BAREKENG: Journal of Mathematics and Its Applications
December 2024 Volume 18 Issue 4 Page 2273–2282
P-ISSN: 1978-7227 E-ISSN: 2615-3017
https://doi.org/10.30598/barekengvol18iss4pp2273-2282

NUMERICAL ERROR METHOD TO DETERMINE THE EFFICIENCY OF REDUCING VIBRATIONS DUE TO EARTHQUAKE LOADS ON BUILDINGS USING FLUID VISCOUS DAMPER

Radius Prawiro [1], Rafki Imani[2*], Nanda[3]

[1] *Information System Department, Computer Science Faculty, Universitas Putra Indonesia "YPTK" Padang*
[2,3] *Civil Engineering Department, Engineering Faculty, Universitas Putra Indonesia "YPTK" Padang*
Jl. Raya Lubuk Begalung, Padang, 25221, Indonesia

Corresponding author's e-mail: ***rafimani17@yahoo.co.id**

ABSTRACT

Article History:

Received: 19th February 2024
Revised: 18th May 2024
Accepted: 14th July 2024
Published: 14th October 2024

Keywords:

FVD Damper;
Displacement;
Earthquake;
Period of Vibration;
Reduction.

According to The Indonesian Earthquake Map, Padang City in West Sumatra is in Earthquake zone 6. This indicates that Padang City is very vulnerable to earthquakes. Meanwhile, developments in the construction of high buildings also continue to show progress all the time. The main problem that is often faced is the issue of structural damage due to earthquakes. Efforts are needed in earthquake engineering on buildings so that collapse can be minimized. The earthquake damping system used is FVD (Fluid Viscous Dampers) with different types. The Type-A damper is FVD-750 kN and the Type-B damper is FVD-1000 kN, and without using a damper. This research aims to analyze the efficiency of reducing earthquake loads such as floor displacement and vibration period of an 18-story building structure 18 meters high from the base.The analysis method used is a numerical method by calculating earthquake load reduction based on numerical error analysis from the two types of dampers used on structures without using dampers. Building planning refers to SNI 1727-2013, SNI 1726-2019, and SNI 2847-2019, and is assisted by ETABS software. Based on SNI 1726-2019, earthquake risk category II, soft soil condition type (SE), earthquake acceleration response value SDS = 0.745g and SD1 = 0.784g are obtained. The earthquake load used is a dynamic load, taking into account that the condition of the building is irregular. Based on the results of the analysis, it was found that the displacement between floors using the Type-AFVD Damper could reduce the displacement by up to 45.72% and with the Type-B FVD Damper it could reduce the displacement by up to 92.72%. Meanwhile, the period of vibration natural using a Type-A FVD Damper can be reduced by up to 12.34% and using a Type-B FVD Damper can be reduced by up to 33.21%.

How to cite this article:
R. Prawiro, R. Imani and Nanda., "NUMERICAL ERROR METHOD TO DETERMINE THE EFFICIENCY OF REDUCING VIBRATIONS DUE TO EARTHQUAKE LOADS ON BUILDINGS USING FLUID VISCOUS DAMPER," *BAREKENG: J. Math. & App.*, vol. 18, iss. 4, pp. 2273-2282, December, 2024.

Journal homepage:*https://ojs3.unpatti.ac.id/index.php/barekeng/*
Journal e-mail: *barekeng.math@yahoo.com; barekeng.journal@mail.unpatti.ac.id*

Research Article ·**Open Access**

1. INTRODUCTION

Many events in everyday life, such as in the field of civil engineering, can be modeled in mathematical formulations with numerical problem solutions[1][2][3][4][5][6][7][8]. An example is an earthquake event. An earthquake event can have an impact on collapse and damage to buildings, so it is necessary to plan in structural engineering [9], [10]. Earthquakes are modeled as dynamic loads that tend to change over time. Dynamic loads from earthquakes can be used as design loads for structural analysis. In structural analysis, the numerical equations of the Linear Equation System (LES) can be used to plan earthquake engineering buildings and calculate internal forces in structures [11][12][13][14].

Earthquake occurs suddenly and cannot be predicted, so people are not prepared to face the impacts of earthquakes, such as loss of homes, property, injuries and even death [15][16]. The West Sumatra Province region is an area that is very vulnerable to earthquake disasters, because it is close to the Mentawai Megathrust Subduction zone and the Sumatra fault [17]. Some of the destructive earthquake events that hit West Sumatra so far are the Aceh earthquake-tsunami (2004), the Solok earthquake in 2005, the Bengkulu earthquake in 2007, the earthquake in Padang City and its surroundings in September 2009, and the earthquake in the Mentawai Islands in 2010 [18][19][20]. The most recent earthquake in the last five years also occurred in the Solok and South Solok areas on February 28, 2019, as well as the earthquake in West Pasaman in February 2022 [21][22][23].

The increase in population has triggered an increase in the construction of structures such as hotels and high buildings. The main problem with this structure is that it has a high risk of vibration during an earthquake which can cause damage and collapse to the building [24][25]. The impact will be even greater if the construction of these buildings and hotels are built near residential areas with dense populations. The solution to overcome this problem can be done by reducing earthquake vibrations that propagate through buildings. This solution has been widely developed as a damper or reducer of earthquake vibrations in buildings by creating structural control systems such as base isolation and tuned mass dumpers [26][27]. Until now, systems like this, apart from being unpopular in use, are still limited to high-rise buildings and are also expensive to implement in Indonesia. So it is necessary to look for other, more affordable alternatives to reduce earthquake vibrations that propagate through buildings. Another possible way is to use a fluid viscous damper (FVD) system which is placed as bracing on building structural elements [28][29][30][31][32][33].

From the description above, it was found that the damper system i.e. FVD, applied to the structure, whether placed as isolation at the base of the building (base isolator) or placed on the bracing elements as a hydraulic damper (viscous damper), can absorb earthquake energy and reduce earthquake loads [34]. The current problem is that it is not yet known how much the damper is able to reduce earthquake vibrations that propagate through the structure. Structural analysis in earthquake engineering problems is a complex and repetitive calculation. Often at certain times, when in the field, researchers only need to know the value of certain parameters without having to calculate the solution, especially in the form of a function first, but simply by modeling it in a simple form and finding the solution using numerical methods [35].

From this description, the calculation of earthquake load reduction is the percentage value or efficiency of earthquake load reduction on a structure (buildings), which can be described using a simple mathematical solution using numerical methods, namely by numerical error analysis. The numerical error analysis method in this research is used because it can make calculation completion more practical and save calculation time. This research aims to calculate the percentage of earthquake load reduction using numerical error analysis as an analysis using numerical methods.

2. RESEARCH METHODS

This research aims to calculate the percentage of vibration reduction efficiency of structures due to earthquake dynamic loads using numerical error analysis. Error analysis is an analysis technique in numerical methods [36][37]. In engineering problems, error analysis can be used to determine work efficiency, and can compare the reliability of one tool against other tools [38][39].

The structure analyzed in this research is an 18-story building structure with a height of 68 m. This building uses a damper system of Fluid Viscous Dampers (FVDs). Fluid viscous damper (FVD) is a tool that is able to demonstrate its efficiency as an energy dissipation system and reduce the effects on structures due to dynamic loading conditions such as earthquakes. FVD generally provides up to 25% attenuation.

For example, reinforced concrete structures equipped with FVD are capable of reaching the total damping is 30%, of which approximately 25% is the damping directly caused by dampers, while the remaining 5% are structural dampers [40][41][42][43]. FVDs with passive behavior usually consist of a hollow cylinder filled with silicone oil (or similar type of fluid) and piston rod with head provided with a hole, which divides the inner volume of the cylinder into two chambers, as shown in **Figure 1 [40]**.

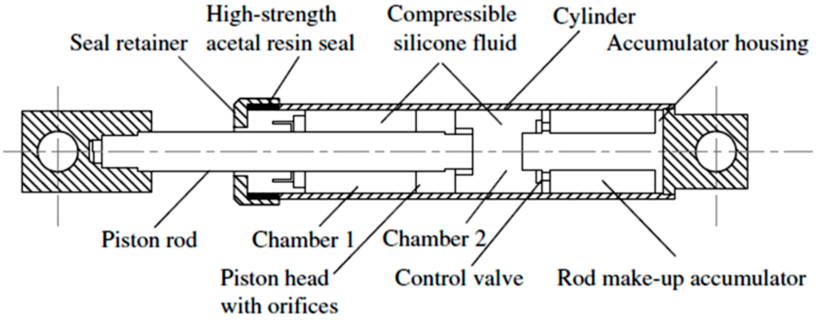


Figure 1. FVD Damper System Mechanism [29][40].

This research uses FVDs, namely Type-A of FVD-750 and Type-B of FVD-1000. The analysis method used is a combination of Earthquake Engineering Structural Analysis Methods and Numerical Analysis Methods. First, a structural analysis is carried out using earthquake engineering analysis, where the calculations refer to the standards SNI-1727-2013, SNI-1726-2019, SNI-2847-2019 [44]. The input data is in the form of dead loads originating from the structure's own weight, live loads originating from dynamic loads, namely loads from earthquake shaking in the form of accelerated response spectrum. For analysis purposes, calculations are carried out on structures that use FVD dampers and on structures that do not use FVD. After the results of the structural analysis have been calculated, with the output being the magnitude of the deviation and period of vibration, the next process is to carry out an analysis of the vibration reduction that occurs due to the load from earthquake shaking on the magnitude of the deviation and period of vibration produced by the structure. The vibration reduction efficiency of the two structural models was calculated using error analysis from numerical methods in percentage (%).

2.1. Structure Data

The building structure data used in this research is a hotel building type with an 18-story reinforced concrete structure with a total height of 68 meters, the length of the building in the x direction is 42 meters and the y direction is 52 meters, and the quality of the materials used is $f'c$ = 25 MPa, $f'c$ = 30 MPa, fy = 390 MPa and fy = 295 Mpa. The element data and structural dimensions used are the plate structure, which consists of a roof plate = 130 mm; floor plate = 150 mm, beam structure consisting of main beam I = 450/700; main beam II = 400/600 and subbeams = 300/400, as well as a column structure consisting of column K1 = 1200/1200; column K2 = 800/800 and column K3 = 500/500.

2.2. Structure Loads

The applied structural load data consists of live load (LL), dead load (DL) and earthquake response spectrum load. The live load is 2400 kg/m^2 which comes from the weight of the corridor, the load from room activities on floors 1-17, storage rooms, meeting rooms, dining rooms and restaurants as well as the weight of the roof on the 18th floor. The dead load is 221 kg/m^2 which comes from the weight floors 1-17, ceramics, plaster, ceiling and weight of floor 18. The earthquake load used is the spectrum response value in units of gravity (g) or ground speed, which has been calculated based on **Figure 2**.

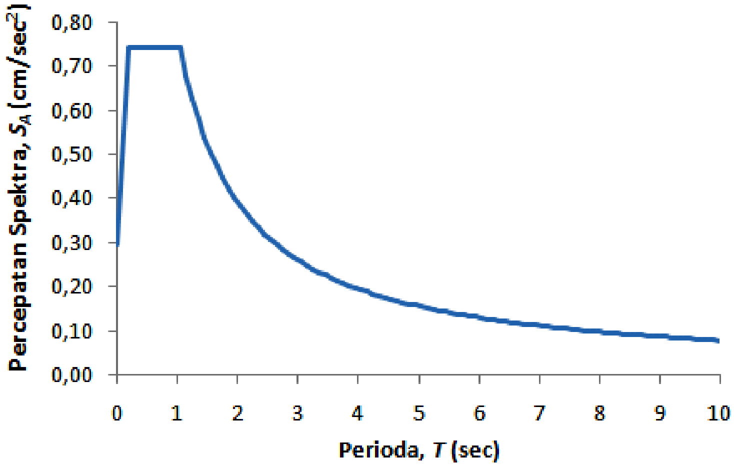


Figure 2. Response spectrum analysis plot

Figure 2 is a plot of the graph of the acceleration response spectrum ($\boldsymbol{SA}$) against the earthquake vibration period (T). This acceleration response spectrum is used as earthquake load data used in structural analysis for forces in the structure. Then the wind load data is given as basic wind speed $\boldsymbol{V}$ = 40 m/sec^2, wind direction factor $\boldsymbol{Kd}$ = 0.85, topographic factor $\boldsymbol{KzT}$ = 1.00, wind gust factor coefficient $\boldsymbol{G}$ = 1.00, internal pressure coefficient, $\boldsymbol{GCPi}$ = +0.18 and -0.18; velocity pressure exposure coefficient, $\boldsymbol{Kz}$ = 1.24; determine the velocity pressure $\boldsymbol{qz}$ = 1033.7632 N/m^2. Wind stresses ($\boldsymbol{P}$) consist of $\boldsymbol{P1}$= -599.58 N/m2, $\boldsymbol{P2}$ = -899,373 N/m^2, $\boldsymbol{P3}$ = -568,569 N/m^2, $\boldsymbol{P4}$ = -485,868 N/m^2, $\boldsymbol{P_1E}$ = 444,518 N/m^2, $\boldsymbol{P_2E}$ = -1292.20 N/m^2, $\boldsymbol{P_3E}$ = -733.971 N/m^2, and $\boldsymbol{P_4E}$ = -630.59 N/m^2.

2.3. Characterictics of Fluid Viscous Damper (FVD)

The damper of structural used is a Fluid Viscous Damper (FVD) with the Type-A of FVD-750 (with strength of 1000 kN) and Type-B of FVD-1000 type (with strength of 1000 kN). The choice of this type of damper is based on the reason that it is rarely used for tall structures [45]. The characteristics of the two types can be seen in Table 1. The stiffness of the damper is calculated using Equation (1), where [46]:

$$K = \frac{AE}{L} \tag{1}$$

where $\boldsymbol{K}$ is the stiffness of the FVD (kg/cm), $\boldsymbol{A}$ is the area of the FVD (cm^2), $\boldsymbol{E}$ is the Modulus of Elasticity (kg/cm^2) and $\boldsymbol{L}$ is the length of the structural element (cm). The use of dampers in structures assumes that most of the energy entering the structure can be absorbed by damper elements and a small portion is absorbed by other structural elements. Fluid Viscous Damper is able to reduce stress and deflection simultaneously, because the FVD force varies only with the speed of movement, and produces a response to the bending stress of the structure. The damping force of the FVD used for structural analysis is calculated by Equation (2), where [47]:

$$F_D = CV^{\alpha} \tag{2}$$

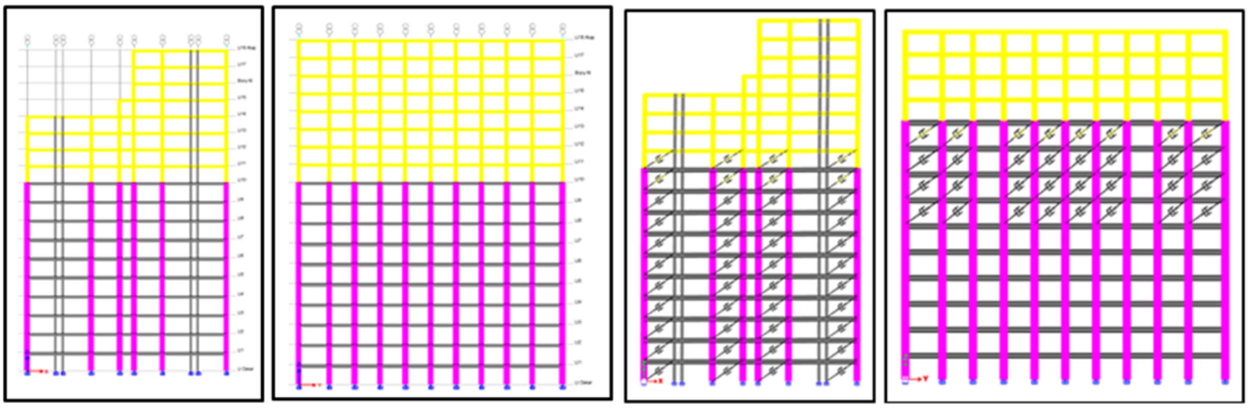
where $\boldsymbol{F_D}$ is the force by the damper (kN), $\boldsymbol{C}$ is the damper constant, $\boldsymbol{V}$ is the speed between the ends of the element (m/sec) and $\boldsymbol{\alpha}$ is the speed coefficient of the damper.

Table 1. The Characteristics of FVD Damper Used

FVD Type (kN/m)	Length of damper (L) (m)	Height of floor (H) (m)	Stiffness(K) (kN/m)	Coefficient (α) (kN.s/m)
Type-A of FVD-750	7.2	4	722380.2746	736.449
	6.9	3.5	750588.4956	
Type-B of FVD-1000	7.2	4	940954.93	981.933
	6.4		1060191.563	
	6.9	3.5	977698.2709	

2.4. Structure Design

Structural analysis is designed for three structural models. Model-A is a structure without using an FVD damper, Model-B is a structure using a Damper Type-A of FVD-750 and Model-C is a structure using a Damper Type-B FVD-1000. **Figure 3** is a model of the designed structure.



(a) (b)

Figure 3. Planned structural model,
(a) Structure without damper, and (b) Structure with FVD

2.5. Vibration Reduction Value with Numerical Error Analysis

The vibration reduction value due to earthquake dynamic loads is calculated based on the resulting structure displacement ($\boldsymbol{D}$, mm) and the time period of structural vibration that occurs ($\boldsymbol{T}$, seconds), which refers to the SNI-1726-2012 Standard. The displacement value is calculated using **Equation (3)**, and the natural vibration period of the structure is calculated using **Equation (4)**.

$$\boldsymbol{D} = \frac{\boldsymbol{C_d d_{xe}}}{\boldsymbol{I_e}} \tag{3}$$

$$\boldsymbol{T} = \boldsymbol{C_t} \times \boldsymbol{h_n^x} \tag{4}$$

where $\boldsymbol{D}$ is displacement or deflection (cm), $\boldsymbol{C_d}$ is the displacement amplification factor, $\boldsymbol{d_{xe}}$ is the displacement at the required location (mm), and $\boldsymbol{I_e}$ is the earthquake priority factor, where the value refers to SNI-1726-2012, $\boldsymbol{T}$ is the period of vibration of the structure (second), $\boldsymbol{C_t}$ is the moment-resisting concrete frame coefficient and $\boldsymbol{h_n^x}$ is the height of the structure (cm). These vibration reduction values are calculated using numerical method, namely numerical error analysis, by **Equation (5)** and **(6)**, where **[48][49]**:

$$R_D = \left|\frac{D_1 - D}{D_1}\right| \times 100\% \tag{5}$$

$$R_T = \left|\frac{T_1 - T}{T_1}\right| \times 100\% \tag{6}$$

where R_D and R_T respectively are the percentage reduction in structural displacement and the percentage reduction in the period of vibration produced by the structure after the FVD damper is placed. D is the displacement before the damper is applied (mm), and D_1 is the displacement after the damper is applied. Meanwhile, T is the amount of the vibration period before the damper is applied and T_1 is the vibration period after the damper is applied (sec).

3. RESULTS AND DISCUSSION

Structural calculations and analysis to determine the amount of displacement and the period of vibration of the structure are assisted with ETABS Software in accordance with the SNI-1726-2012 Standard. Explanation and analysis derivatives are given in the following description.

3.1 Story Drift

The displacement between floors (D) is the difference in deflection at the center of mass at the top level and the bottom level. Displacements between floors must not exceed the permissible displacement (D_a) as specified in SNI-1726-2019 for all levels, with a permissible displacement limit of 70-80 mm. The displacement value for each floor is as given in **Table 2**. The structural displacement value is calculated using **Equation (3)**.

Conceptually, the displacement experienced by the structure due to the earthquake load received is different for each floor. The floor that experiences the greatest displacement is the top floor of the structure[30]. It is known from **Figure 4**, that the maximum displacement between floors occurs on the 18th floor. The structure without dampers is the structure that experiences the largest displacement, this is in line with the research results provided by Khannavar et al (2017) **[24]**. Meanwhile, the structure that experienced the smallest deviation was the structure that used a Type-B of FVD-1000 Damper. The greater the damping force used, the greater the displacement suffered by the structure can be reduced **[31]**.

Table 2. Structure Displacement with and without FVD Damper

Floor	Displacement without FVD (mm)	Displacement with Damper Type-A FVD-750 (mm)	Reduction (%)	Displacement with Damper Type-B FVD-1000 (mm)	Reduction (%)
18	339.753	159.57	53.03	30.89	90.91
17	334.648	140.55	58.00	28.90	91.36
16	327.153	137.68	57.92	27.30	91.66
15	317.122	129.99	59.01	25.20	92.05
14	304.981	123.59	59.48	22.70	92.56
13	290.914	119.86	58.80	19.90	93.16
12	274.827	113.85	58.57	16.90	93.85
11	256.816	109.73	57.27	14.20	94.47
10	237.468	103.91	56.24	12.10	94.90
9	215.111	96.69	55.05	11.10	94.84
8	191.506	87.83	54.14	10.30	94.62
7	166.422	83.64	49.74	9.60	94.23
6	139.878	78.45	43.92	8.70	93.78
5	112.145	75.61	32.58	7.50	93.31
4	83.804	68.30	18.50	6.00	92.84
3	55.893	44.68	20.06	4.40	92.13
2	30.196	26.78	11.31	2.80	90.73
1	9.767	7.87	19.42	1.20	87.71
0	0.000	0.00	0.00	0.00	0.00

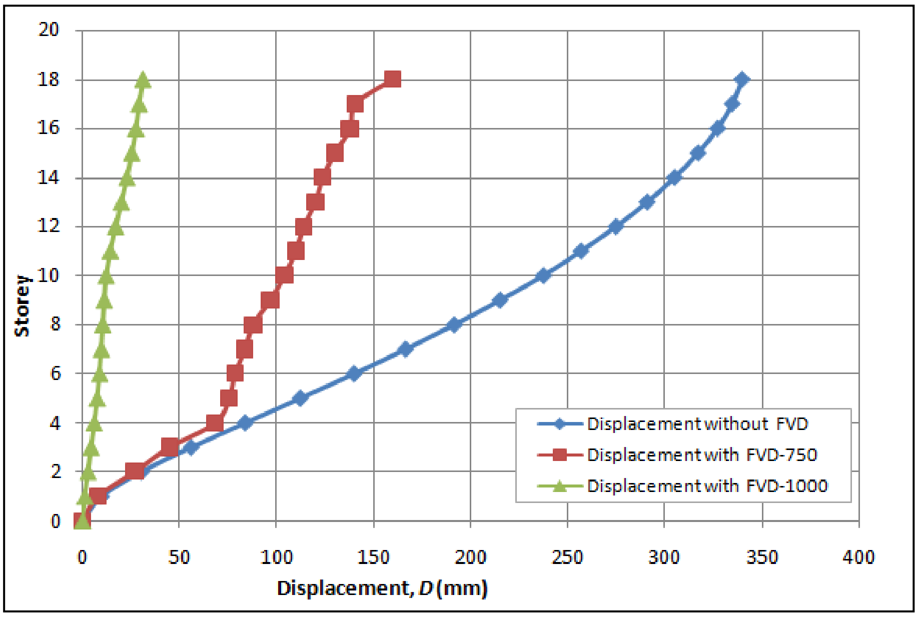


Figure 4. Plot of Structural Displacement for each Floor with and without FVD Damper

Based on Table 2, the vibration reduction value can be calculated for each type of structure, both structures that use FVD dampers and structures that do not use FVD dampers, as shown in Table 3. The reduction value for structural displacement has been calculated based on Equation (5). The maximum displacement reduction of the structure is obtained by the structure using the FVD-1000 type damper, which is 87% - 95% compared to other structures.

3.2 The Natural Period Vibration of The Structure

The natural vibration period of the structure is calculated using Equation (4) and refers to the SNI-1726-2012 standard. The maximum period occurred on floor 1, as shown in Table 3.

Table 3. The Natural Vibration Period of the Structure for each Mode

Mode	Period without FVD Damper (sec)	Period with Type-A of FVD Damper(sec)	Reduction (%)	Period with Type-B of FVD Damper(sec)	Reduction (%)
1	2.901	2.713	6	1.806	61
2	2.842	2.659	6	1.652	72
3	2.535	2222	12	1.332	90
4	0.997	0.909	9	0.938	6
5	0.995	0.876	12	0.894	11
6	0.777	0.588	24	0.649	20
7	0.597	0.529	11	0.470	27
8	0.407	0342	16	0.352	16
9	0.380	0.322	15	0319	19
10	0.197	0.176	11	0.179	10

Table 3 is a comparison of the results of calculating the natural vibration period of the structure within and without using Type-A of FVD-750 Dampers and Type-B of FVD-1000 Dampers. Based on Table 3, it can be seen that the structure's natural vibration time (period) can reduce the period of vibration due to an earthquake using an FVD damper, where it is found that the maximum period of structure vibration occurs on 1st floor.

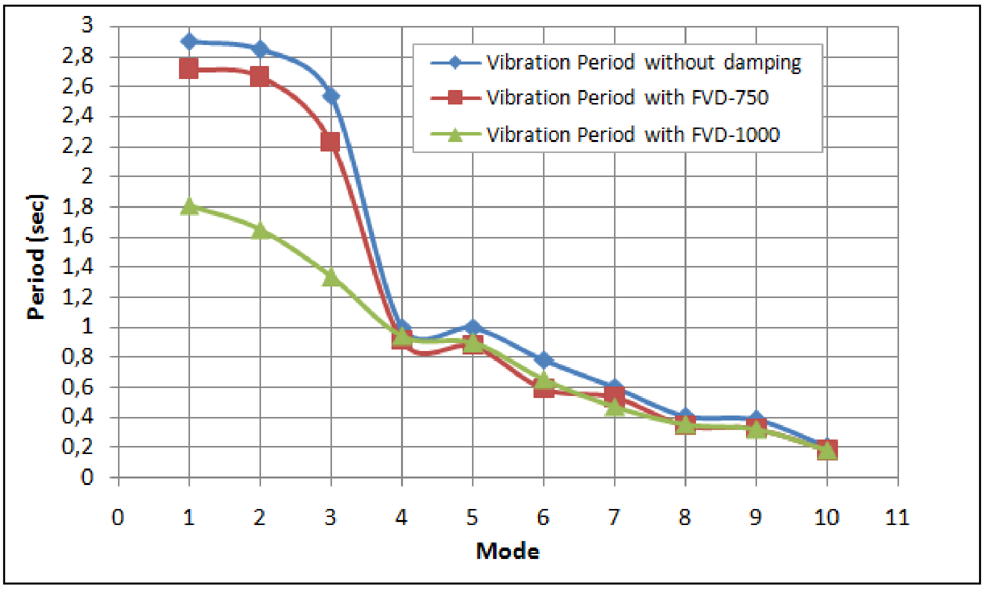


Figure 5. Plot the Natural Vibration Period of the Structure in Each Mode

From Table 3, it is known that the damper that meets the permit limits for the natural vibration period is a structure using a Type-B of FVD-1000 Damper with the maximum reduction efficiency occurring on the 3rd floor, namely 90%, as shown in Figure 5. The maximum vibration period is applied by the structure without dampers (blue line), and is followed afterwards by the structure with the Type-750 FVD damper (red line), while the minimum vibration period is experienced by the structure with the Type-1000 damper (green line). It can be said that structures that use dampers with higher strength types can reduce or reduce earthquake loads even by more than 25% [40].

Based on the results of calculations that have been carried out to calculate the efficiency of reducing earthquake loads on structures, the application of numerical methods, such as numerical error analysis, can be used effectively, because it provides results that are relevant to analysis using structural analysis methods. Besides that, calculations using numerical error analysis can also save analysis time, so that calculations are completed more quickly [35].

4. CONCLUSIONS

An analysis of the numerical reduction of earthquake loads on an 18-story structure using Type-A and Type-B FVD dampers has been carried out. The earthquake loads analyzed are the displacement between floors and the period of vibration of the structure. By numerical analysis using the numerical error equation, it is found that the displacement between floors using the Type-A FVD damper can reduce the displacement by up to 45.72% and with the Type-B FVD damper it can reduce the displacement by up to 92.72%. Meanwhile, the vibration period using a Type-A FVD Damper can be reduced by up to 12.34% and using a Type-B FVD Damper can be reduced by up to 33.21%. This analysis is linear with research conducted by Ras & Boumechra (2016) [31].

ACKNOWLEDGMENT

This research was funded by University of Putra Indonesia, Yayasan Perguruan Tinggi Komputer Padang (UPI-YPTK Padang). Therefore, the authors would like to thank the Chairman of the “YPTK” Padang Foundation and also Prof. Sarjon Defit as Chancellor of the University of Putra Indonesia “YPTK” Padang, West Sumatra.

REFERENCES

[1] M. Irwan, W. Alwi, and R. Ibnas, “Analysis of The Spruce Budworm Model using The Heun Method and Third-Order Runge-Kutta,” *BAREKENG J. Math. Its Appl.*, vol. 16, no. 3, pp. 967–974, 2022, doi: https://doi.org/10.30598/barekengvol16iss3pp967-974.

[2] E. Y. Bunga and M. Z. Ndii, “Application of Differential Transformation Method for Solving HIV Model with Anti-Viral Treatment,” *BAREKENG J. Ilmu Mat. Dan Terap.*, vol. 14, no. 3, pp. 377–386, 2020, doi: https://doi.org/10.30598/barekengvol14iss3pp377-386.

[3] S. N. Aulele, “Model Geographically Weighted Poisson Regression dengan Pembobot Fungsi Kernel Gauss Studi Kasus: Jumlah Kematian Bayi di Jawa Timur Tahun 2007,” vol. 5, no. 2, pp. 25–30, 2011.

[4] F. Fikri, E. Djauhari, and E. Rusyaman, “Solusi Pendekatan Persamaan Gelombang Fraksional Non Linear Menggunakan New Version of Optimal Homotopy Asymptotic Method,” *BAREKENG J. Ilmu Mat. Dan Terap.*, vol. 14, no. 4, pp. 523–534, Dec. 2020, doi: 10.30598/barekengvol14iss4pp523-534.

[5] E. E, P. Rahayu, and F. Zuhairoh, “Perbandingan Solusi Numerik Integral Lipat Dua pada Fungsi Aljabar dengan Metode Romberg dan Simulasi Monte Carlo,” *J. MSA Mat. Dan Stat. Serta Apl.*, vol. 5, no. 1, pp. 46–57, 2017, doi: 10.24252/jmsa.V5N1P46.

[6] J. Hadisusanto and S. Mungkasi, “Penyelesaian Model Epidemiologi SIR Menggunakan Metode Runge- Kutta Orde Tiga Dan Metode Adams-Bashforth Orde Tiga,” *Ournal Math. Comput. Stat.*, vol. 6, no. 2, pp. 149–160, 2023.

[7] H. Hasanuddin, “Analisis Galat Energi dan Galat Fase Metode Forward 4th Order Symplectic Chin-Chen untuk Kasus Sistem Osilator Harmonik Sederhana,” *POSITRON*, vol. 10, no. 2, p. 9, 2020, doi: 10.26418/positron.v10i2.40023.

[8] J. A. Vasquez, “Errors,” in *Numerical Method*, Kavli-Cambridge: ICF-UNAM, 2021, p. 4.

[9] A. Pujianto, “Pengaruh Lapisan Pasir di Bawah Fondasi terhadap Redaman dan Frekuensi Natural Akibat Beban Gempa (Effect of Sand Layer under Foundation on Damping and Natural Frequency Due To Earthquake Loading),” *J. Ilm. Semesta Tek.*, vol. 12, no. 1, pp. 28–43, 2009.

[10] V. P. T. Malladi, “Earthquake Building Vulnerability and Damage Assessment with reference to Sikkim Earthquake,” A Thesis, Faculty of Geo-Information Science and Earth Observation of The University of Twente, Dehradun, India, 2012.

[11] R. Nasmirayanti, R. Imani, U. D. Arman, and A. Sari, “Analisa Linier Eliminasi Gauss-Jordan untuk Analisis Struktur Rangka Batang Segitiga Sederhana,” *Rang Tek. J.*, vol. 5, no. 1, pp. 156–159, Jan. 2022, doi: 10.31869/rtj.v5i1.2975.

[12] Z. Abidin, F. Purnama, and B. Heryadi, “Pengembangan Metode Integrasi Numerik dengan Frekuensi Batas yang Mampu Mereduksi Pengaruh Sinyal Pengganggu terhadap Hasil Integrasi,” *J. Tek. Mesin*, vol. 13, no. 1, pp. 18–24, Oct. 2011, doi: 10.9744/jtm.13.1.18-24.

[13] Y. Yahya, M. Sadali, and M. Mahpuz, “Tingkat Ketepatan Hasil Perhitungan Integrasi Numerik Menggunakan Bahasa Pemrograman C# Pada Metode Reimann dan Trapesium,” *Infotek J. Inform. Dan Teknol.*, vol. 2, no. 1, pp. 8–17, 2019, doi: 10.29408/jit.v2i1.981.

[14] Y. Yudhi, E. Noviani, and S. Aljona, “Solusi Persamaan Emden-Fowler Orde Dua dengan Memanfaatkan Matriks Operasional dari Polinomial Bernstein,” *BAREKENG J. Ilmu Mat. Dan Terap.*, vol. 15, no. 2, pp. 335–346, 2021, doi: 10.30598/barekengvol15iss2pp335-346.

[15] A. Adnan, M. Z. Ramli, and S. M. S. A. Razak, “Disaster Management and Mitigation for Earthquakes: Are We Ready?,” in *9th Asia Pacific structural engineering and construction conference (APSEC2015)*, in APSEC2015. Malaysia, Nov. 2015, pp. 34–44.

[16] D. A. Kourou, A. Ioakeimidou, and D. V. Mokos, “Earthquake Risk Mitigation and Preparedness Communication Policies to Bridge The Gap Between Public Misconceptions and Proper Actions,” presented at the Second European Conference on Earthquake Engineering an Seismology, in August 2014. Istanbul, Aug. 2014, pp. 1–7.

[17] R. Putera, T. Valentina, and D. Irawati, “Earthquake Disaster Mitigation in Padang, Indonesia,” in *Proceedings of the International Conference on Social Sciences, Humanities, Economics and Law*, Padang, Indonesia: EAI, Sep. 2019, p. 5. doi: 10.4108/eai.5-9-2018.2282602.

[18] S. Syamsidik, A. Nugroho, and M. Fahmi, *Aceh Pasca Lima Belas Tahun Tsunami: Kilas Balik dan Proses Pemulihan*. Banda Aceh: Tsunami and Disaster Mitigation Research Center (TDMRC) Universitas Syiah Kuala, 2019.

[19] J. Juhaina, T. K. Fasya, and A. I. Kamil, “Problematika di Balik Proses Relokasi Korban Bencana di Siti Ambia,” *Aceh Anthropol. J.*, vol. 3, no. 1, pp. 86–101, 2019, doi: 10.29103/aaj.v3i1.2788.

[20] I. L. N. Rais and L. Somantri, “Analisis Bencana Gempa Bumi dan Mitigasi Bencana di Daerah Kertasari,” *J. Samudra Geogr.*, vol. 4, no. 2, pp. 14–19, 2021, doi: 10.33059/jsg.v4i2.3773.

[21] S. P. Nugroho, “11 Orang Luka dan 101 Rumah Rusak Akibat Gempa 5,6 SR di Solok Selatan,” BNPB (Badan Nasional Penanggulangan Bencana). Accessed: Mar. 15, 2024. [Online]. Available: https://bnpb.go.id/berita/11-orang-luka-dan-101-rumah-rusak-akibat-gempa-56-sr-di-solok-selatan

[22] A. Permana, “Mengenal Gempa Bumi, Sumber, dan Bahayanya,” Institut Teknologi Bandung. Accessed: Nov. 12, 2023. [Online]. Available: https://www.itb.ac.id/berita/mengenal-gempa-bumi-sumber-dan-bahayanya/57739

[23] R. A. S. Poetro, R. Pakpahan, H. Wahab, and S. Sumarwan, *Membangun Ketangguhan Desa Melalui Upaya Pengurangan Risiko Bencana*. in Buku Pegangan Perencanaan Pembangunan Daerah 2015. Kementerian Perencanaan Pembangunan Nasional, Badan Perencanaan Pembangunan Nasional, 2014.

[24] S. Khannavar, M. H. Kolhar, and A. Algur, “Seismic Analysis of RC Structures Using Friction Dampers,” *Int. J. Res. Appl. Sci. Eng. Technol. IJRASET*, vol. 5, no. XII, pp. 401–410, 2017.

[25] M. Armaly, H. Damerji, J. Hallal, and M. Fakih, “Effectiveness of Friction Dampers on The Seismic Behavior of High Rise Building VS Shear Wall System,” *John Wiley Sons Ltd*, vol. 1, no. 5, p. e12075, 2019, doi: 10.1002/eng2.12075.

[26] L. E. P. Altamira, “Seismic Interstory Drift Demands in Steel Friction Damped Braced Buildings,” A Thesis of Master of Science in Civil Engineering, Universidad de las Américas, Puebla, Mexico, Mexico, 2009.

[27] S. S. Begum and D. G. Vani, “Seisimic Analysis of a High Rise Unsymmetrical Building with Dampers Using ETABS,” *Int. J. Sci. Res. Sci. Technol.*, vol. 2, no. 3, pp. 197–205, 2016.

[28] B. Naresh, J. Omprakash, and P. G. Student, “Seismic Design of Multistorey RCC-Building with Dampers Using ETABS,” *Int. J. Innov. Res. Sci. Eng. Technol.*, vol. 7, no. 1, pp. 180–190, 2018, doi: 10.15680/IJIRSET.2018.0701029.

[29] M. Constantinou, A. Reinhorn, D. P. Taylor, S. Fujii, S. Okamoto, and D. Ozaki, “Application of Fluid Viscous Dampers to Earthquake Resistant Design,” *Res. Accompl.*, 2004.

[30] G. P. Raj and B. D. Kumar, “Effect of The Position and Number of Friction Dampers on The Seismic Response of Unsymmetric Building,” *Int. Res. J. Eng. Technol.*, vol. 05, no. 05, pp. 3044–3050, 2018.

[31] A. Ras and N. Boumechra, “Seismic energy dissipation study of linear fluid viscous dampers in steel structure design,” *Alex. Eng. J.*, vol. 55, no. 3, pp. 2821–2832, 2016, doi: 10.1016/j.aej.2016.07.012.

[32] A. K. Sinha and S. Singh, “Seismic Protection of RC Frames using Friction Dampers,” *Int. J. Civ. Eng. Technol.*, vol. 8, no. 2, pp. 289–299, 2017.

[33] D. Carson, A. Malhotra, P. Gopal, A. Braimah, G. D. Giovanni, and R. Pall, “Friction Dampers for Seismic Upgrade of St. Vincent Hospital, Ottawa,” in *13 WCEE*, in 1952, vol. 13. Vancouver, B.C., Canada, Aug. 2004, p. 10.

[34] I. H. Mualla, “Parameters influencing the behavior of a new friction damper device,” presented at the SPIE’s 7th Annual International Symposium on Smart Structures and Materials, S.-C. Liu, Ed., Newport Beach, CA, Apr. 2000, pp. 64–74. doi: 10.1117/12.383171.

[35] H. Sutedjo, “Error Numerical Analysis,” in *Metode Numerik*, vol. 2, Bandung, pp. 1–20. Accessed: Aug. 21, 2024. [Online]. Available: https://www.scribd.com/document/328856514/BAB-II-ANgka-SIgnifikan-Dan-Galat

[36] R. Munir, “Deret Taylor dan Analisis Galat,” ITB, Bandung.

[37] T. Hidayati, W. G. Aedi, and L. F. Masitoh, *Metode Numerik*, 1st ed., vol. 1. Tangerang Selatan,Banten: UNPAM Press, 2022.

[38] H. Hoel, *Complexity and error analysis of numerical methods for wireless channels, SDE, random variables, and quantum mechanics*. Stockholm: Computer Science and Communication, Royal Institute of Technology (KTH), 2012.

[39] Y. Liu, T. Tang, G. Liu, and M. Olaimat, “Error Analysis of the Numerical Method for Correcting the Propagation of EM waves in the Troposphere,” *J. Microw. Optoelectron. Electromagn. Appl.*, vol. 19, no. 3, pp. 407–414, Sep. 2020, doi: 10.1590/2179-10742020v19i3791.

[40] L. Zoccoli, E. Bruschi, S. Cattaneo, and V. Quaglini, “Current Trends in Fluid Viscous Dampers with Semi-Active and Adaptive Behavior,” *Applied Science*, vol. 13, no. 10358, pp. 2–30, 2023, doi: 10.3390.

[41] Y. Zhao, P. Huang, G. Long, Y. Yuan, and Y. Sun, “Inuence of Fluid Viscous Damper on the Dynamic Response of Suspension Bridge under Random Trac Load,” *Advances in CivilEngineering*, no. 1–15, May 2020, doi: https://doi.org/10.1155/2020/1857378.

[42] K. V. Sharma, V. Parmar, L. Gautam, S. Choudhary, and J. Gohil, “Modelling Efficiency of Fluid Viscous Dampers Positioning for Increasing Tall Buildings’ Resilience to Earthquakes Induced Structural Vibrations,” *Soils Dynamics and Earthquke Engineering*, vol. 173, no. 108108, pp. 102–113, 2023, doi: https://doi.org/10.1016/j.soildyn.2023.108108.

[43] F. Maraqa, E. Al-Sahawneh, A. Mahamied, J. Assbeihat, and Y. Alzubi, “Parametric Study of The Efficiency of Fluid Viscous Damper in Structures with Different Heights,” *International Reviewof Civil Engineering (IRECE)*, vol. 14, no. 5, pp. 99–110, 2023, doi: https://doi.org/10.15866/irece.v14i5.22496.

[44] H. Indarto, “Perhitungan Beban Gempa pada Bangunan Gedung Berdasarkan Standar Gempa Indonesia yang Baru,” *PILAR*, vol. 14, no. 1, pp. 42–57, 2005.

[45] A. Rohman, “Studi Eksperimen Redaman Getaran Translasi dan Rotasi dengan Posisi Sumber Eksitasi DVA (Dynamic Vibration Absorber),” *J. Elem.*, vol. 4, no. 1, p. 07, 2017, doi: 10.34128/je.v4i1.2.

[46] N. L. Hajati and A. N. Hanif, “Kajian Kinerja Struktur Gedung Simetris Menggunakan Peredam Tipe Fluid Viscous Damper,” *J. Rekayasa Hijau J. Teknol. Ramah Lingkung.*, vol. 2, no. 2, pp. 123–136, 2018.

[47] A. Pribadi, E. Desmaliana, and D. T. Fadlisha, “Studi Perbandingan Respon Struktur Gedung Menggunakan Fluid Viscous Damper dengan Variasi Jumlah Lantai,” *RekaRacana J. Tek. Sipil*, vol. 6, no. 1, p. 22, Jul. 2020, doi: 10.26760/rekaracana.v6i1.22.

[48] A. Anonim, “Galat Mutlak dan Galat Relatif,” in *Analisis Galat*, p. 5.

[49] M. Sabawi, “Errors Analysis and Basic Definitions in Numerical Analysis Lecture Notes,” Department of Mathematics College of Education for Women Tikrit University, Lecture Notes.