**Jurnal Aplikasi Teknik Sipil**
*Volume 24, Nomor 3, Agustus 2026*

Journal homepage: http://iptek.its.ac.id/index.php/jats


# Performance Evaluation of Fluid Viscous Dampers in a 13-Story Reinforced-Concrete Building in Surabaya: A Soft-Soil Site Case Study

**Ifarrel Rachmanda Hariyanto[1,*], Nur Ahmad Husin[1], Almasa Zahiro[1], Kohar Yudoprasetyo[1], Yosi Noviari W.[1], Moh. Safi'i Mansur[1], Moh. Fadhlan Rosyidi[1], S. Kamilia A.[1], Naura Firdausi[1], Khansa Fadilah A.[1]**
Department of Civil Infrastructure Engineering, Institut Teknologi Sepuluh Nopember, Surabaya[1]
*Koresponden*, Email: ifarrelrh@its.ac.id*

**Info Artikel**

| | |
|---|---|
| Diajukan | 12 Agustua 2026 |
| Diperbaiki | 18 Agustus 2026 |
| Disetujui | 25 Agustus 2026 |

*Keywords: seismic, FVD, damper, concrete, earthquake*

*Kata kunci:* seismik, FVD, peredam, beton, gempa

***Abstract***

*Buildings on soft soil may develop large lateral deformations, requiring drift control and assessment of associated design consequences. This study evaluates a 13-story reinforced-concrete building in Surabaya using three ETABS models: an existing SMRF with shear walls, an OMRF open frame, and an OMRF with fluid viscous dampers (FVDs). Response-spectrum analysis followed SNI 1726:2019. The selected 14-FVD arrangement reduced maximum deformation from 442.02 to 315.62 mm and restored interstory drift to within the adopted limit. Reinforcement demand decreased by 8.83% for slabs, 24.10% for beams, 19.30% for columns, and 42.08% for pile caps, thus the pile quantity decreased by 45.09%. Connection demand-to-capacity ratios remained below 1.0, with tensile concrete breakout governing at 0.97. Material cost for the modified items increased from IDR 8.49 billion in the existing structure to IDR 38.44 billion in the FVD alternative.*

**Abstrak**

Bangunan bertingkat pada tanah lunak dapat mengalami deformasi lateral besar sehingga pengendalian simpangan perlu dikaji bersama konsekuensi desainnya. Penelitian ini mengevaluasi gedung beton bertulang 13 lantai di Surabaya melalui tiga model ETABS: struktur eksisting SRPMK dengan dinding geser, SRPMB *open frame*, dan SRPMB dengan *fluid viscous damper* (FVD). Analisis respons spektrum mengacu pada SNI 1726:2019. Konfigurasi 14 FVD menurunkan deformasi maksimum dari 442,02 menjadi 315,62 mm dan membuat simpangan antar lantai kembali memenuhi batas yang digunakan. Kebutuhan tulangan pelat, balok, kolom, dan *pile cap* berkurang masing-masing 8,83%, 24,10%, 19,30%, dan 42,08%, sedangkan jumlah tiang pancang turun 45,09%. Seluruh rasio kebutuhan-kapasitas sambungan berada di bawah 1,0, dengan *breakout* beton tarik mengontrol pada rasio 0,97. Biaya material item yang dibandingkan meningkat dari Rp8,49 miliar pada struktur eksisting menjadi Rp38,44 miliar pada alternatif FVD.

## *1. Introduction*

Seismic evaluation of a high-rise building cannot be *limited to the capacities of its beams, columns, and shear walls. Lateral displacement must also be controlled because it is directly related to damage in both structural and nonstructural components. In reinforced-concrete buildings, shear walls are commonly used to increase lateral stiffness and limit deformation under dynamic loading [13]. This requirement becomes more critical on soft soil, where site conditions can lengthen the structural response and increase deformation demand. Accordingly, SNI 1726:2019 requires the evaluation of the fundamental period, base shear, interstory drift, second-order effects, and structural irregularities as an integrated part of seismic assessment [1].*

*Structural response may also be controlled by adding energy-dissipation devices without making the lateral system excessively stiff. One of the most widely used devices is the fluid viscous damper (FVD). Its resisting force is generated by relative motion between the two ends of the device, the piston forces the fluid through an orifice, converting part of the mechanical energy into heat. Experimental studies and field applications have reported reductions in interstory drift, floor acceleration, and story shear when the device properties and locations are properly selected [5], [6], [19].*

*The performance of an FVD system is not governed by nominal capacity alone. The distribution of damping coefficients, damper location and inclination, brace stiffness, and force-transfer details all influence the final response. Two arrangements using the same number of dampers may perform differently when they are placed according to different drift patterns. Previous studies have shown that response-based placement is generally more efficient than uniform distribution [7], [8], [11], [12], [16]-[18].*

*The case study is a 13-story reinforced-concrete academic building in Surabaya [10]. The existing structure uses a special moment-resisting frame (SMRF) with shear walls. To make the contribution of the dampers easier to identify, a comparison model was developed by removing the shear walls and representing the structure as an ordinary moment-resisting frame (OMRF) open frame. FVDs were then added in several arrangements. The open-frame model is used only for comparative purposes and does not imply that the system automatically satisfies all structural-system and height limitations prescribed by SNI. The term soft soil in the title identifies the Site Class SE condition of this case study rather than a limitation of FVD application. FVDs are supplemental damping devices that may also be designed for other site classes, provided that the seismic demand and device parameters are established for the relevant ground condition. In this study, the SE classification is retained because it governs the response spectrum applied consistently to all three models [1], [7].*

*Recent Indonesian studies on reinforced-concrete and infrastructure assessment have likewise shown the value of combining numerical analysis with field-condition evidence and service-life considerations rather than relying on a single performance indicator [21], [22]. This broader assessment perspective is relevant here because the FVD alternative changes not only seismic response but also member demand, foundation requirements, connection demand, and material cost.*

*This study aims to: (1) compare the global response of the existing structure, the open frame, and the open frame with FVDs; (2) identify the most efficient damper arrangement; (3) evaluate changes in internal forces, reinforcement demand, and foundation requirements; (4) verify the capacities of the braces and connections; and (5) review installation, inspection, and material-cost implications. The assessment therefore considers not only seismic-response reduction but also the associated design and economic consequences for a reinforced-concrete building on soft soil.*

***2. Method***

***2.1 Fluid Viscous Damper Principles and Modeling***

*A typical FVD consists of a cylinder, piston, piston rod, seal, accumulator, control valve or orifice, and viscous fluid. When the two ends of the damper move relative to each other, the piston forces the fluid through the orifice. The resulting flow resistance produces a force opposite to the direction of motion and dissipates vibration energy. The main components of the device are shown in **Figure 1**.*

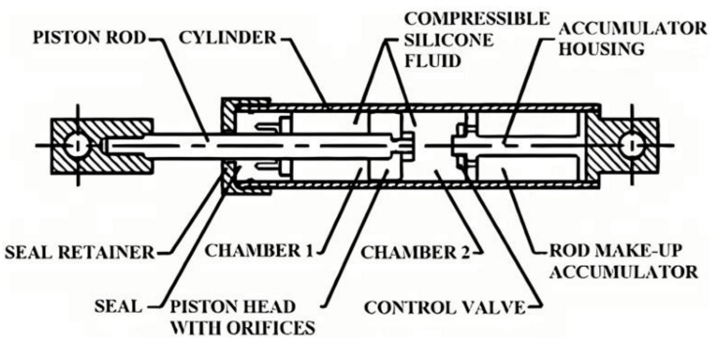



***Figure 1.** Main components of an FVD [Lee et al., 2001].*

*The relationship between the damping force and the relative velocity of the device is expressed in Equation (1).*

$$F_d = C\,|v|^\alpha\, sgn(v) \qquad (1)$$

*In Equation (1), Fd is the damping force, C is the damping coefficient, v is the relative axial velocity, and α is the velocity exponent. For α = 1, the force varies linearly with velocity, whereas α < 1 represents nonlinear behavior. A value of α = 1 was adopted so that the effects of the different arrangements could be compared using the same modeling basis. In detailed design, variations in α should still be examined because the parameter affects peak force, deformation, and dissipated energy [19], [20].*

*The initial damping coefficients were distributed by considering story stiffness, structural period, number of dampers, and installation angle. The adopted expression is given in Equation (2).*

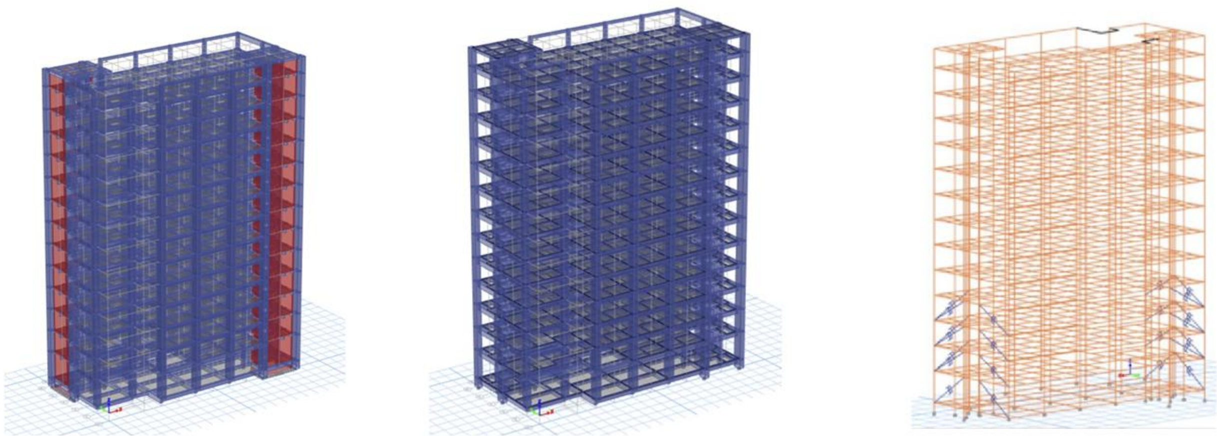
$$C_j = \xi \left(\frac{k_i}{n_i}\right)\left(\frac{T}{\pi}\right)\left[\frac{1}{cos^2\theta_j}\right] \qquad (2)$$

*In Equation (2), Cj is the damping coefficient of the j-th damper, ξ is the target damping ratio, ki is the story stiffness, ni is the number of dampers at that story, T is the structural period, and θj is the installation angle. The equation was used for preliminary sizing. Final device selection must still be checked against the design force, piston velocity, required* *stroke, operating temperature, and manufacturer test data [9], [15].*

### *2.2 Building and Structural Models*

*The case-study building has 13 stories and one roof level and is located in Surabaya on a site classified as Site Class SE (soft soil). The site classification is a property of the investigated building and is not a prerequisite for using FVDs. The primary structure is reinforced concrete, while the FVD braces and connection components are steel. Gravity loading, load combinations, concrete design, and steel-component design follow SNI 1727:2020, SNI 2847:2019, and SNI 1729:2020, respectively [2]-[4].*

*All three models use the same geometry, mass, and diaphragm assumptions. They differ only in their lateral-force-resisting systems: (a) the existing SMRF with shear walls; (b) an OMRF open frame without shear walls; and (c) the OMRF open frame equipped with FVDs. The ETABS models are shown in **Figure 2**.*



*(a) (b) (c)*

***Figure 2.** Models compared: (a) existing SMRF with shear walls, (b) OMRF open frame, and (c) OMRF with FVDs.*

### *2.3 Seismic Analysis and Evaluation Criteria*

*Global analysis was conducted using the response-spectrum method in accordance with SNI 1726:2019. The evaluated parameters included modal mass participation, fundamental period, base-shear scaling, lateral deformation, interstory drift, P-Delta stability coefficient, and horizontal and vertical irregularities. To maintain a consistent basis of comparison, the models used identical geometry, mass, load combinations, and evaluation procedures. The seismic design coefficients, however, follow the lateral-force-resisting system assigned to each model, as summarized in **Table 1** [1].*

***Table 1**. Seismic design coefficients used for the three structural models.*

| Structural model | R | Ω0 | Cd |
|---|---|---|---|
| Existing SMRF + shear walls | 7.0 | 2.5 | 5.5 |
| OMRF open frame | 3.0 | 3.0 | 2.5 |
| OMRF + FVD | 3.0 | 3.0 | 2.5 |

*The lower scaled base shear of the existing wall-frame model should be interpreted together with the coefficients in **Table 1**. The existing dual system uses R = 7.0, whereas both OMRF models use R = 3.0. Because the response modification coefficient reduces the elastic seismic demand used for design, the larger R contributes to a smaller design base shear for the existing model despite its greater lateral stiffness. The final scaled values also depend on modal period and the response-spectrum scaling required by SNI 1726:2019. Thus, the smaller base shear of the existing model does not mean that the shear-wall system experiences less ground motion, it reflects the combined effects of structural-system ductility, period, and code-based scaling [1].*

*In ETABS, each FVD was represented by an axial link with velocity-dependent damping and a series stiffness accounting for the damper and brace. The three investigated arrangements used 22, 14, and 20 devices. The assessment was not limited to response reduction, it also included internal forces, reinforcement weight, pile demand, connection demand-to-capacity ratios, installation sequence, inspection needs, and material cost. This approach is consistent with optimization methods that treat damper placement as an integral part of the design [16]-[18].*

### *2.4 Device Parameters*

***Table 2*** *summarizes the main properties of the FVD adopted in the numerical model. The selected candidate was device model 20880, with a nominal damping-force capacity of 4,337 kN, a mid-stroke length of 1,930.4 mm, and a nominal stroke of 127 mm. The device has a cylinder diameter of 431.8 mm. These dimensions and capacity were used to represent the physical characteristics of the damper and to ensure that the numerical model reflected a commercially feasible device rather than an idealized damping element.*

***Table 2****. Candidate FVD parameters used in the numerical model.*

| *Parameter* | *Value* |
|---|---|
| *Device model* | *20880* |
| *Nominal damping-force capacity* | *4,337 kN* |
| *Mid-stroke length* | *1,930.4 mm* |
| *Nominal stroke* | *127 mm* |
| *Cylinder diameter* | *431.8 mm* |
| *Combined stiffness, Ktotal* | *1,039,530 kN/m* |
| *Damping coefficient, C* | *144,646 kN·s/m* |
| *Velocity exponent, α* | *1.0 (linear)* |
| *Number in selected arrangement* | *14 units* |

*In the ETABS model, the combined stiffness of the damper–brace system was taken as 1,039,530 kN/m, while the damping coefficient was specified as 144,646 kN·s/m. A velocity exponent of α=1.0 was adopted, corresponding to linear viscous behavior in which the damping force varies proportionally with the relative velocity. The selected arrangement consisted of 14 FVD units distributed at the designated structural bays. These parameters were used for the comparative response analysis.*

## *3. Result and Discussion*

### *3.1 Global Response and Modal-Analysis Adequacy*

*Removing the shear walls made the structure substantially more flexible. The maximum deformation of the open frame was 442.02 mm, compared with 112.05 mm for the existing model. Installing 14 FVDs reduced the deformation to 315.62 mm, a reduction of 28.60%. Although this improvement is significant, the deformation of the FVD model remained about 2.82 times that of the existing structure as shown in* ***Fig. 3****. The dampers therefore improved the open-frame response but did not fully replace the stiffness originally provided by the shear walls.*

*The cumulative modal mass participation of all models exceeded 90% in both the X and Y directions, as shown in* ***Fig. 4****. The existing model reached this threshold at Mode 10, whereas the open-frame and FVD models required 11 modes. The identical mode count for the latter two models indicates that installing FVDs at Stories 1-4 and in selected bays did not substantially alter the global modal characteristics. This check confirms the adequacy of the modal analysis rather than the superiority of a particular system.*

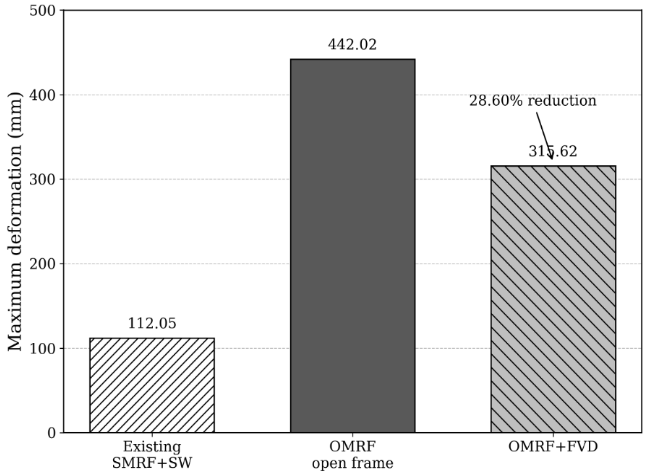



***Figure 3.*** *Comparison of maximum global deformation.*

*The X-direction fundamental period increased from 1.818 s for the existing structure to 3.063 s after the shear walls were removed. After FVD installation, it decreased to 3.011 s. In the Y direction, the period decreased from 2.771 s to 2.733 s. These changes, 1.70% and 1.37%, are relatively small as shown in* ***Fig. 5****. The response reduction was therefore governed mainly by added damping, while the contribution of brace and link stiffness to the global period remained limited.*

*Before scaling, the X-direction base shear was approximately 4,280 kN for the existing model, 7,951.75 kN for the open frame, and 5,101.41 kN for the FVD model. After scaling to the minimum response-spectrum requirement, the corresponding values became 8,517.22 kN, 11,326.60 kN, and 11,438.20 kN, respectively, as shown in* ***Fig. 6****. The existing wall-frame system has the lowest scaled base shear primarily because it is assigned R = 7.0, compared with R = 3.0 for the OMRF models, while period and scaling requirements provide additional influence. For the two OMRF models, the 0.99% difference after scaling results from the scaling procedure and the difference in approximate periods. The scaled base shear should therefore be interpreted together with the design coefficients in* ***Table 1*** *rather than used alone to judge FVD energy-dissipation effectiveness.*

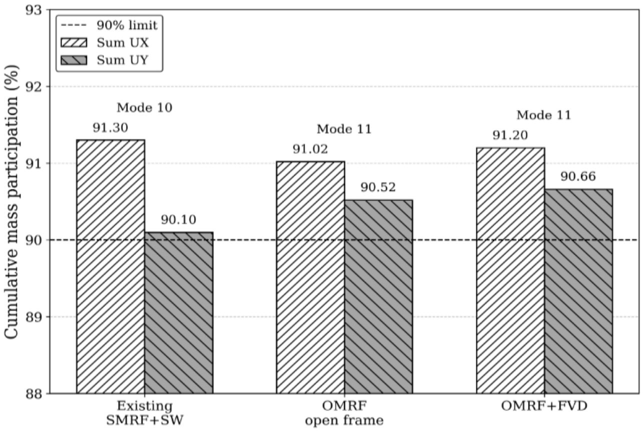



***Figure 4.*** *Cumulative modal mass participation and required number of modes.*

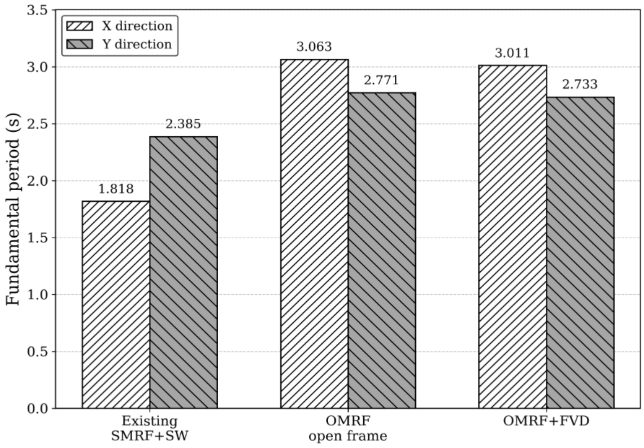



***Figure 5.*** *Comparison of fundamental periods in the X and Y directions.*

***3.2 Interstory Drift and P-Delta Stability***

*In the open-frame model, the typical drift limit of 30.769 mm was exceeded at Stories 2-9. The maximum values reached 50.923 mm in the X direction and 44.015 mm in the Y direction. After the FVDs were installed, the peak drifts fell to 26.412 mm and 23.087 mm, respectively, placing all stories below the adopted limit. Aggregating the results over all stories gave reductions of 54.97% in the X direction and 51.94% in the Y direction, while comparison of the peak values gave reductions of 48.13% and 47.55% as shown in **Fig.** 7.*

*The maximum stability coefficients of the open frame were 0.0560 in the X direction and 0.0466 in the Y direction as shown in **Fig. 8**. With FVDs, the corresponding values decreased to 0.0294 and 0.0247, representing a reduction of approximately 47% based on the peak values. All values remained below the P-Delta limit of 0.10. The reduction is consistent with the lower lateral displacement, which decreases the secondary moments generated by axial forces acting on the deformed configuration.*

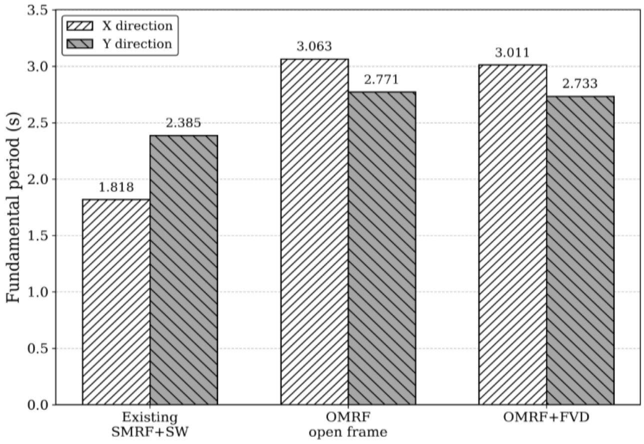



***Figure 6.*** *X-direction base shear before and after scaling*

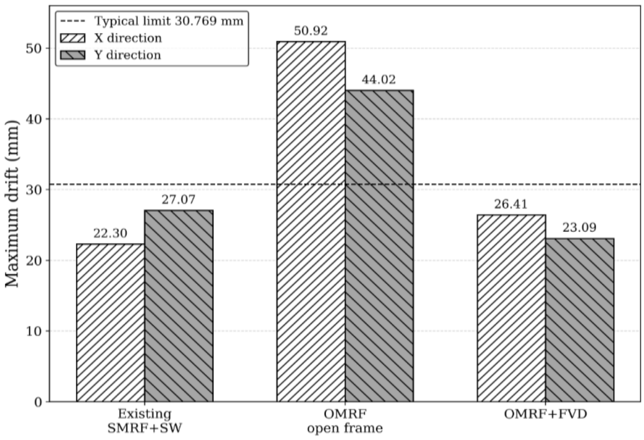



***Figure 7.*** *Comparison of maximum interstory drift and the typical allowable limit.*

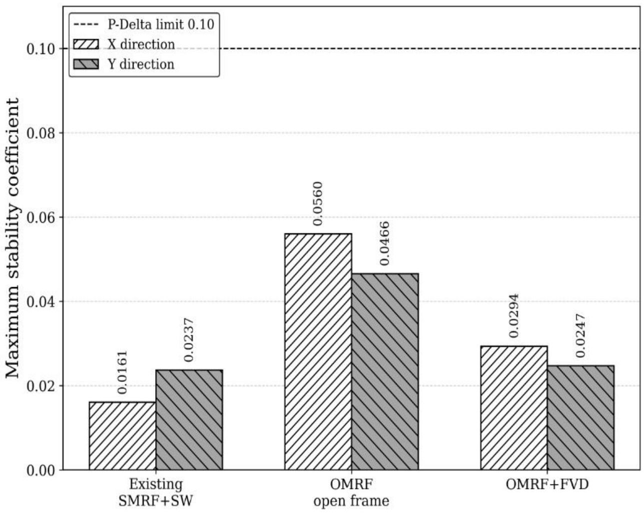



***Figure 8.*** *Maximum stability coefficient for the three models.*

***3.3 Efficiency of FVD Placement Arrangements***

*The differences in drift reduction among the three arrangements were relatively small. Arrangement 3 provided* *the greatest X-direction reduction, 56.89%, whereas Arrangement 1 produced the highest Y-direction reduction, 54.03%. These results show that the number of dampers alone is not sufficient to identify the best arrangement. As shown in **Fig. 9**, device locations should follow the drift distribution and the structural force path [16]-[18].*

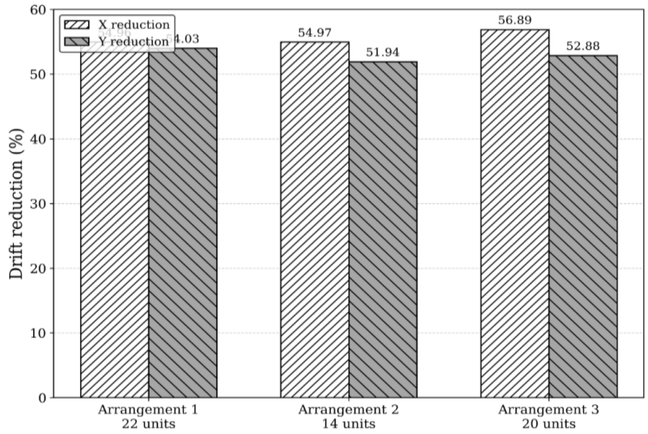



***Figure 9.*** *Drift reduction for the three FVD arrangements.*

*Arrangement 2 used only 14 devices but still achieved an average drift reduction of 53.45%. Its reduction index per device was 3.82, higher than 2.48 for Arrangement 1 and 2.74 for Arrangement 3 as shown in **Fig. 10**.*

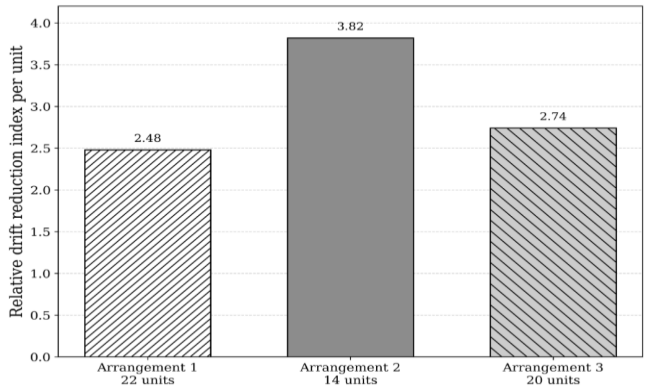



***Figure 10.*** *Relative efficiency index based on the number of devices.*

### *3.4 Effects on Internal Forces in Sample Members*

*For Beam B2, the bending moment decreased by 58.34%-59.26%, while the shear force decreased by 53.93%-54.88%. The largest reduction in column tensile axial force occurred in Arrangement 2, reaching 92.04%. In contrast, the compressive axial force changed by only about 1.46%. This difference is expected because the FVDs primarily affect force components associated with lateral response rather than compression dominated by gravity loading. The comparison is summarized in **Fig. 11**.*

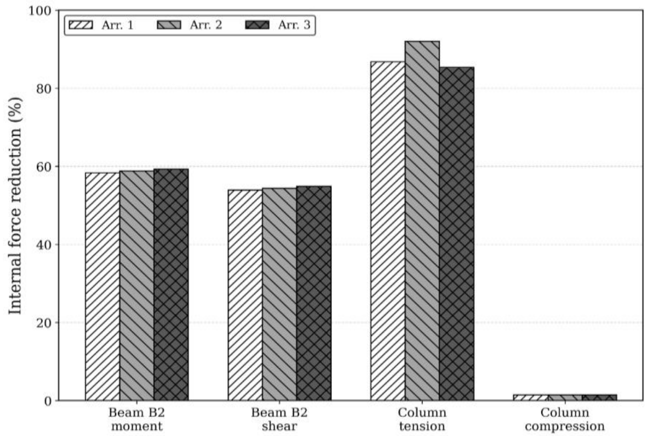



***Figure 11.*** *Percentage reduction in internal forces of the sample members.*

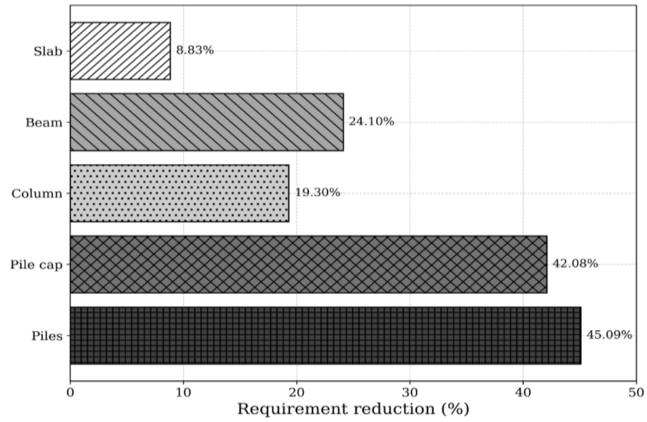



***Figure 12.*** *Reduction in reinforcement and pile requirements.*

### *3.5 Reinforcement and Foundation Requirements*

*The quantity take-off showed lower reinforcement demand in all compared groups. Based on the total calculated quantities, slab reinforcement decreased by 8.83%, beam reinforcement by 24.10%, column reinforcement by 19.30%, and pile-cap reinforcement by 42.08%. The number of piles decreased from 550 to 302, equivalent to 45.09%. The slab reduction occurred mainly at the first story and roof, whereas the changes in beams and columns varied by member type. All percentages were recalculated from the total quantities to maintain consistency with the detailed project data as shown in **Fig. 12** [10].*

### *3.6 FVD Brace and Connection Capacity*

*Damper forces are transferred through a continuous load path comprising the clevis or pin, tang plate, HSS brace, gusset plate, base plate, anchors, and the receiving concrete member. Each component was checked for cyclic tension and compression, shear, bearing, block shear, buckling, weld capacity, and concrete failure. For connections with high stress concentrations, the global checks may be supplemented by sub-assembly modeling to examine stress* *distribution and local failure mechanisms in greater detail [14]. The maximum demand-to-capacity ratio of each connection group is summarized in* ***Fig. 13*** *to identify the governing component.*

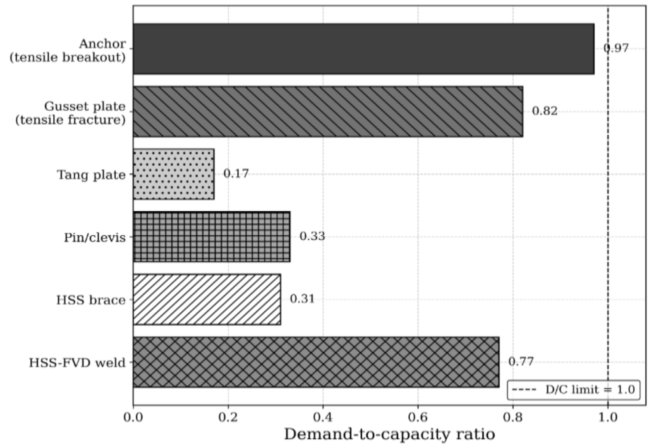



***Figure 13.*** *Critical demand-to-capacity ratios of the brace and connection system.*

*The highest ratio was 0.97 for tensile concrete breakout at the anchors, followed by 0.82 for tensile fracture of the gusset plate and 0.77 for the HSS-FVD weld. The tang plate, pin or clevis, and HSS brace had maximum ratios between 0.17 and 0.33.*

***3.7 Material-Cost Comparison***

*For the material items included in this comparison, IDR 8.49 billion represents the baseline cost of the existing structure, whereas IDR 38.44 billion represents the corresponding cost of the FVD alternative. Reduced reinforcement, smaller pile caps, fewer piles, and removal of the shear walls lowered the structural-material component by approximately IDR 2.96 billion. The FVD procurement and installation allowance was IDR 32.91 billion, representing about 85.6% of the alternative cost. Overall, the compared material cost increased by IDR 29.95 billion, or 352.7%. These values are not the total construction cost, they include only the modified structural and foundation materials together with the FVD system.*

*The present cost comparison does not constitute a full sustainability assessment. A broader evaluation would also consider operational energy and material-resource efficiency, which have been treated as distinct performance dimensions in recent built-environment studies in Indonesia [23], [24].*

***4. Conclusion***

*Removing the shear walls substantially increased the flexibility of the structure. The maximum deformation rose from 112.05 mm in the existing system to 442.02 mm in the open-frame model, while the interstory drift exceeded the allowable limit between Stories 2 and 9. After 14 FVD units were installed, the maximum deformation decreased to 315.62 mm, and the peak drift was reduced to 26.412 mm in the X direction and 23.087 mm in the Y direction. The fundamental periods changed by only 1.70% and 1.37%, confirming that the response improvement was governed mainly by the added damping rather than a major increase in structural stiffness. Among the three layouts, Arrangement 2 provided the best balance between performance and device quantity, with a relative efficiency index of 3.82. In the reviewed member samples, beam moment and shear demands decreased by approximately 54%–59%, while the tensile axial force in the column was reduced by up to 92.04%.*

*The FVD system also reduced the required reinforcement for slabs, beams, columns, and pile caps by 8.83%, 24.10%, 19.30%, and 42.08%, respectively, while the number of piles decreased from 550 to 302 units, equivalent to a 45.09% reduction. All brace and connection components had demand-to-capacity ratios below 1.0, although tensile concrete breakout at the anchors governed with a ratio of 0.97 and therefore requires further verification. For the material items compared in this study, the existing-structure baseline was IDR 8.49 billion and the FVD alternative was IDR 38.44 billion, mainly because the FVD system accounted for approximately IDR 32.91 billion. Overall, the proposed system proved technically effective in reducing deformation, drift, and selected member forces, while future applications could benefit from further optimization of device capacity, damper quantity and placement, connection detailing, supplier selection, and procurement strategy.*

***Appendix***


[1] Badan Standardisasi Nasional, SNI 1726:2019 Tata Cara Perencanaan Ketahanan Gempa untuk Struktur Bangunan Gedung dan Nongedung. Jakarta: BSN, 2019.

[2] Badan Standardisasi Nasional, SNI 1727:2020 Beban Desain Minimum dan Kriteria Terkait untuk Bangunan Gedung dan Struktur Lain. Jakarta: BSN, 2020.

[3] Badan Standardisasi Nasional, SNI 2847:2019 Persyaratan Beton Struktural untuk Bangunan Gedung dan Penjelasan. Jakarta: BSN, 2019.

[4] Badan Standardisasi Nasional, SNI 1729:2020 Spesifikasi untuk Bangunan Gedung Baja Struktural. Jakarta: BSN, 2020.

[5] M. C. Constantinou and M. D. Symans, "*Experimental study of seismic response of buildings with supplemental fluid dampers,*" Structural Design of Tall Buildings, vol. 2, no. 2, pp. 93–132, 1993, doi:

10.1002/tal.4320020203.

[6] M. D. Symans et al., "*Energy dissipation systems for seismic applications: Current practice and recent developments," Journal of Structural Engineering*, vol. 134, no. 1, pp. 3–21, 2008, doi: 10.1061/(ASCE)0733-9445(2008)134:1(3).

[7] D. De Domenico, G. Ricciardi, and I. Takewaki, "*Design strategies of viscous dampers for seismic protection of building structures: A review," Soil Dynamics and Earthquake Engineering*, vol. 118, pp. 144–165, 2019, doi: 10.1016/j.soildyn.2018.12.024.

[8] 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," Soil Dynamics and Earthquake Engineering*, vol. 173, Art. no. 108108, 2023, doi: 10.1016/j.soildyn.2023.108108.

[9] Taylor Devices Inc., Damper Design Manual: *General Guidelines for Engineers*. North Tonawanda, NY, 2020.

[10] A. Zahiro, "Alternatif desain penggunaan perangkat fluid viscous damper (FVD) pada struktur gedung perkuliahan 13 lantai di Surabaya," Proyek Akhir, Institut Teknologi Sepuluh Nopember, Surabaya, 2025.

[11] P. Tiwari, P. Badal, and R. Suwal, "*Effectiveness of fluid viscous dampers in the seismic performance enhancement of RC buildings*," Asian Journal of Civil Engineering, vol. 24, pp. 309–318, 2023, doi: 10.1007/s42107-022-00504-1.

[12] R. A. Patil and P. B. Salgar, "An investigation for enhancing seismic performance of high-rise buildings using fluid viscous damper (FVD)," Asian Journal of Civil Engineering, vol. 25, pp. 4803–4817, 2024, doi: 10.1007/s42107-024-01081-1.

[13] I. R. Hariyanto, B. Suswanto, A. B. Habieb, and I. G. P. Raka, "Studi Analisis Perkuatan Struktur Gedung 5 Lantai di Surabaya Akibat Beban Dinamis Menggunakan Shearwall," Bangunan: Teori, Praktik, Penelitian, dan Pengajaran Teknik Bangunan, vol. 30, no. 2, pp. 153–168, Oct. 2025, doi: 10.17977/um071v30i22025p153-168.

[14] I. R. Hariyanto, B. Suswanto, and A. B. Habieb, "Analisis Numerik Vertical Shear Link (VSL) secara Sub-Assemblage menggunakan Program Bantu ABAQUS," Jurnal Aplikasi Teknik Sipil, vol. 20, no. 3, pp. 333–342, Aug. 2022.

[15] S. Silvestri, G. Gasparini, and T. Trombetti, "*A Five-Step Procedure for the Dimensioning of Viscous Dampers to Be Inserted in Building Structures,*" Journal of Earthquake Engineering, vol. 14, no. 3, pp. 417–447, 2010, doi: 10.1080/13632460903093891.

[16] J.-S. Hwang, W.-C. Lin, and N.-J. Wu, "*Comparison of Distribution Methods for Viscous Damping Coefficients to Buildings*," Structure and Infrastructure Engineering, vol. 9, no. 1, pp. 28–41, 2013, doi: 10.1080/15732479.2010.513713.

[17] L. Landi, F. Conti, and P. P. Diotallevi, "*Effectiveness of Different Distributions of Viscous Damping Coefficients for the Seismic Retrofit of Regular and Irregular RC Frames," Engineering Structures,* vol. 100, pp. 79–93, 2015, doi: 10.1016/j.engstruct.2015.05.031.

[18] C. A. Martínez, O. Curadelli, and M. E. Compagnoni, "Optimal Design of Passive Viscous Damping Systems for Buildings under Seismic Excitation," Journal of Constructional Steel Research, vol. 90, pp. 253–264, 2013, doi: 10.1016/j.jcsr.2013.08.005.

[19] R. D. Riaz, U. J. Malik, M. U. Shah, M. Usman, and F. A. Najam, "Enhancing Seismic Resilience of Existing Reinforced Concrete Building Using Non-Linear Viscous Dampers: A Comparative Study," Actuators, vol. 12, no. 4, Art. no. 175, 2023, doi: 10.3390/act12040175.

[20] X. Lan, G. Wei, and X. Zhang, "*Study on the Influence and Optimization Design of Viscous Damper Parameters on the Damping Efficiency of Frame Shear Wall Structure*," Buildings, vol. 14, no. 2, Art. no. 497, 2024, doi: 10.3390/buildings14020497.

[21] K. Yudoprasetyo, A. D. Prasetya, M. F. Rosyidi, I. R. Hariyanto, Y. N. Wibowo, R. B. A. Affandhie, M. S. Mansur, K. F. Ashara, M. S. Darmawan, M. A. Alrasyidi, and H. Wahyudi, "Upaya Penguatan Keselamatan Prasarana Sekolah melalui Evaluasi Teknis Struktur Kolom pada Bangunan Pendidikan di Bojonegoro," Inovasi Jurnal Pengabdian Masyarakat, vol. 3, no. 3, pp. 255–266, Dec. 2025, doi: 10.54082/ijpm.1063.

[22] K. Yudoprasetyo, M. F. Rosyidi, I. R. Hariyanto, Y. N. Wibowo, M. S. Mansur, H. Wahyudi, and A. D. Prasetya, "Integrasi Bridge Management System (BMS) dan Non-Destructive Testing (NDT) untuk Prediksi Umur Jembatan pada Ruas Jalan Jawa Timur," Jurnal Sainstek STT Pekanbaru, vol. 14, no. 1, pp. 50–60, 2026, doi: 10.35583/js.v14i1.432.

[23] A. Y. Zuhdy, N. Firdausi, I. R. Hariyanto, and M. A. Alrasyidi, "*Identification of factors influencing indoor electricity consumption in Surabaya and energy saving*

*strategies in tropical climate*," Smart Cities and Regional Development Journal, vol. 9, no. 4, pp. 93–104, 2025.

[24] Y. Tajunnisa, A. A. Cahyani, H. Masrafat, I. R. Hariyanto, Y. N. Wibowo, M. R. Alfayet, and V. N. Halisah, "FABAKO: Program Pemanfaatan Limbah Fly Ash dan Bottom Ash (FABA) sebagai Paving Jalan untuk Meningkatkan UMKM Masyarakat Paiton," Sewagati, vol. 8, no. 5, pp. 2205–2217, 2024, doi: 10.12962/j26139960.v8i5.2186.

**Halaman ini sengaja dikosongkan**