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Vibration modeling and simulation of braced and unbraced steel structure

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ABSTRACT

Repeated dynamic loads on multiple stories structure may cause damage in the midst of natural disaster, such as earthquakes and landslides, hence it is necessary to observe how the response occurs. Therefore, this paper studies the performance of two-story steel frame without braces and with inverted V concentric braces. Both frames were given a static and a dynamic load in the form of a sinusoidal load for 2 seconds in the form of forced harmonic vibration. After the dynamic load is turned off, harmonic free vibration applies. Vibration is given to the weakest orthogonal axis on the frame with a frequency of 0,5 Hz; 1,03 Hz; 1.7 Hz. To reduce the deviation between stories that occur due to dynamic loads, bracing is provided as a stiffening element. The test variations are called models 1, 2 and 3 with model 1 unbraced frame and model 2 braced frame with the same load between floors, while model 3 unbraced frame model with weight 2nd floor is 3 times larger than 1st floor. It found that the braced frame has a minimum drift and its drift is enhanced with the increase of load capacity.

Keywords: bracing; displacement; structural response; vibration

1 Introduction

Loads are unexpected or difficult to predict, such as dynamic loads (live loads, dynamic equipment, wind, earthquakes, collisions, and explosions) that work at certain times and accelerations. In structures that receive dynamic loads, the loading can be in the form of graphs of sine and cosine functions which can cause damage to a building structure. Hence, it is necessary to observe how the response occurs in the building when it receives this load.

A structure may experience displacement in two or more directions. In this study, however, the structure is considered to experience displacement primarily along in the x-axis direction. This is because displacement in other directions is ignored since only a small amount of movement occurs. According to the mathematical solution, a structure can be assumed to be a spring element that has one direction of movement at one node at the end of the spring element. The one-level structure is simplified into a mathematical model, such as a cantilever with spring stiffness, and obtaining a displacement force perpendicular to the stem axis so that the structure is called a Single Degree Of Freedom (SDOF)[1].

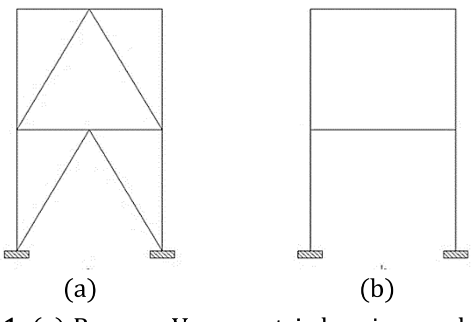

Figure 1. (a) Reverse V concentric bracing model, (b) Unbraced model

Steel has superior properties in terms of strength (tension), stiffness (deformation) and collapse behavior (ductility) [2], [3]. Therefore, it is not surprising that in every construction project, both bridges and buildings are always needed, although not always dominating or majority. Steel can also be profiled so as to produce a large moment of inertia

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with a small cross-sectional area, resulting in multi-story building structures that have a lower weight than concrete structures.

This research is expected to provide useful new information regarding the response that occurs due to dynamic loads with a sinusoidal pattern with a comparison of the inverted V-braced concentric model and the unbraced model so as to reduce the possibility of damage occurring to a building [4]–[6].

This study examines the information on the comparison of mass and stiffness with sinusoidal loads where the results in this study the greater the mass, the greater the maximum displacement, the greater the stiffness, the smaller the maximum displacement.

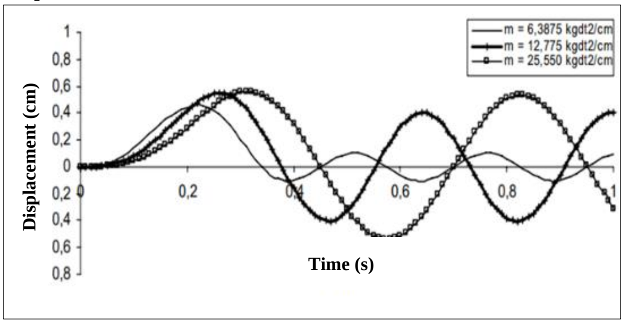


Figure 2. Time history vs displacement with mass variation

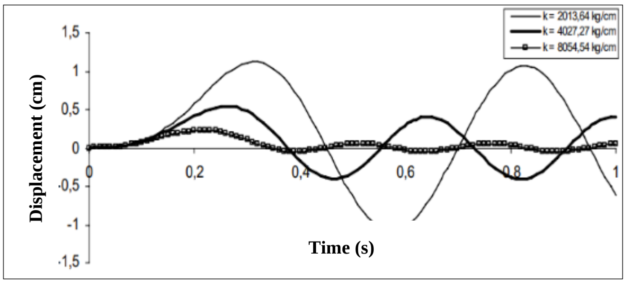


Figure 3. Time history vs displacement with varying stiffness

Structures loaded by forces or displacements whose magnitude is expressed by the sine or cosine function of time in Equation 1 as follows:

$p(t) = \sin(\Omega t)$ or $p(t)=\cos \Omega t$ .... (1)

An example of the harmonic motion is the movement of rotational machines which produce harmonic effects due to the eccentricity of a rotating mass. Where *p(t)* is the force, *t* is time, and *Ω* is the frequency of the displacement. The value of the external force (steady-state response *U* as a function of force *p*) can be described in Equation 2 below.

$U(p)=U\cos(\Omega t)$ .... (2)

Equation 3 indicates the equation of harmonic motion without damping [7].

$m\ddot{u} + ku = p \cos\Omega t$ .... (3)

where *m*, *k*, *u*, and *ü* is the mass, stiffness, displacement, and acceleration of the structure during loading time, respectively.

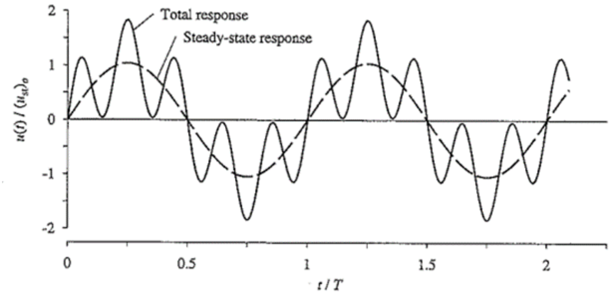


Figure 4. Non-damping harmonic motion system based on a model in [8].

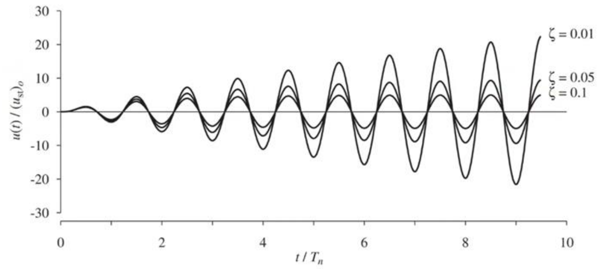


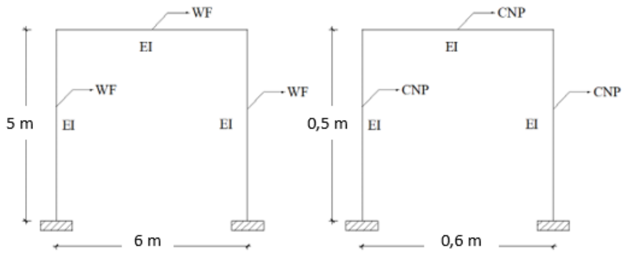
Figure 5. Resonance with damping.

In this idealization, beams and floors are rigid and mass is distributed throughout the building, centered on the floor plane [9], [10]. This assumption is generally appropriate for multi-story buildings. In Figure 5, a two stories frame with mass concentrated on each floor has two DOF, which are lateral displacements u_1 and u_2 on both floors in the x direction [11]. The forces acting for each floor mass mj can be seen in Figure 5 including the external force pj (t), the elastic force f_{sj}, and the damping force f_{Dj}. Elastic and damping forces show opposite directions because both forces are internal forces that resist motion.

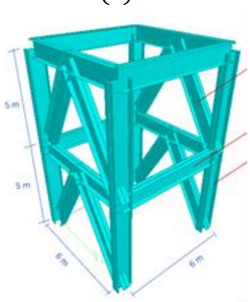
A vertical truss, or its equivalent of the concentric, or eccentric type, provided in a building frame system or multiple systems to withstand seismic lateral forces. Each structural model must be designed, loaded, and interpreted according to a set of similarity requirements that link the model to the structure [12]. This similarity requirement is based on modeling theory, which can be derived from a dimensional analysis of the physical phenomena involved in structural behavior. The use of dimensions dates back to early history when humans first attempted to define and measure physical quantities. These fundamental sizes are usually referred to as dimensions [13].

Most structural modeling problems are mechanical in nature; thus strength, length, and time are most important in structural work, thermal problems require additional temperature measures

[13]. Each size or dimension has an associated standard unit in several of the different unit systems in use today (U.S Customary, SI, metric, etc.). Dimensions and units are logical quantities that are now taken for granted [13].



(a)



(b)

Figure 6. Model scaling on frame structures. Figures in (a) are frame structure before scaling and (b) is frame structure after scaling

Dimensional analysis is very useful in the investigation of any physical behavior because it allows the experimenter to combine variables into appropriate groupings. In Figure 6. it can be seen that the scale used is 1:10 because Figures 6.a and 6.b have the same modulus of elasticity of steel which has been determined in SK SNI T-15-1991-03 of 200,000 MPa and different moments of inertia, so to meet the model scaling requirements in the cross-sectional characteristics I × WF must be ± 1/10 I × CNP.

2 Methods

The test variations are called models 1 and 2, with model 1 unbraced frame and model 2 braced frame with the same load between floors contained in Table 1. In this study, a model scale of 1:10 was used, from the results of stress mechanics calculations with 2 dimensions of canal steel, it can be concluded that the CNP 80 x 20 x 5 x 1 mm in the Mega Baja Malang shop obtained an I_x value of 19.767 cm^4 and an I_y value of 1.223 cm4 and in SNI 07 – 7178 – 2006 the size of the WF cross section is 100 × 50 × 5 × 7 mm, the I_x value is 187 cm^4 and I_y is 14.8 cm^4. Since the value of the moment of inertia in the x direction corresponds to a scale of 1:10 ± CNP 80 × 20 × 5 × 1 mm, the closest to the actual structure in the WF table in SNI 07 – 7178 – 2006 is the WF profile 100 × 50 × 5 × 7 mm. In this study, 2 CNP channel steel 80 × 20 × 5 × 1 mm will be used as a structural model material. The 3D shape of the two-stories frame structure using inverted V concentric bracing is described in the STAAD Pro V8i SS6 auxiliary program is the pre-scaled frame structure that is planned to use 100 × 50 × 5 × 7 mm WF profile steel.

Table 1 Experimental Frame Models

Model 1 (Braced Frame)	Model 2 (Unbraced Frame)
	

In the loading concept, in addition to the frame components, slabs and live loads in the form of concrete are used, the load of which is the same for both types of frames on each story. In the mix design of concrete, formwork is first made which is also a plate element in the frame.

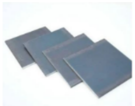
Table 2. Loading in experiment

Structural Elements	Dimension (mm)	Loading (kg)
Column	80x20x5x1	19,637
Beam	80x20x5x1	47,130
Plate	600x600x12	1,037
Live load		17,584
Total		85,388

With the total load as shown in table 2, it is estimated that the displacement that occurs on each floor is sufficiently optimal. The details of materials used during our experiment can be found on Table 3.

Table 3. Materials used in experiment

Material	Descriptions
	This study will use CNP canal steel 80 x 20 x 5 x 1 as the model structure and bracing.



This study will use an iron plate 300 x 300 x 3 mm.

This study will use bolts with a diameter of 6 mm and a length of 20 mm.

This study will use a weight meter in grams.

This study will use calipers to re-check the material dimensions of the structure.

This study will use a Stanley meter to re-check the dimensions of the structural material.

This research will use a universal tensile testing machine to determine the quality of the steel used.

This study will use a vibrating table measuring 1 m x 1 m with a maximum horizontal displacement of 20 cm

This research will use the ADXL 345 acceleration sensor which will be placed on a vibrating table on each model floor.

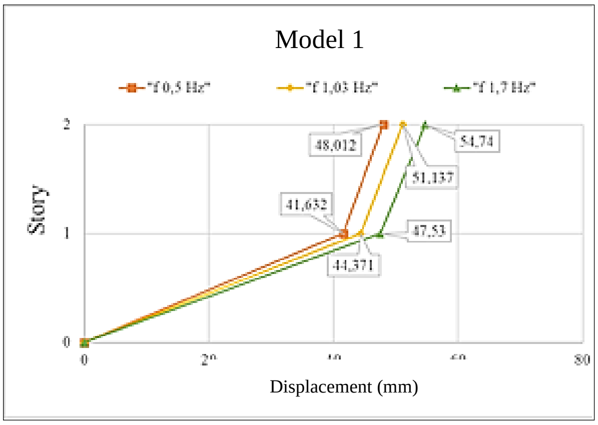
This research will use the HC-SR04 Ultrasonic Sensor which will be used to measure the displacement that occurs in the model.

Tests were carried out for each frame with a frequency of 0.5 Hz, 1.03 Hz, and 1.7 Hz. The recorded data in the testing method are time, acceleration and displacement data.

3 Results and Discussion

From the modeling results, the largest deviation value of model 1 at a frequency of 0.50 Hz on the 1st floor is 47.53 mm and on the 2nd floor is 54.74 mm. Model 2 at a frequency of 0.50 Hz on the 1st floor is 0.112 mm and on the 2nd floor is 0.2 mm. The deflections of each model at this frequency are shown on Figure 7.

Meanwhile, from the modeling results, the largest deviation value of model 1 at a frequency of 1.03 Hz on the 1st floor is 61.31 mm and on the 2nd floor is 70.49 mm. Model 2 at a frequency of 1.03 Hz on the 1st floor is 0.132 mm and on the 2nd-floor is 0.236 mm. The deflections of each model at this frequency are shown on Figure 8.



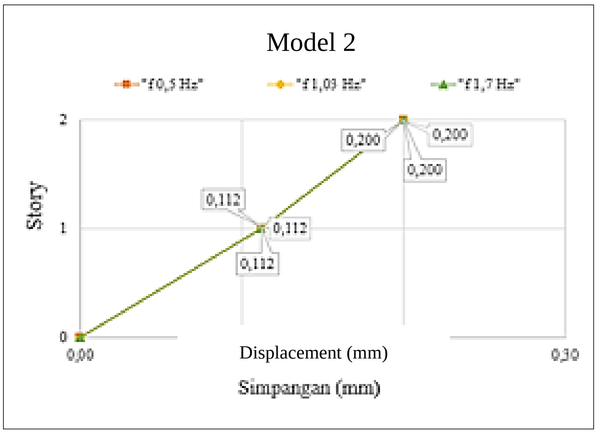


Figure 7 Model 1 and 2 FEM Dynamic response analysis at 0.50 Hz frequency

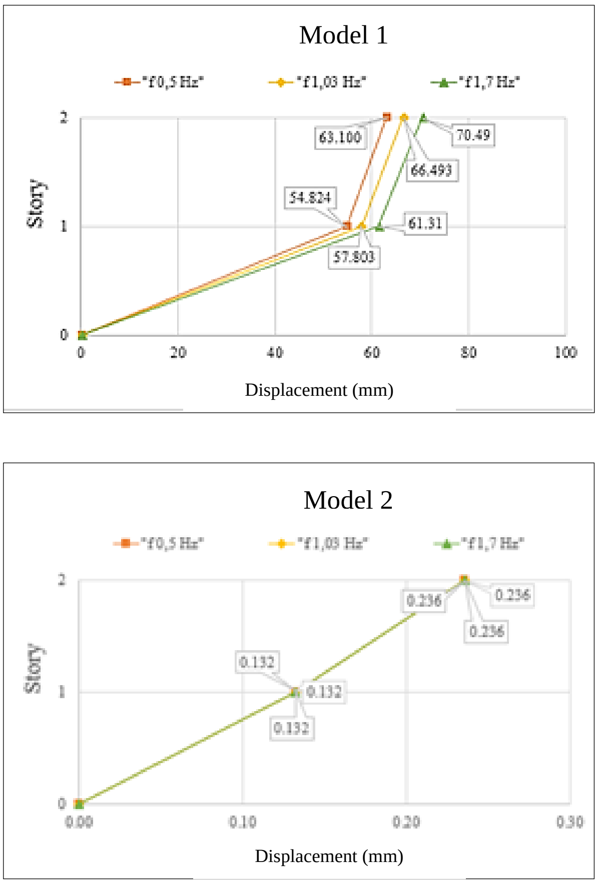
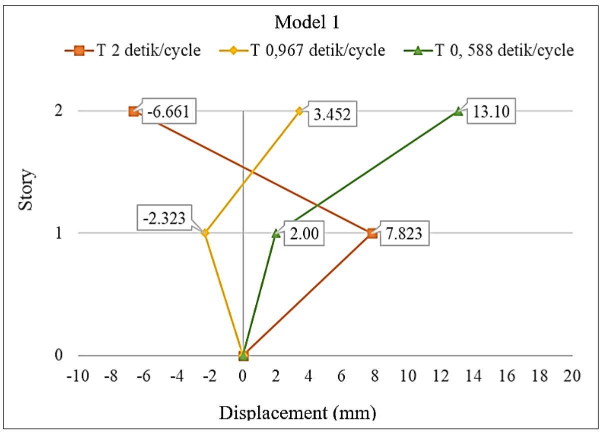


Figure 8 Model 1 and 2 FEM Dynamic response analysis at 1.03 Hz frequency

From the experimental results, the largest deviation value for model 1 at a frequency of 1.70 Hz on the 1st floor is 42.24 mm and on the 2nd floor is 25.44 mm. Model 2 at a frequency of 1.70 Hz on the 1st floor is 1.21 mm and on the 2nd floor is 3.71 mm. The deflections of each model at this frequency are shown on Figure 9.



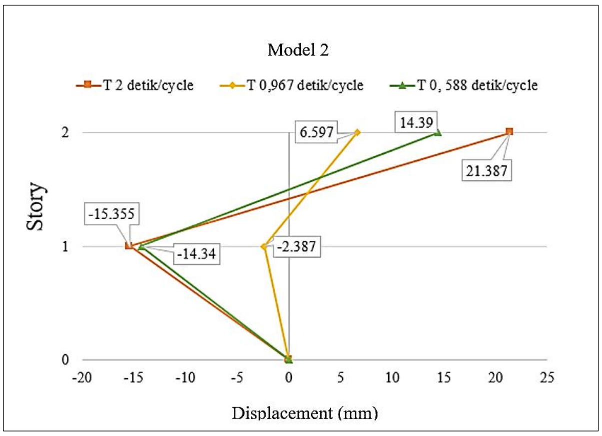


Figure 9 Model 1 and 2 FEM Dynamic response analysis at 1.70 Hz frequency

4 Conclusion

From the model that has been analyzed through finite element methods and tested by using a vibrating table, it is found that the frame model using bracing has 50% smaller displacement than the model without using bracing.

5 Acknowledgement

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