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# Simple Laboratory Test to Measure Damping Properties of Hardened Mortar or Concrete Elements

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**Abstract:** Concrete or mortar is the common material for earthquake resistant buildings in earthquake-prone areas. One of the crucial requirements of the earthquake resisting structure is the ability to reduce the earthquake energy as indicated by the damping ratio which can be upgraded by high damping materials. Currently, there are many researchers conducting damping properties investigation on several materials to improve the damping capacity of structures, but they are lack of literatures about the methodology of damping experiments. Therefore, this research aims to present a simple laboratory test to measure damping properties of mortar or concrete elements. It also presents the application of this method for a 100 x 100 x 500 $mm^3$ mortar beam by two load variations (10 and 15 N) and five times loading for each variation. The result shows that the damping ratio of the mortar beam is 2.27% and 2.37% for 10 and 15 N load. Besides, it is known that the magnitude of the external forces also influences the damping ratio. This provides further research opportunities to improve the quality of testing methods. The experiment with more various loads and number of specimens to get the broader analysis is suggested.

**Keywords:** Damping ratio, fundamental frequency, concrete or mortar, ASTM E 756-05

## 1. Introduction

Concrete and mortar are widely used as building materials for structural or non-structural element. Reinforced concrete is generally used as a structural element like the main column, main beam, practice column, sloof, ring-balk, and floor plate. However, mortar is often used as a non-structural element like a plastering and mortar bed joint of masonry wall structure. Concrete and mortar are comprised of cement, aggregate, and water. Concrete commonly uses coarse and fine aggregate but mortar only uses fine aggregates. Thus, mortar is often referred as fine aggregate concrete.

In Indonesia, there are many buildings built on earthquake prone areas, mostly using concrete and mortar. However, these buildings do not meet the requirement of earthquake resistance structure such as having lightweight material, having high ductile and being able to dissipate more of earthquake energy. Previous studies aiming to improve the ability of concrete and mortar materials in dissipating earthquake energy have been widely carried out by way of increasing the damping ratio of the material. (Faizah, Priyosulistyo, & Aminullah, 2019) stated that the addition of rubber tire crumb (RTC) to mortar mixtures can increase damping ratio of hardened mortar up to 175%. Meanwhile, (Jianmin, Zhimao, Hui, & Xing, 2013) investigated the damping ratio of polymer concrete by adding carboxylic

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styrene-butadiene latex (CSBL) in normal concrete. The results indicated that the damping ratio of polymer concrete beam is 50% higher than the normal concrete. Damping behavior of concrete polymer has also been studied by adding polypropylene fibers and styrene-butadiene rubber (latex) to normal concrete. The increase in damping value in this polymer concrete reaches 21% (Nabavi, 2008).

Standard test method to measure the damping properties of materials were given by (ASTM E756-05, 2005) and also be presented by previous researchers with various methods. The ASTM E756-05 method is not friendly for concrete or mortar material, hence, it must be added by several items. Modification of the ASTM E756-05 method was presented by previous researchers, but there has been no appropriate method yet found for mortar or concrete element using a simple method. Some researchers used a complicated method to identify damping properties of concrete, for example, using a shake table method (Nabavi, 2008) or full scale method (Butterworth, Lee, & Davidson, 2004).

This study presents alternative method to measure the damping properties of concrete or mortar material using a simple and easy method to do. This paper does not only describe the methodology of the new method but also applies it with a laboratory experiment to investigate the damping properties of mortar beam. This finding is expected to give an interesting solution for new researches to carry out the experiment by a simple method.

## 2. ASTM E756-05 standard test method

ASTM E756-05 provides test method for measuring the vibration-damping properties of materials including the loss factor ($\eta$) and Young's modulus ($E$) or the shear modulus ($G$). This method sometimes is referred to as the Oberst Beam Method (OBM) which is useful for materials such as metals, enamels, ceramics, rubber, plastics, reinforced epoxy matrices, and woods. OBM is the classical method for the characterization of damping materials based on a multilayer cantilever beam which consists of a base beam and one or two layers of other materials shown in Fig.1. The base beam in ASTM E756-05 method is almost always made of a lightly damped material such as steel and aluminium (Koruk & Sanliturk, 2010). It seems to be not recommended for concrete and mortar material testing.

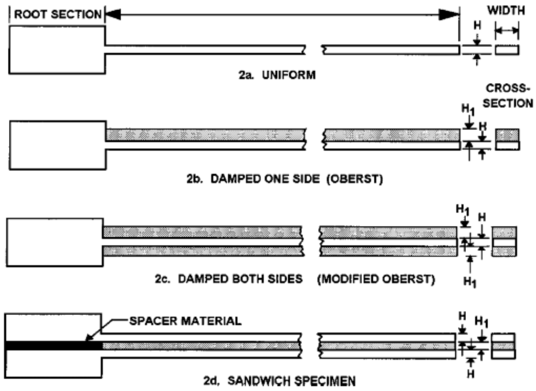


**Fig. 1 - Test Specimen of ASTM E756-05 Testing**

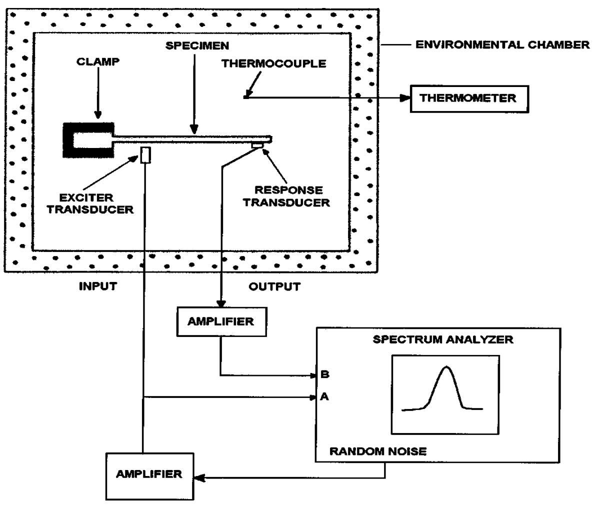


**Fig. 2 - Experimental set-up of ASTM E756-05 method**

The measurement in this test method applies cantilever beam theory, whereas the damping material properties expressed by mathematical models include simple beam and plate analogies as well as finite element analysis models. Experimental set-up of ASTM E756-05 method uses a two channel spectrum analyser and random noise excitation signal as presented in Fig.2.

## 3. The early methodology to measure damping properties of materials

The researchers developed various methodologies to investigate the damping behavior of concrete materials. Jianmin et al. (2013) used the vibration test and fatigue experiments to investigate the damping properties of polymer concrete. Damping properties were expressed with loss factor measured by using dynamic viscoelastometer and analyzed by scanning electron microscope. Nabavi (2008) did an experiment in order to determine damping ratio by an impact hammer excited to the concrete frame to vibrate freely. The impact force was converted to electrical current by piezoelectric sensors and then was displayed in the matrix form using Vee-Pro software. Afterwards, the time-amplitude matrix was converted to Frequency-FFT (voltage) matrix using MATLAB Program to get the damping ratio.

Some researchers modified Oberst Beam Method on ASTM E756-05 to new method that corresponded to their specimens. Koruk & Sanliturk (2010) measured dynamic properties of damping materials using Oberst Beam Method (OBM). They said that OBM is referenced in some standards and widely used in scientific studies, but detailed information in the literature on how to perform a successful Oberst Beam experiment is very limited. The cantilever beam used in this experiment and the measurement system is given in Fig. 3 and 4 respectively.  It was found that the electromagnetic effect depends on the beam length as this changes the effective free length of the beam.

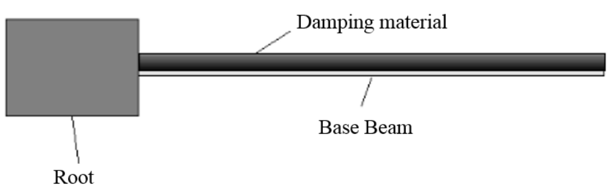


**Fig. 3 - Cantilever beam used in the experiment by Koruk and Santliturk (2010)**

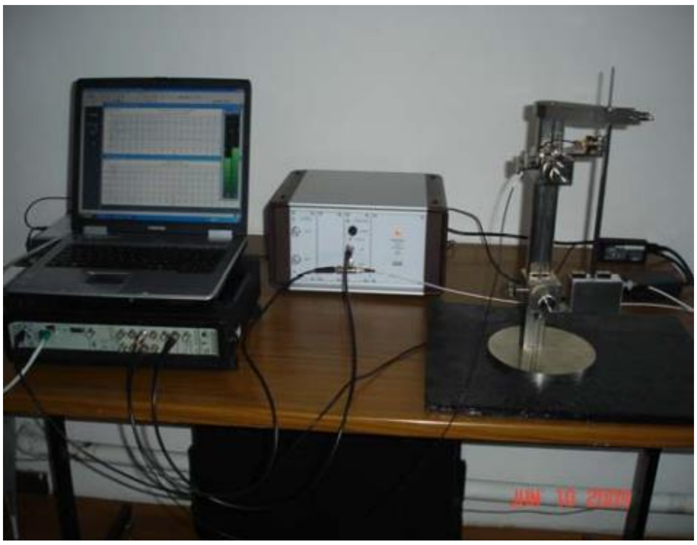

**Fig. 4 - Measurement systems in the experiment by Koruk and Santliturk (2010)**

Hujare & Sahasrabudhe (2014) also used Oberst Beam test specimens and an impulse technique as ASTM E756-05 method to determine the performance of damping provided by different viscoelastic materials (VEM). The constrained layer damping (CLD) consists of base beam and viscoelastic materials as the core layer as shown in Fig. 5

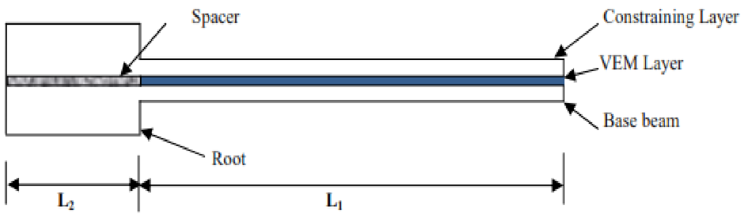


**Fig. 5 - Sandwich CLD beam in Hujare and Sahasrabudhe (2014)**

On the other hand, Pérez-Peña, García-Granada, Menacho, Molins, & Reyes (2016) carried out a specimen of the material vertically to the workbench given in Fig. 6. The displacement of the end of the specimen was measured and recorded by a laser transducer in the form of analog voltage signal. Furthermore, the digitized signal was treated with Catman TM software for post-processing and was introduced into the adjustment program coded in Matlab TM to obtain the natural frequency and damping ratio.

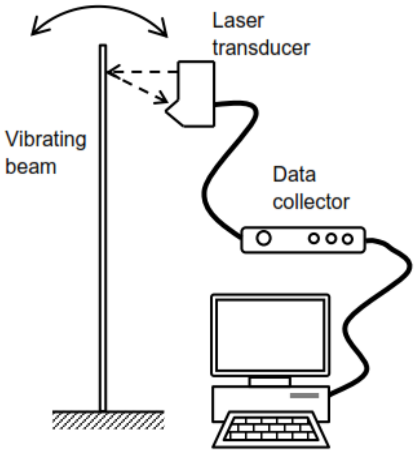


**Fig. 6 - Experimental Set-up of Pérez-Peña et al. (2016)**

The damping experiment based on ASTM E756-05 is also used by Wojtowicki, Jaouen, & Panneton (2004) where his classical cantilever oberst beam was replaced by a double sized free-free beam excited in its centre as shown in Fig.7, and then is applied to a thick and soft viscoelastic material. Various methods in damping measurements are also presented by previous researchers, including (Butterworth et al., 2004), (Umashankar, Gangadharan, Desai, & Shivamurthy, 2010), (Cai & Sun, 2010), (Pereira, Arenas, & Zumelzu, 2011), (Ben, Ben, K, Vikram, & Ratnam, 2008) and (Chandan & Patil, 2016).

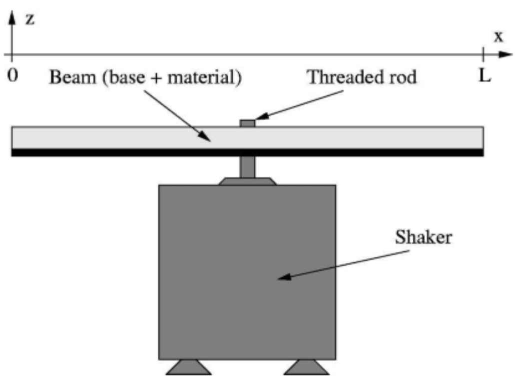


**Fig. 7 - Experimental set-up by Wojtowicki, Jaouen & Panneton (2004)**

## 4. Methodology of simple laboratory

Damping properties of mortar or concrete material can be investigated by a simple laboratory test using a simple equipment to ease the investigation. The researchers modified ASTM E756-05 method by observing the other related research to get the most appropriate method for concrete and mortar materials. The investigation applied impulse technique with a mortar or concrete beam as the specimen requiring a unit dynamic laboratory equipment (Fig. 8) including Dewe-43 universal data acquisition instrument (Fig. 8a), Dewesoft program installed in computer (Fig. 8b), a sensor (Fig. 8c) and strain gauge connector (Fig. 8d). The clamp equipment was also prepared for clamp one end of the specimen by dimension illustrated in Fig. 9. It was made from iron material by ±3mm thick-ness in order to bind the specimen firmly.

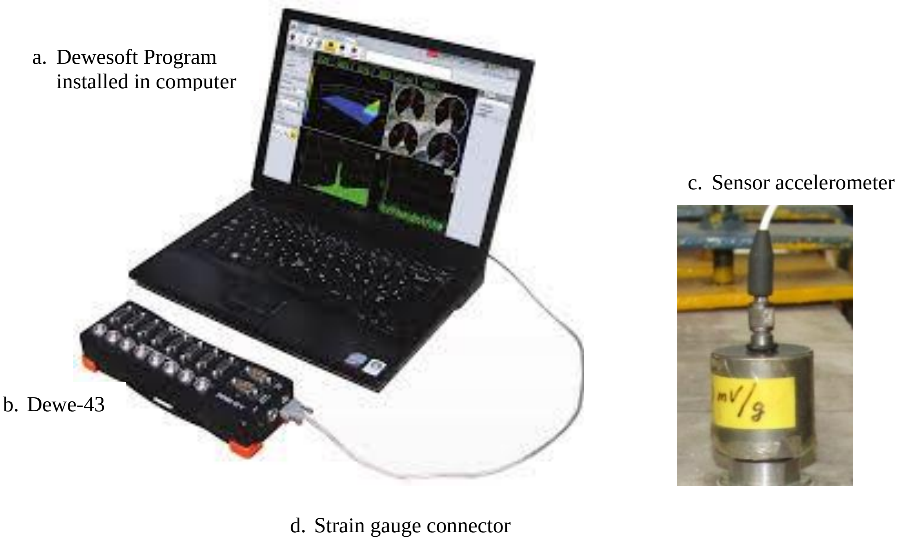


**Fig. 8 - A unit dynamic laboratory equipment**

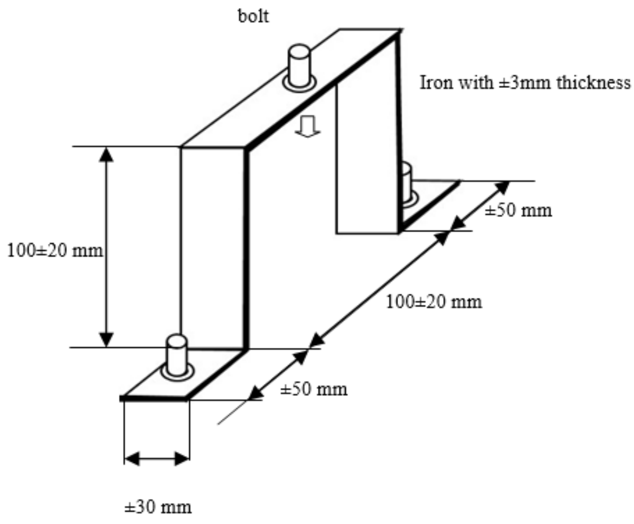


**Fig. 9 - Sketch of the clamp**

## 4.1 Preparing specimens

The test specimen was a mortar or concrete beam with a specific characteristic adapting the research objective. There were various mixing methods and material variations to make the beam with a dimension of 100 x 100 x 500 $mm^3$ as shown in Fig. 10. Many researchers used various additives or replacement materials added in the mixtures in order to improve the damping properties of the composite such as rubber tire crumb (Faizah et al., 2019), nano particulate composites (Umashankar et al., 2010), and butyl rubber vinyl (PVC) (Chandan & Patil, 2016). After being molded, the specimen was cured for 28 days to get their full strength and they were ready for the test. However, the beam can also be tested on 7, 14, or 21 days old to investigate the damping behaviour in different ages.

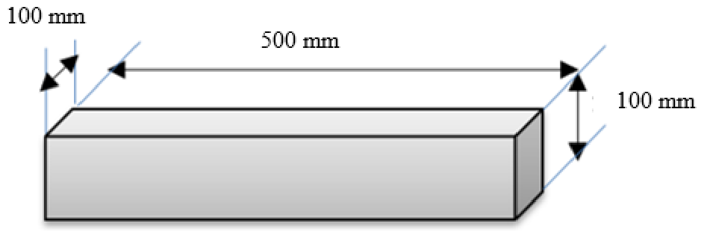


**Fig. 10 - The beam specimen of mortar or concrete**

## 4.2 Experimental procedure

A simple experiment to investigate damping properties of the beam specimen was done by generating the free vibration on the beam and then recording it using a sensor. The researchers should keep the situation quiet during testing because the sensor is very sensitive to external sounds and vibrations.

The beam specimen was placed in a clamped position at one end and free on the other end as shown in the experimental set-up on Fig. 11. The tension of the clamp must be detected by using a torque wrench equipment, to keep a similar tension on various testing. After the position was determined, the load was hung on the free end by a string and kept stable. Furthermore, the string was cut to generate a free vibration on the beam which was recorded by a sensor installed on the free end of the beam connected by a dewe-43 universal data acquisition instrument. The dewe-43 was connected by Dewesoft program installed in the computer to convert the form of vibration data from analogue into digital signals and to transform them into frequency domain (FFT). This experiment can identify the frequency fundamental of the beam and the vibration caused by cutting of the load-string.

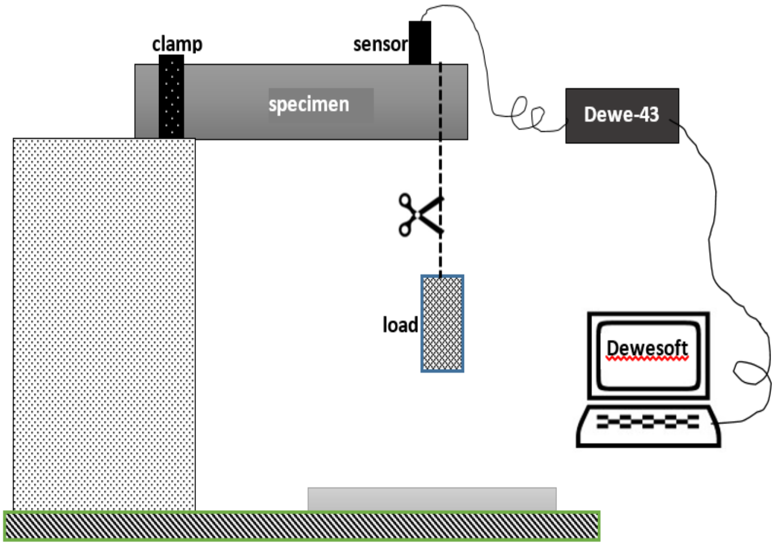


**Fig. 11 - Experimental set-up of simple laboratory**

## 4.3 The analysis of damping ratio

Damping properties of the beam is expressed by damping ratio (ξ) which can be identified by analyzing the wave using the logarithmic decrement method as explained by Faizah et al. (2019). The wave analysis was obtained from Dewesoft program output shown in Fig. 12. The damping ratio (ξ) can be calculated by eq.1, where Y1 is the maximum magnitude of the wave and Y2 is the half of Y1 magnitude approximately (Y2 ≈ 0.5 Y1). The number of cycles between Y1 and Y2 (N) is also calculated and included in the estimation of the damping ratio using Eq. 1.

$$\xi = Ln\left[\frac{Y_1}{Y_2}\right] x\ 100\ x\ \frac{1}{Nx2\pi} \quad (1)$$

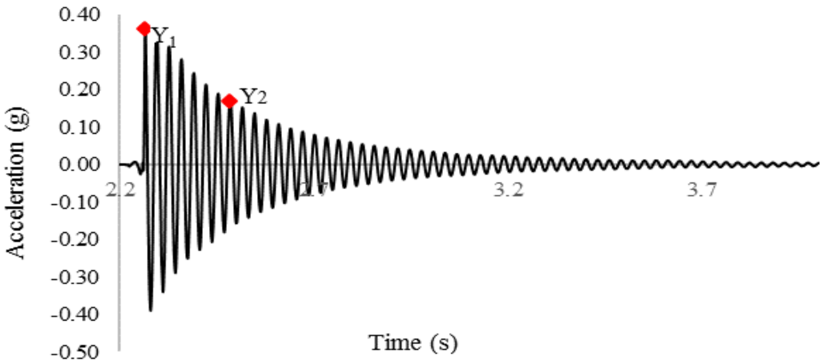


**Fig. 12 - The logarithmic decrement signal at the free end of the beam**

## 5. Testing Program

The testing program in order to apply a simple laboratory test were conducted in the Laboratory Structures of Civil and Environmental Engineering Department of Gadjah Mada University, Indonesia. The specimen was a mortar beam mixed from sand, Portland cement and water taken from the local areas. Sand was taken from Cangkringan, Sleman regency which has a specific gravity of 2.74 and unit weight of 1508 kg/m$^3$, while Gresik cement was used in this research. Mix design method of mortar mixture referred to ASTM C305-06, standard practice for mechanical mixing of hydraulic cement pastes and mortars of plastic consistency (ASTM, 2006). Material requirements in mortar mixtures determined based on the absolute volume ratio is presented in Table 1.

**Table 1 - Mix Design of Mortar Mixture**

| Materials | Weight (gr) | |
|---|---|---|
| | 1 m$^3$ | 100 x 100 x 500 mm$^3$ |
| Cement | 446.76 | 6.90 |
| sand | 1616.92 | 24.98 |
| water | 268.06 | 4.14 |

Fresh mortar was molded in the mold with the dimension of 100 x 100 x 500 mm$^3$. After the mortar beam was removed from the mold, it was cured to keep its moisture by covering it with a wet cloth until the test time. The mortar beam was tested at the age of 28 days old in dry conditions. Before the test, the specimen was measured in length, width and height to determine the actual volume. Then, it was also weighed in order to calculate the unit weight of specimen. The unit weight of the specimen in this study was 2180.3 kg/m$^3$ as shown in Fig. 13.


**Fig. 13 - Mortar beam specimen**

The specimen of 100 x 100 x 500 mm$^3$ mortar beam was investigated and installed by experimental set-up as shown in Fig. 14 referring to an experimental set-up and procedure of simple laboratory. The experiment was carried out with two various loading, 10 and 15 N, in the same beam, and was also repeated for 5 times in each loading. After cutting the load-string, sensor recorded the vibration in the beam and then the vibration was converted by Dewesoft program to generate a wave shown in Fig. 15. Damping ratio of the specimen was analyzed by logarithmic decrement method. After the value of maximum and a half-magnitude of the wave ($Y_1$ and $Y_2$) and number of cycles between $Y_1$ and $Y_2$ (N) was determined from the body of the wave, the damping ratio could be counted.

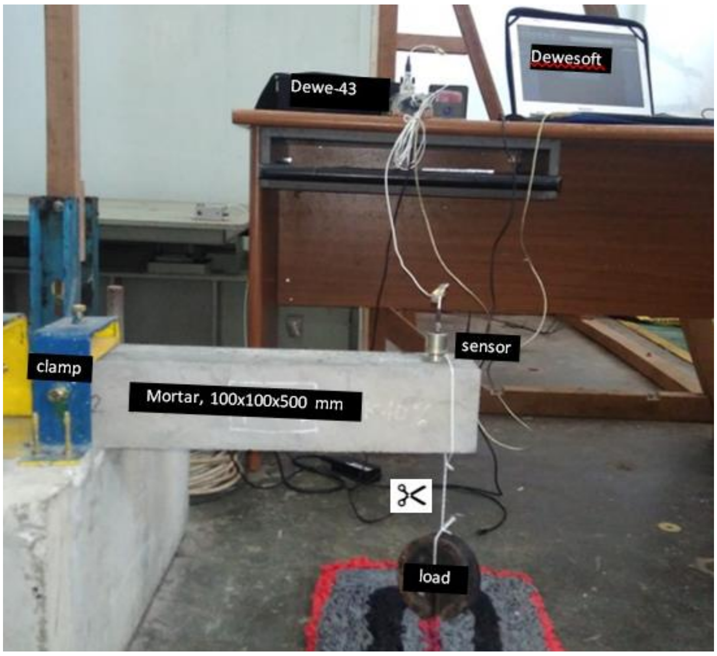


**Fig. 14 - Experimental set-up of testing program**

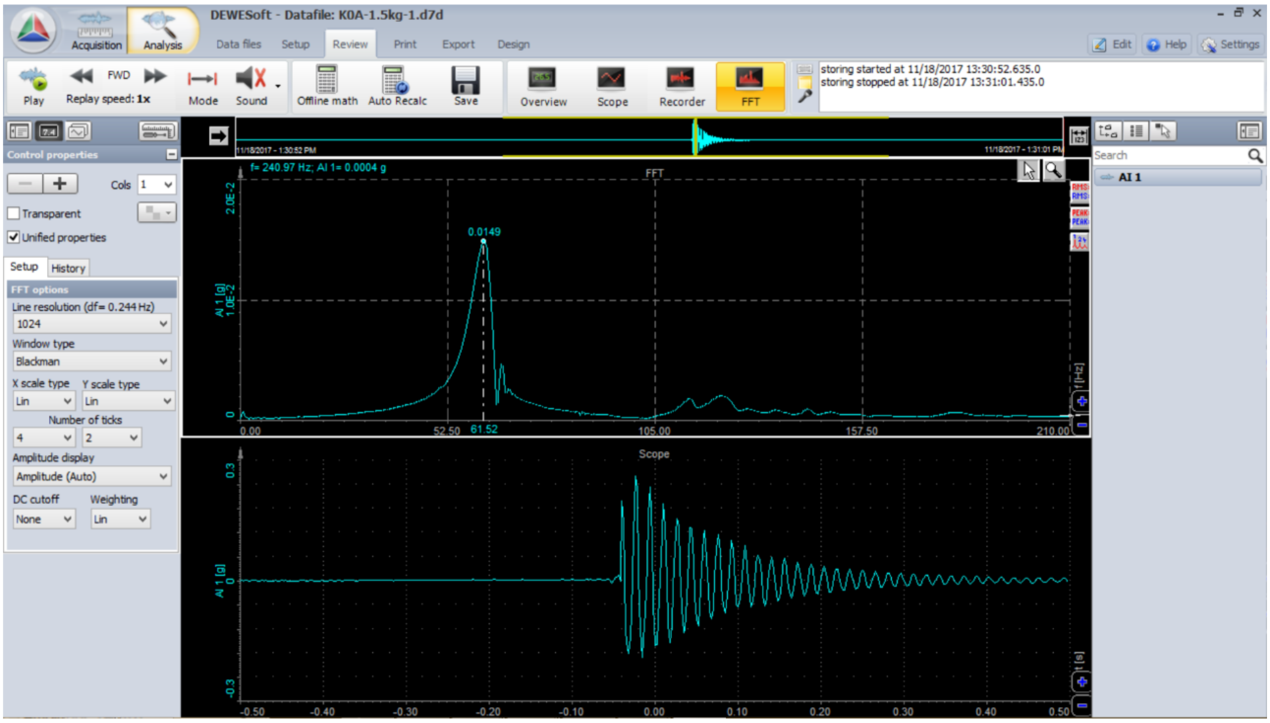


**Fig. 15 - The Dewesoft output**

## 6. Results and Discussion

In this paper, the experimental result including maximum and a half-magnitude of the wave (Y1 and Y2), frequencies, and damping ratios were presented in Table 2. This result shows that the average of Y1 value resulted from 10 N load was less than 15 N load because the larger load might cause a greater vibration, but conversely, it causes lower frequency. In other words, energy dissipation (damping ratio) increases with the strain of amplitude increasing (Mei, Su, Li, & Wang, 2018). On the basis of this result, it is conclusive that the larger load causes the higher damping ratio of materials. The result also shows that the average of damping ratio of beam mortar is 2.27% and 2.37% for 10 N and 15 N. It is in line with the requirement of typical damping for various materials and systems mentioned by Irvine (2004) in Table 3. The value of damping properties of the specimen in this research meets the requirement of the large building during an earthquake. On the other hand, it is less than the requirement of a reinforced concrete structure because the reinforcement is not used in the mortar.

**Table 2 - The Result of Laboratory Test**

| Load (N) | No. | $Y_1$ (g) | $Y_2$ (g) | $\Delta t$ (s) | N | f (Hz) | $\delta$ | $\xi$ (%) |
|---|---|---|---|---|---|---|---|---|
| 10 | 1 | 0.175 | 0.096 | 0.064 | 4 | 62.50 | 0.600 | 2.389 |
| | 2 | 0.159 | 0.062 | 0.102 | 6 | 58.82 | 0.946 | 2.509 |
| | 3 | 0.192 | 0.088 | 0.090 | 6 | 66.67 | 0.778 | 2.064 |
| | 4 | 0.190 | 0.089 | 0.074 | 5 | 67.57 | 0.756 | 2.407 |
| | 5 | 0.169 | 0.080 | 0.096 | 6 | 62.50 | 0.749 | 1.986 |
| Average | | 0.177 | | | | 63.61 | 0.766 | 2.271 |
| 15 | 1 | 0.259 | 0.112 | 0.082 | 5 | 60.98 | 0.838 | 2.667 |
| | 2 | 0.257 | 0.127 | 0.082 | 5 | 60.98 | 0.703 | 2.237 |
| | 3 | 0.315 | 0.139 | 0.082 | 5 | 60.98 | 0.816 | 2.598 |
| | 4 | 0.261 | 0.120 | 0.098 | 6 | 61.22 | 0.774 | 2.054 |
| | 5 | 0.266 | 0.130 | 0.082 | 5 | 60.98 | 0.715 | 2.278 |
| Average | | 0.271 | | | | 61.025 | 0.769 | 2.367 |

**Table 3 - Typical Damping of Various Materials and Systems [17]**

| Materials or Systems | Damping Ratio $\xi$ (%) |
|---|---|
| Metals (in elastic range) | <0.01 |
| Continuous metal structures | 2 - 4 |
| Metal structure with joints | 3 - 7 |
| Small diameter piping systems | 1 - 2 |
| Large diameter piping systems | 2 - 3 |
| Rubber | ≈ 5 |
| Large building during earthquake | 1 - 5 |
| Prestressed concrete structure | 2 – 5 |
| Reinforced concrete structures | 4 - 7 |
| Prestressed concrete | 4 - 7 |
| Partially prestressed concrete | 0.8 – 1.2 |
| Composite | 0.2 – 0.3 |
| Steel | 0.1 – 0.2 |

The increase in value of load, maximum magnitude (Y1), frequency (f), and damping ratio ($\xi$) are presented in Table 4. It shows that the increase of the Load and the Y1 is nearly same. However, the frequency and the damping ratio is the opposite. This finding opens up a new opportunity to describe clearly about the relationship between loads, frequencies and damping ratios. Further experiment with more various loads and number of specimens to get the broader analysis is suggested.

**Table 4 - The increasing of Load, $Y_1$, f and $\xi$ value**

| Load | $Y_1$ (g) | $Y_2$ (g) | $\xi$ |
|---|---|---|---|
| 50% | 53% | -4% | 4% |

## 7. Conclusion

The simple laboratory test to measure the damping properties of the hardened mortar or concrete material was presented. The experimental procedure was clearly explained using a simple and practical equipment for mortar or concrete materials. Here, it is also confirmed that there is no experimental method yet to measure damping properties of mortar or concrete materials which is a simple method. It is also applied in the simple test laboratory for a mortar beam by dimension of 100 x 100 x 500 $mm^3$. The result shows that the damping ratio of the mortar beam is 2.27% and 2.37% for 10 and 15 N load. Besides, it is known that the damping ratio is influenced by the magnitude of the external force. The finding from this experiment has a clear-cut result, although it has only been tested on a small number of specimens. This opens up further research opportunities to improve the quality of testing methods, for example the experiment application with more various loads and number of specimens.

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