group (4-4R), type 6 group (6-4R). All data is recorded in the Dewesoft X3 software and analyzed to obtain natural frequency and damping ratio values.

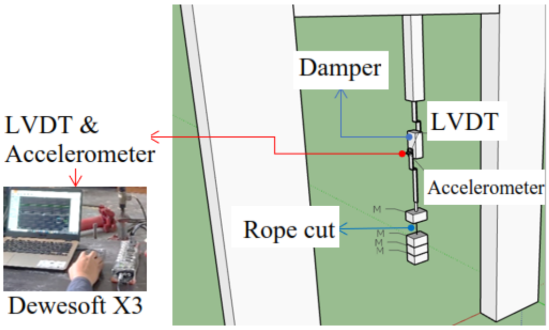

Fig.12 Material damping test (experiment E)

Experiment F is a dynamic test with a shaking table instrument with earthquake dancing software and Dewesoft X3 software. In the earthquake dancing software, the excitation value given to the damper will be input. The design excitation value is the displacement value and the frequency value. The displacement value variations given are 6.25mm, 12.5mm, 18.75mm, 25mm. each displacement value will be assigned a frequency of 0.5Hz, 1.0Hz, 1.5Hz, and 2.0 Hz (Fig. 13-14).

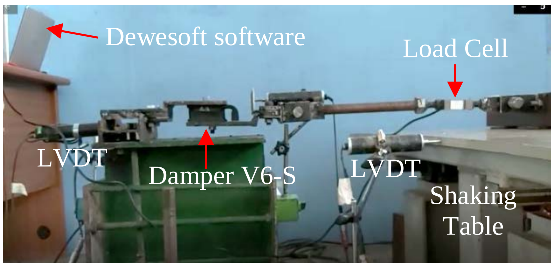

Fig.13 Setting up a single rubber damper dynamic test on a shaking table (experiment F)


Fig.14 Damper design with 4 rubbers on setting up test (experiment F)

In F experiment, to get the damping ratio value of the material, supporting instruments will be used, namely load cells and LVDT which are connected to a computer installed with Dewesoft X3 software so that data on the relationship between load and displacement will be obtained and plotted in the form of a curve. The graph or curve will form a hysteresis loop which will be analyzed for its shape and area value.

The requirement applies to all variations or types of dampers that will be installed, and it states that each damper device must have its properties verified through testing, including both numerical model tests and laboratory studies. The damper device prototype test was carried out on a full scale with a minimum of two specimens, and the force and displacement parameters were measured with precision and accurately read on the digital instrument. One that is controlled in seismic testing is the maximum displacement value of the damper, which represents the value of the MCE_R ground motion. Ten cycles of displacement on the damper device with a simulated earthquake load of 0.33 times the displacement of the MCE_R. Five cycles of displacement on the damper device with a simulated earthquake load of 0.67 times the displacement of MCE_R. Three cycles of displacement on the damper device with a simulated earthquake load 1.0 times the displacement of the MCE_R.

At room temperature, each damper device will be loaded with a series of sinusoidal cycles with a frequency of $1/(1.5(T_1)$, indicating that plastic hinges have occurred in the building, implying that the building has become plastic as its period increases from (T_1) to period $1.5(T_1)$. In an effort to see the viscoelasticity of the damper device, it is necessary to look at the two frequency variables, namely low frequency and high frequency. To represent high frequency (high mode), the specimen also applies a variable for high frequency, namely $2.5(T_1)$. At low frequencies, it will be represented by a value of 0.05 Hz. The parameter measured is the area of the hysteresis loop formed from the two frequency variables above. The difference between the area of the hysteresis loop at high frequencies and the area of the hysteresis loop at low frequencies will show the properties of the viscoelastic material.

7. RESULT AND DISCUSSION

7.1 Rubber Characterization

All specimens had an average tensile strength between 16 and 17 MPa, according to the findings of the tensile strength test comparing the two rubber brands. This study's tensile strength result is comparable to Bijarimis's, which was determined to be in the range of 16.5 to 21.2 MPa [15], and Chen’s at 17.22 MPa [9] .

At the elongation break test, the specimen can expand by 358.33 to 480 percent of its initial length when put under pressure. The V-M rubber shows the greater break elongation than V-H. This finding suggests that the V-M rubber is the softest and most elastic. This result is in line with Chen's study with 436 percent of break elongation [9]. The hardness test result is around 55.01 to 64.23, which slightly agrees with Chen’s report at 75.

Table 3 Engine Mounting Rubber Characterization Test, V-H and V-M brand

Performance Index	Test Value	
	V-H	V-M
Tensile strength (N/mm^2)	17.53	16.79
Break elongation (%)	358.33	480
Hardness (shore A)	64.23	55.01
Density ($gr.cm^3$)	1.19	1.14

The results of the density test comparing the two rubber brands reveal that all specimens had an average density of 1.16 gr/cm^3. This figure is consistent with the findings of Edeskar's investigation [16].

7.2 Static Test

Experiment A was carried out at the Kayaba Astra Indonesia company with a spring tester machine. Data analysis was carried out on five damper variants in Table 4 to see the stiffness value. The results of the analysis showed that the best value for the modified elastomer bearing pad (V-BP) was 392.62 N/mm^2. Although it has the best value, this damper design is not practical in its manufacture because it requires more complicated modifications compared to the other four designs. From this result, it was decided to use the highest value of one of the dampers with EMR material, which will then be compared to the next method. The V6-S, which is a spare part of the Mitsubishi Colt Diesel Engine Mounting vehicle (ME011832), achieves the best value with a 210.35 N/mm^2 stiffness value.

Table 4 Engine Mounting Rubber Stiffness (Kayaba-Astra) (experiment A)

EMR Variant	Stiffness, k (N/mm^2)
V-BP	392.62
V3-S	51.351
V4-S	70.393
V6-S	210.35
V7-S	39.665

Experiment C is a follow-up experiment that calls for the use of improved procedures or the setup of laboratory equipment. This test no longer includes the type I variant. When the remaining four versions were examined once more, the results showed the same consistent trend as experiment A's findings. The rubber of the Mitsubishi ME011832 Colt Diesel EMR, which is measured at 189.872 N/mm^2, delivered the greatest stiffness results (Table 5).

Table 5 Single rubber static test in the UGM structure laboratory (experiment C)

Damper Type	Stiffness, k (N/mm^2)
V6-S	210.35 (experiment A) 189.872
V3-S	64.016
V4-S	103.351
V7-S	19.008

Further research and development were carried out on experiment D using a better implementation method and producing stiffness values for seven EMR variants with sixteen damper designs.

Table 6 Stiffness for Single rubber variant and Group rubber variant (4 rubbers) (experiment D)

Damper Desain	Stiffness, (N/mm^2)
V3-S (single-small)	60.749
V4-S (single-medium)	122.862
V6-S (single-big)	178.04
V3-4R (4 rubbers-small)	154.225
V4-4R (4 rubbers-medium)	401.342
V6-4R (4 rubbers-big)	533.737

In the damper design with a single rubber, the best stiffness performance is in the V6-S (Mitsubishi ME011832 Colt Diesel) EMR's rubber, which reaches a stiffness of 178.04 N/mm^2, and the V10-2R (Truck Colt Diesel Mitsubishi Canter double 125 PS) value of 146.32 N/mm^2, which is consistent with the result at experiment C. In the damper with two EMR rubber designs, the highest is on the V10-2R damper at 231.03 N/mm^2, while in the damper with four EMR rubber designs, the highest is on the V6-4R at 533.737 N/mm^2 (Table 6 and Table 7).

Table 7 Stiffness for Single rubber variant and Group rubber variant (experiment D)

Damper Desain		Stiffness, N/mm^2
V8-S	1 rubber	50.643
V8-2R	2 rubbers	96.822
V8-4R	4 rubbers	174.33
V9-S	1 rubber	99.082
V9-2R	2 rubbers	187.05
V10-S	1 rubber	146.32
V10-2R	2 rubbers	231.03
V11-S	1 rubber	86.802
V11-2R	2 rubbers	149.35

7.3 Dynamic Test

The dynamic test is carried out by applying a gravitational load that is hung by a rope and then cut in order to obtain a vibration response from the damper test object. Data reading using Dewesoft X3 instrument software to obtain a graph of decay behavior (Fig.11) and processed to get the value of the damping ratio (Table 8-9).

Table 8 Damping ratio of single rubber damper (S) and group rubber damper (4R) (experiment E)

Varian EMR	ξ, % Single	Group
V3	11.901 (V3-S)	17.293 (V3-4R)
V4	11.443 (V4-S)	7.236 (V4-4R)
V6	9.295 (V6-S)	8.801 (V6-4R)

Table 9 Damping ratio of single rubber damper (S) and group rubber damper (2R and 4R) (experiment E)

Varian EMR	Desain	ζ, %
V8	V8-S	11.015
	V8-2R	11.522
	V8-4R	9.469
V9	V9-S	11.141
	V9-2R	12.841
V10	V10-S	9.303
	V10-2R	11.032
V11	V11-S	14.986
	V11-2R	13.666

The best value of damping ratio is in variant 11 with one and two EMR designs (V11-S and V11-2R). V11 is the EMR with the largest rubber dimension, especially in the shear area, so the variable dimensions are very influential on the damping ratio value.

7.4 Shaking Table Test

A dynamic test was carried out on the damper material with a shaking table instrument for the selected damper device, V6 single (V6-S) variant selected from the most optimal previous stages results (Table 8). The load protocol on the shaking table input were two variations of displacement control (12.5 mm and 18.75 mm) and four variations of frequency (0.5 Hz, 1.0 Hz, 1.5 Hz, and 2.0 Hz).

Numerical analysis was also carried out with SAP2000 software for the purpose of validating the experimental data results (Fig.18). The analytical method and numerical solution applied are the direct integration nonlinear time history method with a displacement load of 12.5 mm. Comparison of the hysteresis area between the numerical analysis with SAP2000 software and the results of the laboratory experimental analysis is 14,407.925 Nmm and 12,827.7 Nmm. The hysteresis curve of high-damping rubber material in Chen's [9] and Chang's [17] also has a hysteresis value and shape that are similar to the experimental results and numerical analysis in this study.

Table 10 Damping ratio and stiffness of V6-S rubber at displacement load 12.5mm (experiment F)

Frequency	ξ, %	Stiffness, (N/mm^2)
0.5	6.923	206.75
1.0	8.478	211.23
1.5	8.906	201.85
2.0	9.237	201.91

Table 11 Damping ratio and stiffness of V6-S rubber at displacement load 18.75mm (experiment F)

Frequency	ξ, %	Stiffness, (N/mm^2)
0.5	6.544	204.9
1.0	6.033	210.02
1.5	6.382	204.07
2.0	5.950	204.65

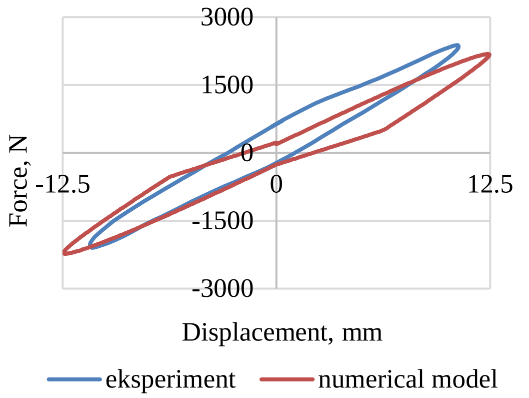

Fig.18 Comparison of hysteresis area between numerical analysis and laboratory experimental analysis (V6-S ; 2 Hz ; 12.5 mm)

8. CONCLUSION

All specimens had average tensile strengths between 16MPa and 17MPa, according to the characterization rubber test, which is comparable with the findings of previous studies. The specimen can expand by 358.33 to 480 percent during the elongation break test, and the V-M rubber shows greater than the V-H, indicating that it is the softest and most elastic rubber.

The hysteretic curve generated by experimental modelling on the proposed damper, both on the scaled model and on the prototype, can be represented in constitutive behaviour on a numerical model with the appropriate elastoplastic damper parameters, ready to be used for nonlinear time history analysis modelling in order to design retrofitting of existing buildings, including predicting seismic performance during an earthquake.

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