Analysis of the Influence of Fluid Viscous Damper Placement on Building Structures with Dynamic Earthquake Load Method

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Abstract

The increase in seismic activity in Indonesia, with the potential threat of large-magnitude megathrust earthquakes, highlights the urgency of effective disaster mitigation in buildings. Although modern buildings are designed to be earthquake-resistant, strong vibrations can still cause structural damage such as cracks in beams and columns. To dampen vibrations and reduce inter-story drift and deformation, the use of earthquake dampers such as Fluid Viscous Dampers (FVD) is an innovative solution. Structural model analysis was conducted in 2 (two) stages: the first stage involved dynamic analysis using response spectrum with a high seismic risk level. The structure was modeled in 3 damper placement patterns and 1 model structure without dampers as a comparison in terms of structural performance. Based on the analysis, the seismic base shear with dampers resulted in a dynamic shear force of 9027.35 kN, which is greater than the seismic base shear without dampers, which was 7916.67 kN. In the floor displacement analysis, structures with dampers showed smaller floor displacements of 128.66 mm in the X-direction and 85.55 mm in the Y-direction at the 24th floor, compared to structures without dampers, which had displacements of 162.40 mm in the X-direction and 148.65 mm in the Y-direction. For inter-story drift analysis, structures using dampers showed 17.446 mm in the X-direction and 14.3 mm in the Y-direction, while structures without dampers showed 63.965 mm in the X-direction and 81.796 mm in the Y-direction

Keywords: *Fluid Viscous Damper,* Inter-story Drift, Kinerja Struktur.

1. PENDAHULUAN

Recently, Indonesia has been alerted by the Meteorology, Climatology, and Geophysics Agency (BMKG) regarding increased seismic activity that has the potential to trigger megathrust earthquakes. Earthquakes caused by megathrusts are predicted to occur in the near future and have the potential to produce large magnitudes. Although many buildings in Indonesia have been designed to be earthquake-resistant, the vibrations produced can still cause structural damage, both minor and severe, such as cracks in beams and columns. This highlights the importance of planning building construction in accordance with standards to withstand earthquake loads and dampen vibrations, so that the building structure does not collapse entirely.

Vibrations due to earthquakes can cause inter-story drift and deformation in building structures. These displacements and deformations can be reduced by using dampers, such as fluid viscous dampers. However, in Indonesia, the use of earthquake dampers, especially Fluid Viscous Dampers (FVD), in buildings is still limited. This is due to the lack of competent experts in the design and installation of FVDs, as well as a limited understanding of the effectiveness of this technology in earthquake mitigation.

Fluid viscous dampers work by converting earthquake kinetic energy into heat through viscous motion. This process helps reduce vibrations in building structures during an earthquake. Fluid viscous dampers can relatively significantly increase the structural damping of the critical mass from the energy generated by an earthquake, significantly improving structural damping and reducing drift and deflection in building structures (Pribadi et al., 2020). However, with the increasing complexity of modern building structures and the frequency of earthquake events, the need for more innovative earthquake mitigation systems, such as fluid viscous dampers, is becoming more urgent.

This research aims to determine the influence of Fluid Viscous Damper placement and to determine the influence of structural performance before and after using Fluid Viscous Damper based on the ATC-40 standard at the Hilton Hotel Kota Baru Parahyangan, located in the Kota Baru Parahyangan area, West Bandung Regency.

1.1. Fluid Viscous Damper

A Fluid Viscous Damper is a device used to dampen vibrations in a building caused by earthquakes through a fluid mechanism. (Abdullah N.M et al., 2022). The main function of this equipment is to absorb earthquake energy and reduce the planned earthquake forces borne by structural elements. Thus, the building structure becomes more elastic and capable of dampening earthquake shocks borne by structural elements. According to (Suhendro Sinaga et al., 2023), FVDs also function as additional dampers by simultaneously reducing stress and deflection during loading and reducing them. The working principle of a fluid viscous damper is similar to that of a spring. This damper works by providing resistance force caused by external forces in the opposite direction. This working mechanism is analogous to the suspension or shock absorber in a car..

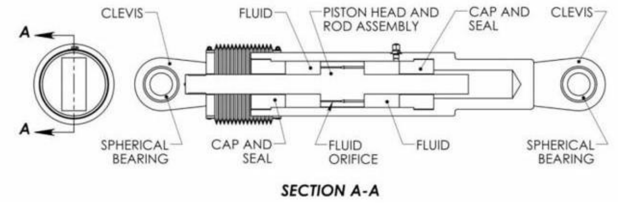


Figure 1 Section A-A Fluid Viscous Damper

According to (Taylor Devices Inc., 2024), the stiffness of a fluid viscous damper can be determined by the following equation.

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

Keterangan:
K = stiffness of the fluid viscous damper (kg/m)
A = surface area of the fluid viscous damper (m^2)
E = modulus of elasticity (kg/m^2)
L = length of the fluid viscous damper (m)

1.2. *Dynamic analysis*

Dynamic analysis is a structural analysis method that distributes earthquake shear forces by considering the dynamic effects of ground motion on the structure at all floor levels. The purpose of dynamic analysis is to design earthquake-resistant structures with more accurate evaluations and to understand the behavior of the structure under earthquake loads. Dynamic analysis can be performed in two ways: elastic and inelastic. The elastic method is divided into Time History Modal Analysis, which requires earthquake acceleration records from different locations but with similar characteristics to the planned building structure's location, and Response Spectrum Modal Analysis, where the maximum response of each vibration mode is obtained from the Design Response Spectrum. Meanwhile, inelastic dynamic analysis is used to obtain the structural response due to very large earthquake effects through the Direct Integration Method.

1.3. Level Kinerja Struktur

This method is used as a reference for structural planning or for evaluating existing structures. Building performance based on the capacity spectrum method is determined by observing deformation limits. Drift limitations for various performance level categories are presented in Table 1 .

Table 1 Structural Performance Level

Level Kinerja				
Batas Simpangan Maksimum	Immediate Occupancy	Damage Control	Life Safety	Strutural Stability
Maksimum Drift	0.1	0.01-0.02	0.02	0.33
Maksimum Inelastic Drift	0.005	0.005-0.015	No limit	No Limit

Sumber: (ATC 40, 1996)

2. METODE PENELITIAN

The structural model analysis was carried out in 2 (two) stages; the first stage involved dynamic analysis using response spectrum with a high seismic risk level. The structure was modeled in 3 damper placement patterns and 1 model structure without dampers as a comparison for structural performance aspects. Structural performance aspects include seismic base shear, fundamental period of the structure, inter-story drift, and structural performance level based on ATC-40.
Loading:
The dead load of the structure is automatically calculated by the ETABS program; therefore, only additional dead loads (SIDL) need to be input. The additional dead load values based on (SNI-1727:2020) for this building structure model are as follows:

- Sand, per cm thickness : 1600 kg/m2

- Cement mortar, per cm thickness : 21 kg/m2
- Ceramic : 24 kg/m2
- Wall : 144.29 kg/m2
- Mechanical Electrical and Ceiling : 25 kg/m2

The live load of a structure is categorized based on the function of each room in the building structure. In this final project, the live loads are as follows:

- Private rooms and corridors : 192 kg/m2
- Roof live load : 96 kg/m2

The building structure data includes the following:

1. Building Function : Hotel
2. Structural System : Dual system of special moment-resisting frames and shear walls
3. Number of Floors : 23 Floors and 1 Roof Floor
4. Building Height : 92.8 m
5. Material : Reinforced concrete with concrete strength *f'c* = 30 – 50 Mpa
6. Reinforcing Steel Yield Strength : *fy* = 650 MPa
   : *fy* = 525 Mpa

The specifications for the FVD-1000 fluid viscous damper are as follows :

1. Damping force (F_d) : 1000 kN
2. End-to-end element velocity : 1.2 m/s
3. Damping velocity coefficient (α) : 0.45
4. Modulus Young (E) : $2*10^5$ kg/m^2

Model struktur dibuat dalam 4 variasi berdasarkan peluang terjadinya deformasi lateral dalam 2 arah sumbu (sumbu X dan sumbu Y)

1. Without FVD : building structure without using FVD.
2. Pattern 1 : building structure using dampers installed parallel to the X-axis.
3. Pattern 2 : building structure using dampers installed parallel to the Y-axis.
4. Pattern 3 : building structure using dampers installed on both axes, X and Y.

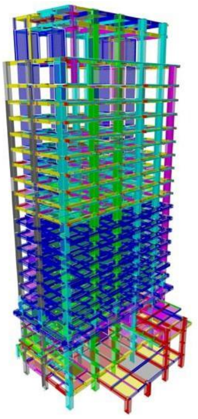


Figure 2 Configuration Structural Without FVD

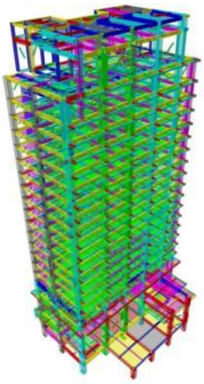


Figure 3 Configuration Structural with Damper Pattern-1

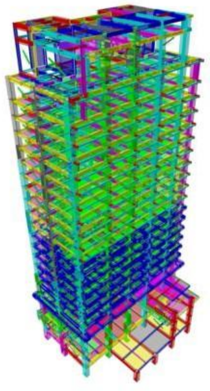


Figure 4 Configuration Structural with Damper Pattern -2

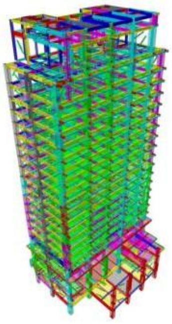


Figure 5 Configuration Structural with Damper Pattern -3

3. RESULT AND DISCUSSION

3.1 Base Shear

Base shear is the equivalent earthquake load acting at the base of the building. The calculation of seismic base shear is performed to obtain a comparison between the generated shear forces. This comparison is used as a basis for scaling dynamic earthquake forces, ensuring that the analysis results meet consistency and validation requirements against the static approach in accordance with the provisions in (SNI-1726:2019). Table 2 shows that for the FVD placement, specifically the 2-axis configuration, Pattern-3 in both X and Y directions has the smallest base shear value. This indicates that with the same load, the structural supports are more capable of resisting the load, suggesting that a centric damping force formation (centered on the building's core) is better.

Table 2 Base Shear

Basic Types of Shear Force	Base Shear (kN)			
	Without FVD	Pattern-1	Pattern -2	Pattern -3
FX	7916.67	12443.46	7698.31	9027.35
FY	8613.07	7779.55	12569.67	12226.40

3.2 Displacement

Joint displacement, or elastic displacement at the supports calculated due to design earthquake forces, is obtained from ETABS analysis for each structure, as shown in Table 5 and Table 6.

Table 3 Displacement X-axis

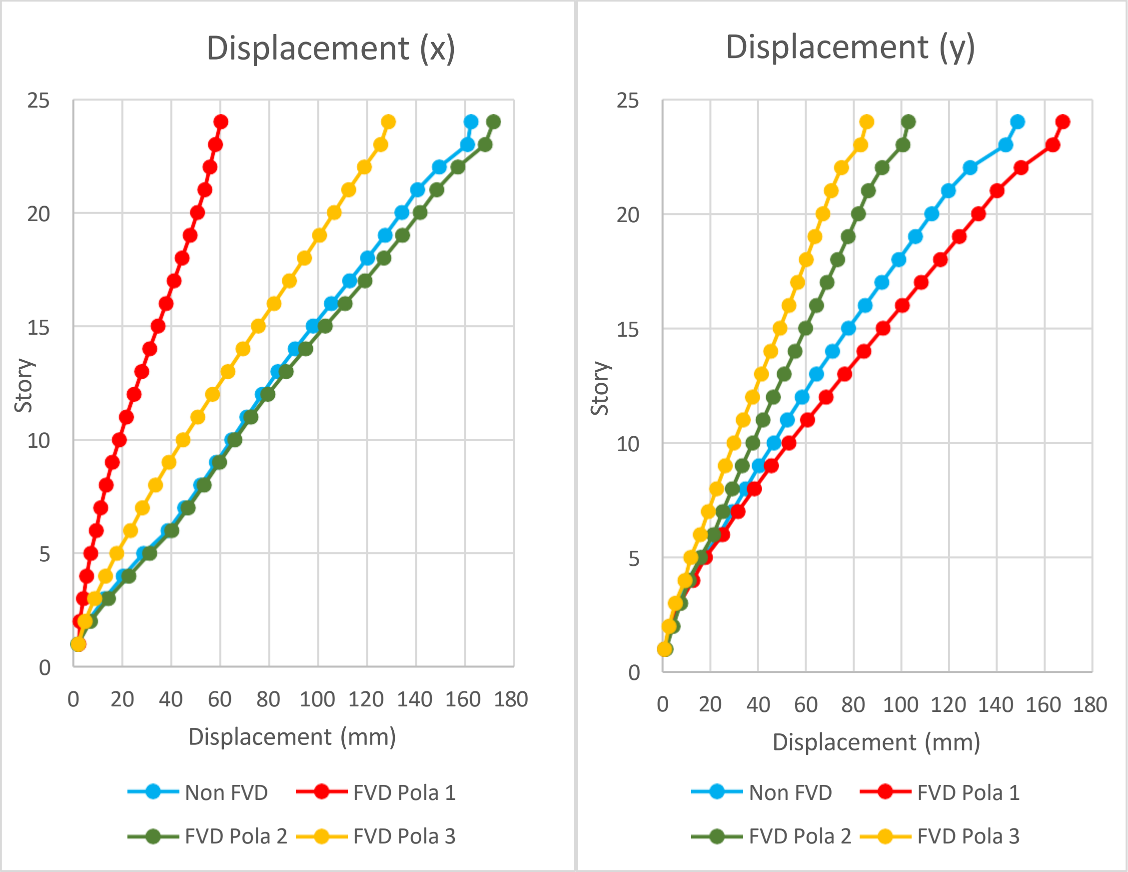
Story	Displacement X-axis (mm)			
	Without FVD	Pattern-1	Pattern -2	Pattern -3
1	162.40	60.302	171.60	128.66
2	161.02	58.114	168.20	125.49
3	149.39	55.794	156.98	118.91

4	140.61	53.754	148.36	112.47
5	134.16	50.794	141.55	106.60
6	127.33	47.701	134.38	100.59
7	120.20	44.519	126.87	94.47
8	112.90	41.248	119.06	88.23
9	105.43	37.957	111.05	81.95
10	97.98	34.639	102.96	75.64
11	90.65	31.326	94.90	69.33
12	83.56	28.049	87.02	63.11
13	77.22	24.844	79.47	56.93
14	70.88	21.750	72.53	50.85
15	64.73	18.803	66.06	44.89
16	58.40	16.046	59.75	39.15
17	52.05	13.536	53.45	33.61
18	45.51	11.310	47.01	28.32
19	38.71	9.390	40.33	23.40
20	28.78	7.159	31.25	17.85
21	20.45	5.469	22.77	13.26
22	12.82	4.158	14.41	8.86
23	6.09	2.756	7.14	4.90
24	1.90	2.411	2.01	2.12

Table 4 Displacement Y-axis

Story	*Displacement* Y-axis (mm)			
	Without FVD	Pattern-1	Pattern -2	Pattern -3
1	148.65	167.51	102.98	85.55
2	143.68	163.36	100.69	82.95
3	128.81	150.18	92.02	75.00
4	119.73	140.06	86.26	70.63
5	112.77	132.24	82.03	67.26
6	105.85	124.30	77.76	63.79
7	98.89	116.33	73.39	60.24
8	91.90	108.34	68.95	56.63
9	84.87	100.36	64.50	52.97
10	77.94	92.33	60.02	49.22
11	71.18	84.32	55.51	45.39
12	64.58	76.37	50.98	41.52
13	58.50	68.48	46.48	37.67
14	52.35	60.70	42.10	33.84
15	46.72	53.02	37.83	29.98
16	40.55	45.68	33.40	26.33
17	34.85	38.54	29.22	22.76

18	29.28	31.72	25.27	19.29
19	23.78	25.32	21.34	15.95
20	17.21	18.05	15.83	11.87
21	10.28	12.85	11.17	9.46
22	6.97	7.35	7.73	5.42
23	3.66	3.48	4.47	2.77
24	0.91	0.96	1.62	0.86



a. X-axis b. Y-axis

Figure 6 Displacement

3.3 Interstory Drift

Interstory Drift, or amplified elastic displacement obtained from ETABS analysis, will be compared with ultimate limit performance, as described below.

Table 5 Interstory Drift X-axis

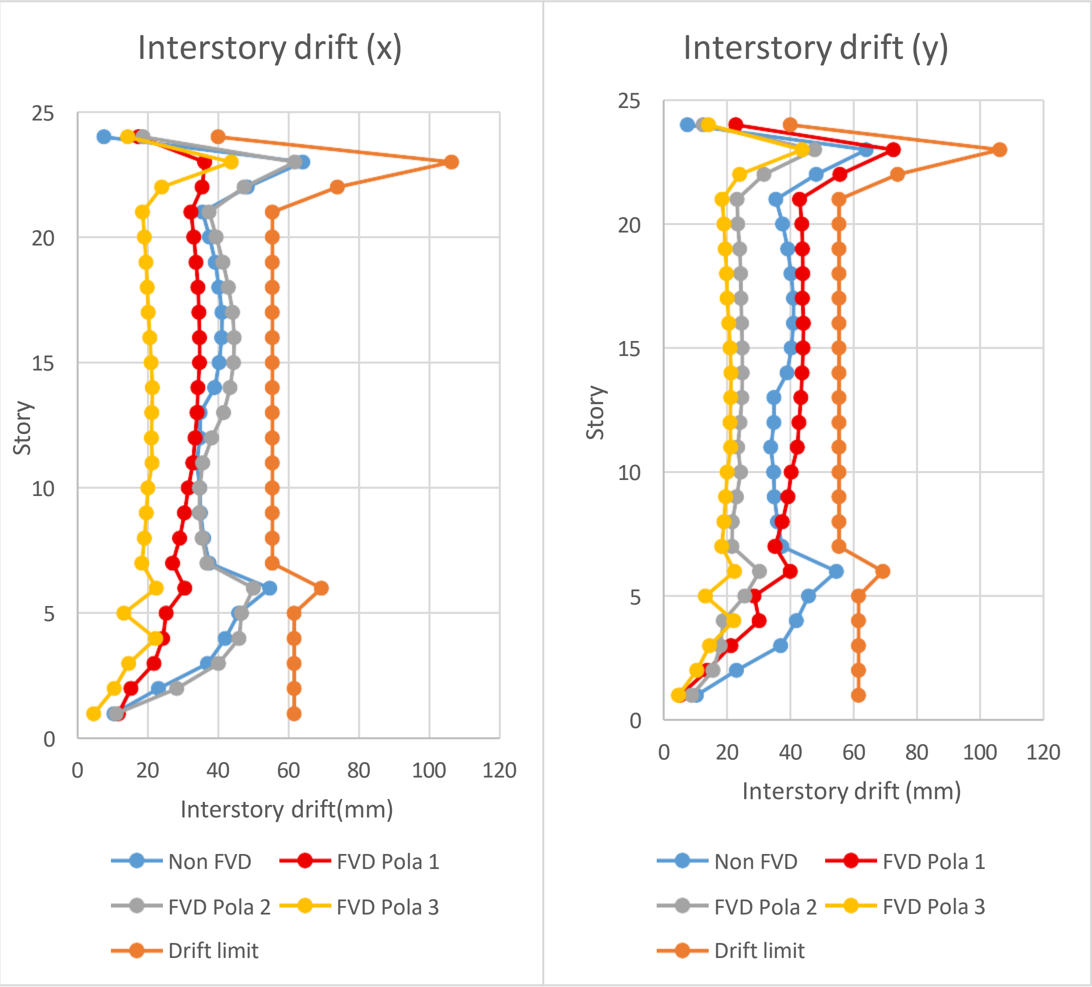
Story	Elevation (m)	Interstory Drift Without FVD (mm)	Interstory Drift Pattern-1 (mm)	Interstory Drift Pattern-2 (mm)	Interstory Drift Pattern-3 (mm)
24	92.8	7.607	12.034	18.728	17.446
23	90.2	63.965	12.760	61.721	36.185
22	83.3	48.252	11.220	47.366	35.437
21	78.5	35.508	16.280	37.466	32.263
20	74.9	37.571	17.012	39.429	33.050

19	71.3	39.177	17.501	41.349	33.677
18	67.7	40.183	17.991	42.922	34.298
17	64.1	41.063	18.101	44.039	34.557
16	60.5	40.997	18.249	44.506	34.678
15	56.9	40.277	18.222	44.336	34.705
14	53.3	38.990	18.024	43.367	34.216
13	49.7	34.903	17.628	41.514	34.023
12	46.1	34.843	17.017	38.137	33.413
11	42.5	33.858	16.209	35.613	32.780
10	38.9	34.777	15.164	34.716	31.559
9	35.3	34.958	13.805	34.645	30.476
8	31.7	35.937	12.243	35.398	29.112
7	28.1	37.422	10.560	36.768	27.066
6	24.5	54.604	12.271	49.951	30.498
5	20	45.804	9.295	46.640	25.245
4	16	41.987	7.211	45.931	24.244
3	12	37.021	7.711	40.035	21.764
2	8	23.040	1.898	28.215	15.274
1	4	10.450	13.261	11.028	11.666

Table 6 Interstory drift Y-axis

Story	Elevation (m)	Interstory Drift Without FVD (mm)	Interstory Drift Pattern-1 (mm)	Interstory Drift Pattern-2 (mm)	Interstory Drift Pattern-3 (mm)
24	92.8	27.363	22.825	12.573	14.300
23	90.2	81.796	72.540	47.702	43.720
22	83.3	49.946	55.655	31.713	24.018
21	78.5	38.274	42.977	23.260	18.519
20	74.9	38.055	43.670	23.441	19.107
19	71.3	38.253	43.874	24.079	19.503
18	67.7	38.451	43.945	24.382	19.894
17	64.1	38.693	43.852	24.486	20.130
16	60.5	38.115	44.176	24.646	20.614
15	56.9	37.169	44.039	24.822	21.027
14	53.3	36.289	43.764	24.877	21.324
13	49.7	33.424	43.379	24.761	21.186
12	46.1	33.847	42.785	24.129	21.038
11	42.5	30.949	42.268	23.485	21.230
10	38.9	33.957	40.354	24.338	20.081
9	35.3	31.361	39.270	22.996	19.624
8	31.7	30.591	37.499	21.742	19.074
7	28.1	30.267	35.178	21.588	18.370
6	24.5	36.157	39.991	30.305	22.462

Story	Elevation (m)	Interstory Drift Without FVD (mm)	Interstory Drift Pattern-1 (mm)	Interstory Drift Pattern-2 (mm)	Interstory Drift Pattern-3 (mm)
5	20	38.093	28.611	25.647	13.250
4	16	18.200	30.250	18.926	22.220
3	12	18.222	21.280	17.936	14.597
2	8	15.114	13.871	15.681	10.483
1	4	5.011	5.280	8.883	4.730



a. X-axis b. Y-axis

Figure 7 Interstory Drift

3.4 Level Kinerja Struktur

Tables 9 and 10 show that the performance level of each structural configuration, both without FVD and with FVD placement, based on ATC-40, is at the Immediate Occupancy performance level. The smallest maximum total displacement in both axial directions occurred in Pattern-3, with values of 0.00139 m in the X-direction and 0.00092 m in the Y-direction.

Table 7 Comparing Structural Performance Level X-axis

Structural Configuration	Target Displacement (m)	First Displacement (m)	Maximum Total Displacement	Structural Performance Level	Maximum Inelastic Displacement	Structural Performance Level
Without FVD	0.16240	0.0019	0.00175	IO	0.00173	IO

Structural Configuration	Target Displacement (m)	First Displacement (m)	Maximum Total Displacement	Structural Performance Level	Maximum Inelastic Displacement	Structural Performance Level
Pattern-1	0.06030	0.00241	0.00065	IO	0.00062	IO
Pattern -2	0.17160	0.00201	0.00185	IO	0.00183	IO
Pattern -3	0.12866	0.00212	0.00139	IO	0.00136	IO

Table 8 Comparing Structural Performance Level Y-axis

Structural Configuration	Target Displacement (m)	First Displacement (m)	Maximum Total Displacement	Structural Performance Level	Maximum Inelastic Displacement	Structural Performance Level
Without FVD	0.14865	0.00091	0.00160	IO	0.0016	IO
Pattern-1	0.16751	0.00241	0.00181	IO	0.0018	IO
Pattern -2	0.10298	0.00201	0.00111	IO	0.0011	IO
Pattern -3	0.08555	0.00212	0.00092	IO	0.0009	IO

7. Kesimpulan

- Overall, it can be concluded that the structural performance improved after using a passive control system, and fluid viscous dampers contributed significantly to damping force and stiffness. In this case, especially for Pattern-3, the maximum total displacement in the X-direction was 0.00139 m, and the maximum total displacement in the Y-direction was 0.00092 m, representing approximately 20% of the maximum total displacement before using FVD..
- Based on the maximum total displacement in the X-direction, the largest value was found in the Pattern-2 placement configuration, which was 0.00185 m, and the largest maximum total displacement in the Y-direction was found in the Pattern-1 placement configuration, which was 0.00181 m.
- Based on the inter-story drift in the X-direction, the largest value was found in the structure configuration without FVD, which was 1.16 cm on the 23rd floor, and the largest inter-story drift in the Y-direction was found in the structure configuration without FVD, which was 1.4872 cm.
- The performance level of the building structure both without Fluid Viscous Dampers (FVD) and with Fluid Viscous Dampers (FVD) using different placement patterns, based on ATC-40, is at the Immediate Occupancy (IO) level.

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