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OPTIMUM DESIGN OF TUNED MASS DAMPER PARAMETERS TO REDUCE SEISMIC RESPONSE ON STRUCTURE USING GENETIC ALGORITHM

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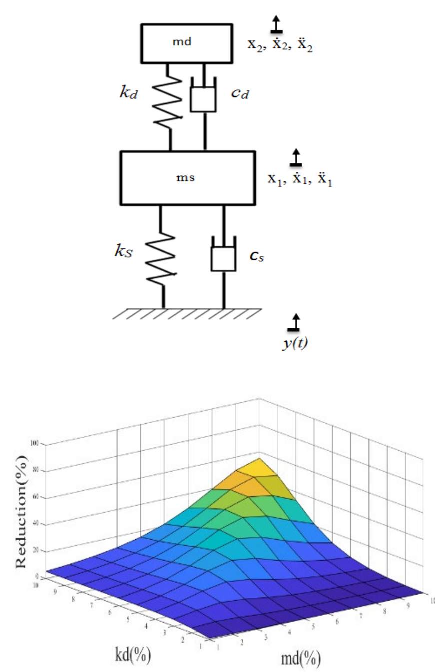
Graphical abstract



Abstract

A tuned mass damper (TMD) is a system to improve structural performance in reducing vibration response under seismic loads. This study optimizes TMD parameters using a genetic algorithm. In this study, the structure is modeled as a spring-mass system to obtain mathematical equations. Then, those equations are used to estimate vibration due to seismic loads. A genetic algorithm is used to find optimum parameters which correspond to minimum vibrations. The simulation result shows that the genetic algorithm can find values of parameters such as the ratio of mass, stiffness, and damping values which reduces vibrations on the structure. Based on the tests, it is found that the best combination of genetic algorithm parameters to produce the most optimal fitness value is population size 30, generation size 800, crossover probability 0.5, and mutation probability 0.5. Applying the genetic algorithm shows that the optimal parameter ratio values of TMD to reduce the vibration response are 10% mass, 10% stiffness, and 1% damping of mass, stiffness, and damping in the structure. The result of the vibration response analysis shows that the maximum amplitude value of the main structure without TMD is 0.24259 m reduced to 0.034385 m with the addition of TMD. This shows that the TMD successfully reduces vibrations in the main structure with a percentage of 85.94%. Where the TMD manages to dissipate the energy that should only be received by the structure to the TMD itself.

Keywords: Genetic Algorithm, Seismic Loads, Structure, TMD, Vibration Response

1.0 INTRODUCTION

Structural failure is a phenomenon in which the structure's inability to accept disturbance forces is caused by earthquakes or wind loads [1]. The damper can be used as a solution to improve structural performance in reducing vibration due to disturbance forces in the form of wind loads or seismic loads.

Several studies have been conducted to maximize the damper function in improving the performance of the structure. The addition and design of base isolation to the structure are carried out to improve the structure's performance by reducing the movement of the structure to overcome the risk of destruction due to seismic loads [2]. Research on the addition of a fluid viscous damper to high-rise structures has been carried out to increase the flexibility of the structure in receiving disturbances due to seismic loads and wind loads [3]. However, these studies still need to be evaluated and further developed, because their application tends to be recommended for designing new building structures.

The addition of a damper in the form of additional mass to the structure can be used as a solution. Because this damper can be applied to reduce vibration both in new structures that will be built or in existing structures. The principle of adding a damper in the form of additional mass on the structure is applied to the

TMD. In its application, TMD has several advantages: its robust design, has no effect on high temperatures, provides large structural damping, and it is relatively inexpensive [4].

The TMD has been successfully applied to various high-rise structures including the Taipei 101 building in Taipei, the Trump World Tower in New York, the Canadian National Tower in Toronto, the Akita Tower in Akita, the Sydney Tower in Sydney, the City Corp Center in New York, and John Hancock Tower in Boston [5]. TMD is considered effective in minimizing the vibration response to avoid the risk of damage to the structure [6]. The addition of a damper in TMD is based on the assumption that the energy entering the structure will be absorbed not only by the structure itself, but also by the mass, stiffness, and damping elements of the TMD [7, 8].

Research on the application of the pendulum tuned mass damper (PTMD) was conducted to minimize the seismic response in the power plant structure [9]. Dynamic response of the scaled structure with one liquid tuned mass damper (LTMD) was once used as a research topic to study the dynamic response of structures with the addition of LTMD and structures without LTMD [10]. Research on the application of inverted pendulum-tuned mass dampers (IPTMD) was carried out on a 10-story structure to reduce dynamic responses due to wind loads and seismic loads [11].

Research on the design of TMD on damped linear structures using the equivalent linearization method based on orthogonal functions has been carried out to improve the performance of structures in receiving seismic responses [12]. The following study about the performance of tuned mass dampers against structural collapse due to near-fault earthquakes discussed the efficiency of TMD in steel-frame structures to prevent structural collapse due to seismic loads [13].

The TMD is successfully developed in reducing seismic responses in a study on actual nuclear piping. Therefore, it helps improve the seismic performance of nuclear pipes [14]. Research on tuned mass damper system modeling on structures using MATLAB SIMULINK has been carried out by varying the value of the TMD parameter ratio to obtain a dynamic response graph for a 2-story structure without TMD and with the addition of TMD [15]. Therefore, a certain method is needed to obtain the optimal parameters. Studies on optimization cases have been conducted by previous researchers [16, 17, 18, 19].

In this study, the optimal TMD parameters are designed to reduce the vibration response of structures due to seismic loads using a genetic algorithm. This genetic algorithm has been successfully used to solve cases related to optimization problems [20, 21, 22]

. So that by applying the genetic algorithm, the optimal values ratio of mass, stiffness, and damping of TMD will be obtained to reduce the vibration response in the structure.

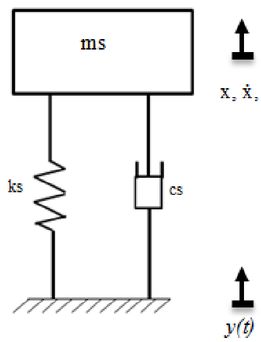
Modeling the damper system in this structure can be a solution to overcome structural failure, especially in Bengkulu Province which is an earthquake-prone area [23]. The output of this study is a graph of the vibration response of structures without TMD and structures with the addition of TMD which show the optimal values of mass, stiffness, and damping of the TMD to reduce vibrations in the structure. Observations from the graphical phenomenon of the simulation results in this study will be a reference that shows the effectiveness of TMD in reducing vibration in the structure.

2.0 METHODOLOGY

The amplitudes of vibrations are calculated using a set of equations derived below. A genetic algorithm is used to find the values of parameters of the TMD which corresponds to the minimum amplitude of vibrations. The optimum values of parameters are used in the simulations to study the corresponding vibrations.

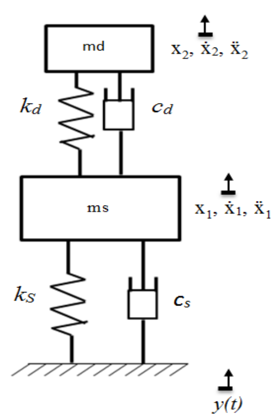
Mathematical Modelling of Structures

The mathematical equation of the structure is used to analyze the vibration response in structures without TMD and structures with the addition of TMD. Figure 1 shows the dynamic modeling of the main structure without TMD in which mass of structure, damping, and stiffness are defined as ms, cs, and ks, respectively. Moreover, structure modeling with the addition of TMD in this study is shown in Figure 2.



ms = mass of structure (kg)
cs = damping of struktur (N-s/m)
ks = stiffness of structure (N/m)
y(t) = deviation of earthquake (disturbance)
x = displacement of structure (m)
$\dot{x}$ = velocity of structure (m/s)
$\ddot{x}$ = acceleration of structure (m/s^2)

Figure 1 Dynamic modeling of structure without TMD



ms = mass of structure (kg)
cs = damping of structure (N-s/m)
ks = stiffness of structure (N/m)
y(t) = deviation of earthquake (disturbance)
md = mass of TMD (kg)
cd = damping of TMD (N-s/m)
kd = stiffness of TMD (N/m)

Figure 2 Dynamic modeling of structure with the addition of TMD

From the modeling of the structure without TMD in Figure 1, the structure model can be derived into mathematical Equations in Eq. (1).

$$m_S\ddot{x} + c_S\dot{x} + k_S x = k_s\, y \sin \omega t \qquad (1)$$

Moreover, from the structure modeling with the addition to TMD in Figure 2, the structure model can be derived the main structure mathematics equation in Eq. (2).

$$([M](-\omega^2) + [C](j\omega) + [K])\begin{Bmatrix} A_1 \\ A_2 \end{Bmatrix} e^{j\omega t} = \begin{Bmatrix} k_s y \\ 0 \end{Bmatrix} e^{j\omega t} \quad (2)$$

Where $M = \begin{bmatrix} m_s & 0 \\ 0 & m_d \end{bmatrix}$, $C = \begin{bmatrix} c_s + c_d & -c_d \\ -c_d & c_d \end{bmatrix}$, and $K = \begin{bmatrix} k_s + k_d & -k_d \\ -k_d & k_d \end{bmatrix}$

Then from the mass matrix (M), damping matrix (C), and stiffness matrix (K), the amplitude of the main structure (A_1) and amplitude of damper (A_2) are obtained from the Eq. (3).

$$\begin{Bmatrix} A_1 \\ A_2 \end{Bmatrix} = (K - M\omega^2 + j\omega C)^{-1} \begin{Bmatrix} k_s y \\ 0 \end{Bmatrix} \quad (3)$$

Genetic Algorithm

In this study, the genetic algorithm finds the ratio value of mass, stiffness, and damping of TMD to minimize the amplitude in the main structure. The schematic of the genetic algorithm can be seen in Figure 3.

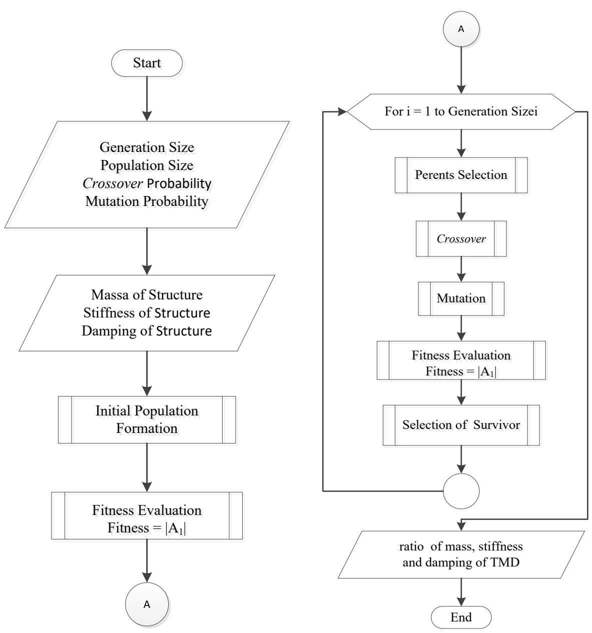


Figure 3 Genetic Algorithm Stages Schematic

Initial Population

The initial population is generated randomly. In this study, the population was determined as a batch of the chromosome that contains 3 genes that corresponds to the ratio of mass, stiffness, and damping in TMD. The values are real random numbers following Eq. 4.

$$x_{min} < x_r < x_{maks} \quad (4)$$

Where x_{min} is the minimum limit of the random number of 0.01, xr is the result of the random number and x_{maks} is the maximum limit of the random number of 0.1. So, the population can occur as a set given in Eq. 5.

$$[(md_1\ kd_1\ cd_1) \ldots (md_n\ kd_n\ cd_n)] \quad (5)$$

Where md is the value of the TMD mass ratio, kd is the value of the TMD stiffness ratio, and cd is the value of the TMD damping ratio.

Fitness Evaluation

The fitness evaluation determines the quality of the chromosomes. The fitness value is a measure of the optimality of the solution to the objective function determined. The fitness evaluation is carried out using Eq. (8) by substituting the ratio value of mass, stiffness, and damping of TMD obtained in the chromosome representation. So that the fitness value can be formulated in Eq. 6. In this study, the best fitness is fitness with the smallest value.

$$f = |A_1| \quad (6)$$

Parents Selection

Parent selection is performed to select chromosomes that will be used as parents in the crossover and mutation process. In this study, parent selection is performed using the roulette wheel method. The steps for parent selection are as follows:

1. The total fitness of the population is calculated using Eq. 7.

$$Total\ fitness = \sum_{i=1}^{UP} \blacksquare f(i) \quad (7)$$

where:
Up = Population size
f(*i*) = The fitness value of the *i*-th chromosome

2. Selection Probability value of each chromosome is calculated using Eq. 8.

$$Selection\ Prob = \frac{f(i)}{Total\ fitness}, \quad (8)$$
$$i = 1,2,3 \ldots UP$$

3. Cumulative probability value of each chromosome is calculated using Eq. 9.

$$\text{Cumulative Prob (i)} = \sum_{i=1}^{i=j} \text{Selection Prob (j)} \quad (9)$$

A random value is formed from 0.01 to 1 in each chromosome. The chromosome is selected by selecting a higher cumulative probability value from the random value that is formed.

Crossover

This function aims to cross two pairs of parent chromosomes till the two new chromosomes that expectedly will be better than the parents. The illustration of the crossover process of this study is shown in Figure 4.

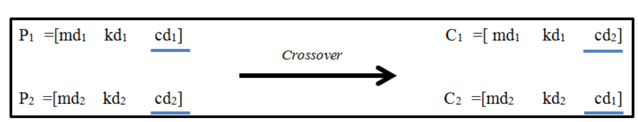


Figure 4 Crossover Process Illustration

P_1 and P_2 are a pair of chromosomes that are selected as parents as the result of the process of crossover, while C_1 and C_2

are offspring of the result of the process of crossover. The probability of crossover and the random number of 0.01 to 0.9 that formed in each pair of chromosomes are involved in the process of crossover. Crossover is performed in *i*-th chromosome if the *i*-th random value is less than the probability of crossover.

Mutation

Mutation aims to change the genes on the chromosomes randomly. As a result, a variety of new candidate solutions occurred. The illustration of the mutation process in this study is shown in Figure 5.

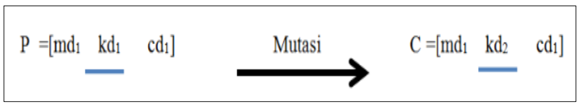


Figure 5 Mutation Process Illustration

P is the chromosome that is mutated and C is the chromosome that results from the mutation. The mutation process in chromosomes involves a mutation probability and a random number of 0.01 to 0.9 is formed on each chromosome. The *i*-th chromosome is mutated if the *i*-th random number is less than the mutation probability.

Selection of Survivor

This selection is used to select the chromosomes that are retained in the next generation. This stage is carried out by including chromosomes in a new population resulting from crossover and mutation combined with chromosomes in the previous population. Then the ranking is carried out based on the fitness value from the smallest value to the largest value. Then the chromosomes with the best fitness value are selected as many as the population size. The selected chromosomes are retained for the population in the next generation.

State Space Equation

The mathematical equation of the structure that has been obtained is converted into the form of the general state-space equation. Furthermore, the vibration response analysis is performed using the state space.

State Space Equation of Structure without TMD

Referring to the mathematical equation of the structure without TMD in Eq. 1, it can be defined $x = [x \; \dot{x} \;]$ as a state, the input is $u = k_s y \sin \omega t$ as the input, and $y = x$ as the output. So that Eqs. 10 and 11 are obtained;

$$\dot{x}_1 = \dot{x} \tag{10}$$

$$\dot{x}_2 = \ddot{x} = \frac{1}{m_s}(k_s y \sin \omega t - k_s x - c_s\dot{x}) \tag{11}$$

Then the state space equations of the structure without TMD in Eq. 2 replaces a second order differential equation with a single first order matrix differential equation. The state space matrices are defined as shown in Eqs. 12 and 13. Eq. 12 is called the state equation, and Eq. 13 is called the output equation.

$$\begin{Bmatrix} \dot{x} \\ \ddot{x} \end{Bmatrix} = \begin{bmatrix} 0 & 1 \\ \frac{-ks}{ms} & \frac{-cs}{ms} \end{bmatrix} \begin{Bmatrix} x \\ \dot{x} \end{Bmatrix} + \begin{Bmatrix} 0 \\ \frac{1}{ms} \end{Bmatrix} u \tag{12}$$

$$y = [1 \quad 0] \begin{Bmatrix} x \\ \dot{x} \end{Bmatrix} + \{0\} u \tag{13}$$

Furthermore, the state space matrix is obtained as shown in Eqs. 14-17.

$$A = \begin{bmatrix} 0 & 1 \\ \frac{-ks}{ms} & \frac{-cs}{ms} \end{bmatrix} \tag{14}$$

$$B = \begin{Bmatrix} 0 \\ \frac{1}{ms} \end{Bmatrix} \tag{15}$$

$$C = [1 \quad 0] \tag{16}$$

$$D = \{0\} \tag{17}$$

State Space Equation of Structure with addition TMD

Referring to Eqs. 2 and 3 which are the mathematical equation of the structure with the addition of TMD, one can be defined $x = [x_1 \; \dot{x}_1 \; x_2 \; \dot{x}_2 \;]$ as state, $u = k_s y \sin \omega t$, and the output is $y = (x_1, x_2)$, so that;

$$\dot{x}_1 = \dot{x}_1 \tag{18}$$

$$\dot{x}_2 = \ddot{x}_1 = \frac{1}{m_s}[k_s y \sin \sin \omega t - (k_s + k_d)\, x_1 - (c_s + c_d)\, \dot{x}_1 + c_d \dot{x}_2 + k_d x_2] \tag{19}$$

$$\dot{x}_3 = \dot{x}_2 \tag{20}$$

$$\dot{x}_4 = \ddot{x}_2 = \frac{1}{m_d}(c_d \dot{x}_1 - c_d \dot{x}_2 + k_d x_1 - k_d x_2) \tag{21}$$

Then the state space equations of the structure with the addition of TMD in the form of a matrix are obtained as shown in Eqs. 22 and 23.

$$\begin{Bmatrix} \dot{x}_1 \\ \ddot{x}_2 \\ \dot{x}_2 \\ \ddot{x}_2 \end{Bmatrix} = \begin{bmatrix} 0 & 1 & 0 & 0 \\ \frac{-(ks+kd)}{ms} & \frac{-(cs+cd)}{ms} & \frac{kd}{ms} & \frac{cd}{ms} \\ 0 & 0 & 0 & 1 \\ \frac{kd}{md} & \frac{cd}{md} & \frac{-kd}{md} & \frac{-cd}{md} \end{bmatrix} \begin{Bmatrix} x_1 \\ \dot{x}_1 \\ x_2 \\ \dot{x}_2 \end{Bmatrix} + \begin{Bmatrix} 0 \\ \frac{1}{ms} \\ 0 \\ 0 \end{Bmatrix} u \tag{22}$$

$$y = \begin{bmatrix} 1 & 0 & 0 & 0 \\ 0 & 0 & 1 & 0 \end{bmatrix} \begin{Bmatrix} x_1 \\ \dot{x}_1 \\ x_2 \\ \dot{x}_2 \end{Bmatrix} + \begin{bmatrix} 0 & 0 \\ 0 & 0 \end{bmatrix} u \tag{23}$$

Hence, the state space matrix is defined as shown in Eqs. 24-27.

$$A = \begin{bmatrix} 0 & 1 & 0 & 0 \\ \frac{-(ks+kd)}{ms} & \frac{-(cs+cd)}{ms} & \frac{kd}{ms} & \frac{cd}{ms} \\ 0 & 0 & 0 & 1 \\ \frac{kd}{md} & \frac{cd}{md} & \frac{-kd}{md} & \frac{-cd}{md} \end{bmatrix} \tag{24}$$

$$B = \begin{Bmatrix} 0 \\ \frac{1}{ms} \\ 0 \\ 0 \end{Bmatrix} \quad (25)$$

$$C = \begin{bmatrix} 1 & 0 & 0 & 0 \\ 0 & 0 & 1 & 0 \end{bmatrix} \quad (26)$$

$$D = \begin{bmatrix} 0 & 0 \\ 0 & 0 \end{bmatrix} \quad (27)$$

Analysis of Structural Vibration Response

Analysis of the vibration response in this study is performed using the state space Simulink. Vibration response analysis is performed on structures without TMD and structures with the addition of TMD. The state-space matrix that has been obtained in the previous chapter is the basis for making block diagrams of Simulink state space as seen in Figure 6.

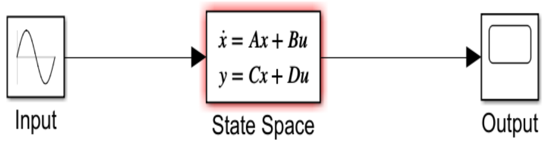


Figure 6 State Space Simulation Block

To support simulations on Simulink, some parameters are needed, such as mass, stiffness, and damping structure. The value of each supporting parameter in the Simulink simulation can be seen in Table 1.

Table 1 Simulink Simulation Parameters

Parameters	Values	Unit
Mass of structure	360,000	Kg
Stiffness of structure	650,000,000	N/m
Damping of structure	6,200,000	N-s/m

Meanwhile, the mass, stiffness, and damping values of the TMD are determined using a genetic algorithm in the previous stage. The input noise force in this simulation uses a sine wave on the Simulink which can produce a steady-state response. The calculation of the structural disturbance input in this simulation uses the equation shown in Eq. 28.

$$f(t) = k_s\, y \sin \omega t \quad (28)$$

Where y is the disturbance in the structure which is an earthquake deviation that often occurs in Bengkulu Province at a magnitude of ML 5.0 [24]. ω is the frequency of the disturbance whose value is the same as the natural frequency value of the system, calculated using Eq. 29.

$$\omega = \sqrt{\frac{k_s}{m_s}} \quad (29)$$

The output of this state-space Simulink simulation is a displacement vs time graph showing the vibration response to the structure.

3.0 RESULTS AND DISCUSSION

The tuned mass damper damping system modeling in the structure in this study aims to reduce vibrations in the structure due to earthquake disturbance forces. In this study, the value of the TMD parameters ratio is calculated using a genetic algorithm. Analysis of the vibration response of the structure damper system in this study uses the state space. The result of this study is a graph of the comparison of the dynamic response of structures without TMD and structures with TMD.

Application of Genetic Algorithm

In this study, the genetic algorithm is implemented to obtain a solution in the form of the optimal value of the mass ratio, stiffness, and damping of the TMD to reduce the vibration response of the main structure. In its computation, the genetic algorithm runs randomly. So, to get the best chromosome, one of the chromosomes with the smallest fitness value, genetic algorithm parameter testing is performed that consists of the population size, generation, and combination of crossover and mutation probability which will be analyzed from the results of the most optimal fitness value. This is necessary to obtain a suitable combination of parameter values.

Population Size Testing

Population size testing is used to determine the optimal population size to solve the problems in this study. The population size test is done by varying the population size by 10 multiples of the population size 10 to 100. The population size test is carried out at the generation size of 500, with the crossover probability of 0.5 and the mutation probability of 0.5. The test is carried out ten times for each variation in population size and then the best fitness value is taken. This is performed to get results that represent the full ability of the algorithm. The results of this population size test are in the form of a graph of the population size vs the best fitness of each population size variation as seen in Figure 7.

Based on the graph of the test results in Figure 7, shows that population size has an effect on the result of fitness value from the genetic algorithm process. At a population size of 10 to 30 the fitness value gets smaller as the population size increases. This is because the larger population size causing results in greater chromosome variations in it. As a result, the chromosomes selected as parent candidates in the crossover and mutation recombination process will have a wider variety. So that it affects the resulting fitness value to be more optimal.

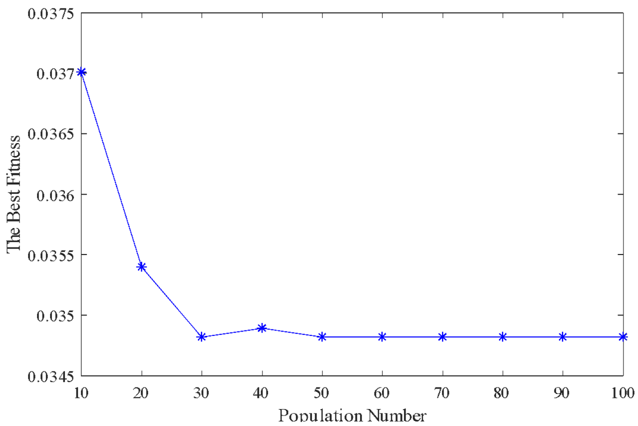


Figure 7 Graph of Fitness Value Based on Population Size Testing

Furthermore, in population size of 30 to 100, there is a change in the fitness value, which increases in the size of 40 population and falls back to size 50 but it is not significant. Then the graph tends to be stable in a straight line. The number of changes is not so large occur because the initial chromosome initialization in the genetic algorithm is carried out randomly. As a result, the offspring chromosomes produced in the crossover and mutation process are similar to the chromosomes in the previous population. then the resulting fitness values do not change significantly.

A small increment of fitness value corresponding to population size of 40 in comparison to one of 30 is shown in Fig. 7. This represents the random nature of GA i.e.; several runs of GA will give usually different results. Fig. 7 is an indication of the behaviors of the GA based on several simulation. Each simulation is a random sample of the whole search space. The results given in Figure 7 indicate that each population size corresponds to different sets of samples. Therefore Figure 7 is *approximately* monotonically decreasing.

Variance of fitness values for population size 30 to 100 is relatively small. On the other hand, the higher population size, the heavier computational burden. Therefore, it is important to choose a small population size. Based on Figure 7, population size of 30 is a good choice since it can get good fitness value with small computational burden.

Generation Size Testing

The generation size test is performed to determine the number of generations that can produce the best solution in this case by varying the generation size multiples of 100 from the generation size 100 to 1000. In testing this number of generations, a population size of 30 is used which is considered to produce the most optimal fitness value in a size testing population, the crossover probability is 0.5 and the mutation probability is 0.5. The test is performed ten times on each variation of the size of the generation then the best fitness value is taken. This is carried out to get results that represent the full ability of the algorithm. The results of this generation size test are in the form of a graph of the best size vs fitness of each generation size variation as seen in Figure 8.

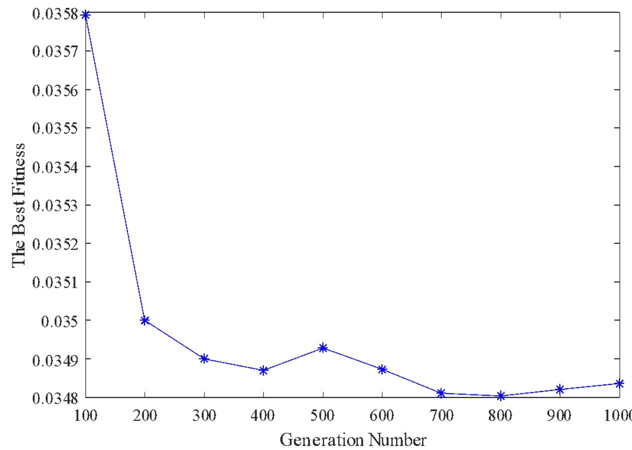


Figure 8 Graph of Fitness Value Based on Generation Size Testing

Figure 8 shows that the fitness value generated in the size range of 100 to 800 generations tends to get smaller along with the increase in the size of the generation and there is only an increase in the fitness value at the size 500. This shows that the larger the size of the generation, (approximately) the smaller fitness value generated is. Furthermore, at sizes 800 to 1000, there is an increase in fitness values are less than 0.0001. Hence, the size of 800 is chosen to reduce the computational burden.

The high generation size results in more frequent crossover and mutation processes. In each generation, crossover and mutation will be carried out. So, the larger the generation size, the more frequent crossover and mutation processes will be carried out so that the new chromosomes that are produced will be more varied and allow for variations in the resulting fitness values. So that the opportunity to get the optimal fitness value is higher.

Testing the Combination of Crossover Probability and Probability of Mutation

Testing the combination of crossover probability and mutation probability is carried out to determine the combination value between the crossover probability and the mutation probability that will produce the most optimal fitness value. The parameters used are population size and generation size, it is obtained that a size of 30 and a generation size of 800 are the most optimal results from previous tests.

The comparison of the combination of the crossover probability and the mutation probability of this test are 0.1: 0.9, 0.2: 0.8, 0.3: 0.7, 0.4: 0.6, 0.5: 0.5, 0.6: 0.4, 0.7: 0.3, 0.8: 0.2, and 0.9: 0.1. The test is carried out ten times on each variation of the combination of crossover probability and mutation probability then the best fitness value is taken. This is performed to get results that represent the full ability of the algorithm. The results of testing the combination of the crossover probability and the mutation probability can be seen in Figure 9.

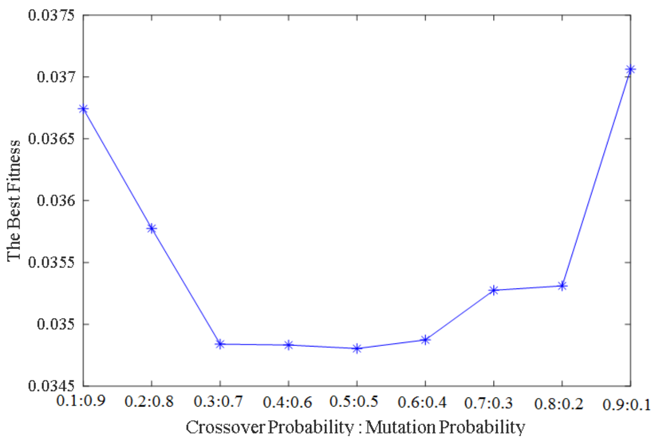


Figure 9 Graphic of the Fitness Value of the Combination of Crossover and Mutation Probabilities

Figure 9 shows that the combination of the crossover and mutation probability values affects the resulting fitness value. The smaller difference between crossover and mutation probabilities, the smaller fitness value. The use of crossover and mutation probability values that are too large or too small does not seem to correspond to optimal fitness values. This is because the combination of crossover probability that is too small and the mutation probability is too large to make the crossover process less frequent, while the mutation process becomes more frequent. As a result, the resulting fitness value is not optimal.

Likewise, the use of a combination of crossover probability that is too large and the mutation probability is too small makes the crossover process more frequent while the mutation process is less frequent. As a result, the resulting fitness value is also not optimal. So, to produce an optimal fitness value, you must use a crossover and mutation probability with a balanced value.

Note that fitness values of two other combinations, i.e. 0.3:0.7 and 0.4:0.7, are very close the one of 0.5:0.5. However, the fitness value of combination 0.5:0.5 is still the lowest one. On the other hand, the computational burden does not vary significantly because of variation of these combinations. Hence, the value of the fitness function is used solely to find the best combination. The combination of crossover probability and mutation probability in this study is 0.5: 0.5.

The Best Solution Obtained

In optimization research using genetic algorithms, a series of tests for the genetic algorithm parameters are needed to obtain the appropriate parameter value combination. In this study, a combination of genetic algorithm parameters with the most optimal fitness value is obtained, namely population size of 30, number of generations of 800, crossover probability 0.5, and mutation probability 0.5.

Based on the values of these parameters, we implement the genetic algorithm using Matlab 6 on a laptop with Windows 10 processor. The details of the algorithm have been explained in the Method section. All computations were done before 3 seconds. The solution corresponds to the chromosome of the individual with the smallest value of fitness function in the final population as given in Eq. 10. The values of TMD mass ratios are 10%, stiffness is 10%, and damping is 1% for mass, stiffness, and damping of the main structure.

Note that the GA parameters is problem-specific. It means that other buildings may have different optimal values. However, the approach to find the optimal (good) values here can easily be applied to other situations.

Structural Vibration Response

To analyze the effectiveness of the addition of TMD in reducing vibration in structures, an analysis of vibration responses is performed with TMD and without TMD. The results of this study have been monitored and presented as a comparison of 2D displacement vs time graphs that show the vibration response of structures with TMD and without TMD.

The vibration response in structures without TMD will be a reference for calculating the amount of reduction in vibration response in structures with the addition of TMD. This will be a reference that shows the effectiveness of the addition of TMD to the structure. In the analysis of the vibration response of the structure with the addition of TMD, the parameters are used in the form of mass ratio, stiffness, and damping which are obtained from calculations using genetic algorithms. The vibration response of the structure with TMD and without TMD is shown in Figure 10.

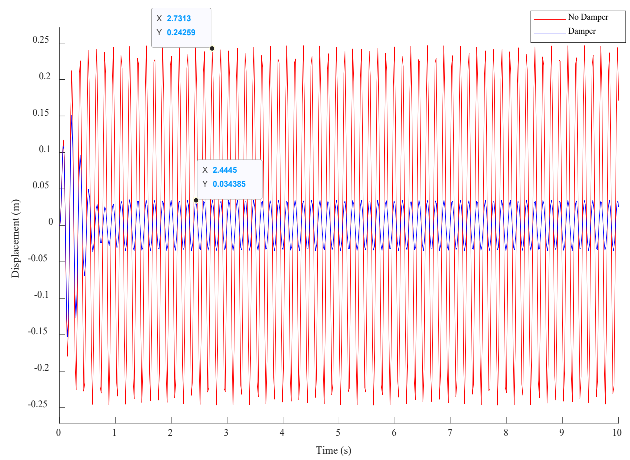


Figure 10 Vibration Response on Structure with and without using TMD

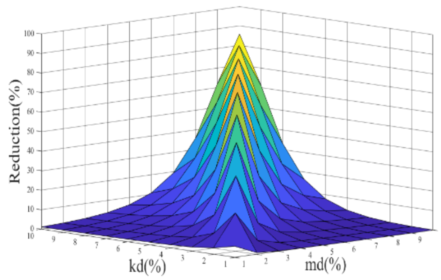
From the graph of the comparison of the vibration response of structures with TMD and without TMD in Figure 10, it can be seen that the maximum displacement value of the main structure without TMD is 0.24259 m and reduced to one with the addition of TMD is 0.034385 m. This shows that TMD is successful in reducing vibrations in the main structure with a reduction percentage of 85.94%. Where the energy received by the structure is not only absorbed by the structure itself, but also by the mass, stiffness, and damping elements in the TMD.

Genetic Algorithm Calculation Performance

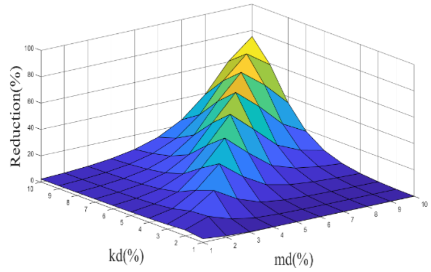
To test the performance of the TMD parameter calculation results from the genetic algorithm, the parameter is tested with the variation of mass ratio and stiffness ratio of 1% to 10% along with damping ratio of 1% to 5% to the mass, stiffness, and damping of the main structure. This is performed by comparing the vibration reduction value of the structure with the composition of the parameters generated by the genetic algorithm and the parameters that are determined by trial and error. The results of vibration reduction in the structure with each variation of the mass ratio (md) and stiffness ratio (kd) at each variation damping ratio (cd) are presented graphically in Figure 11.

The percentage reduction graph obtained in Figure 11 shows that the best reduction values TMD mass ratio is 10%, stiffness is 10% and damping is 1%. The value of the parameter ratio is the composition of the parameter ratio which is the same as the result of the calculation of the genetic algorithm, with a reduction of 85.94%. The resulting reduction percentage value is getting smaller in the composition of the TMD parameter ratio, which is getting away from the TMD parameter ratio calculated by the genetic algorithm.

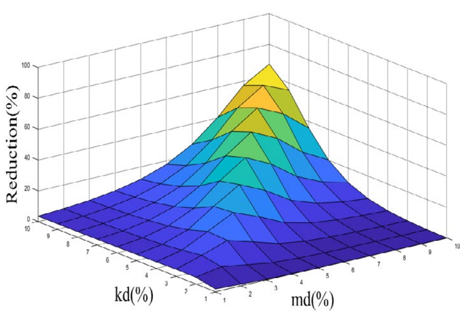
This indicates that the value of the TMD parameter ratio calculated by the genetic algorithm may be the optimal ratio value for reducing vibration in the structure and the genetic algorithm is an effective method to determine the optimal TMD parameters for reducing vibration in structures. Mathematical proof of the optimality is beyond the scope of this paper and is one of the related future works.



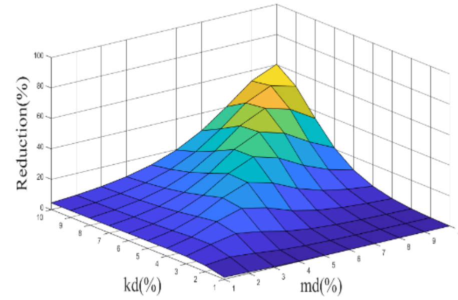
(a)



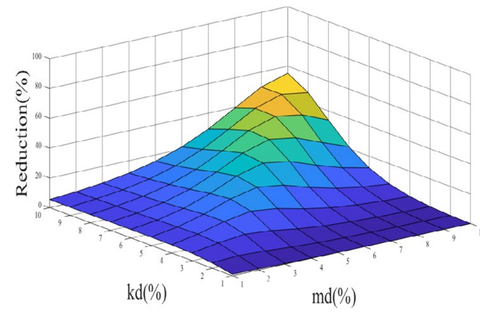
(b)



(c)



(d)



(e)

Figure 11 Vibration Reduction of The Structure: a). at TMD Damping Ratio 1%, b). at TMD Damping Ratio 2%, c). at TMD Damping Ratio 3%, d). at TMD Damping Ratio 4% and e). at TMD Damping Ratio 5%

4.0 CONCLUSION

Based on the previous discussion, the following conclusions are obtained;

- The genetic algorithm can solve the optimization problem of determining the value of the TMD parameters which is effective in reducing the vibration response of the structure.
- By applying the genetic algorithm, the optimal damper parameters are obtained to reduce the vibration response of the structure with the ratio of mass 10%, stiffness 10%, and damping 1% of mass ratio, stiffness, and structure damping with a reduction percentage of 85.94%.

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