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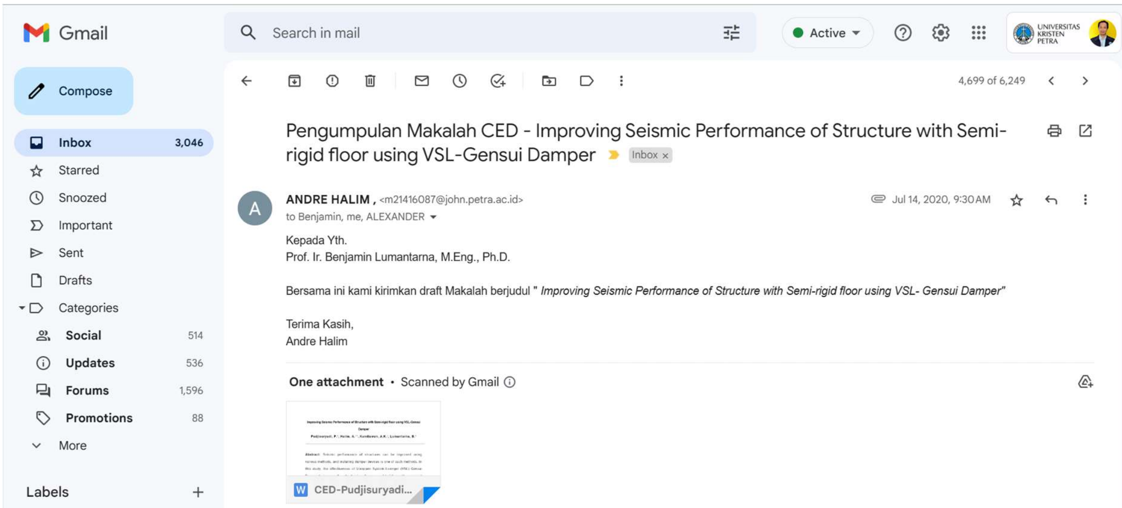

Improving Seismic Performance of Structure with Semi-rigid floor using VSL-Gensui Damper

Pudjisuryadi, P.[1], Halim, A.[1]*.,Kandiawan, A.K.[1], Lumantarna, B.[1]

Abstract: Seismic performance of structures can be improved using various methods, and installing damper devices is one of such methods. In this study, the effectiveness of Vorspann System Losinger (VSL) Gensui Damper to improve the structural performance of building with semi-rigid floors is investigated. The considered building is subjected to spectrum consistent ground accelerations generated from El Centro 18 May 1940 earthquake N-S and E-W components per Indonesian Seismic Code (SNI 1726:2012) for Mataram City. Modified Simplified Sequential Search Algorithm (MSSSA) and Optimum Damper Allocation Method (ODAM) methods are used to efficiently place the dampers on the building until certain criteria are met. Results show that installation of VSL Gensui Dampers can effectively reduce structural drifts. Furthermore, it should be noted that the placement of dampers must be well distributed among frames in the same story, since their drifts may differ significantly in building with semi-rigid floors.

Keywords: Drift; damper placement method; Non-Linear Time History Analysis; semi-rigid floors; strengthening; VSL Gensui damper.

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Introduction

In seismically active countries such as Indonesia, consideration of earthquake load in building design is imperative. Indonesia has SNI 1726:2012 [1], as its guidelines for designing building structures to withstand earthquake load. In conjunction with structural codes such as concrete design code (SNI 2847:2013) [2] and steel design code (SNI 1729:2015), the Indonesian Seismic Code (SNI 1726:2012) should be used to ensure buildings capability to withstand earthquakes.

One of the most common criteria that are not accurately assumed is floor rigidity. In SNI 1726:2012, there is a clause which states, "Diaphragms of concrete slabs or concrete filled metal deck with span-to-depth ratios of 3 or less in structures that have no horizontal irregularities are permitted to be idealized as rigid" [1,3]. However, in buildings with concrete slabs, rigid floor diaphragm is usually assumed regardless of the large diaphragm span-to-depth ratio. This may cause inaccurate story drifts in the building model [4].

In the effort of improving the seismic performance of existing structures, many techniques can be used, and one of them is by installing dampers. A damper is an energy dissipation system that can be installed in a structure. The use of energy dissipation systems for an earthquake-resistant structure is useful for improving the seismic performance of a structure [5,6]. In this study, a type damper produced by VSL, namely VSL Gensui Damper, is used to improve the seismic performance of a structure. VSL Gensui Damper is a wall type viscoelastic damper that consists of multilayer of rubber and steel that has 400x400x15mm in dimension (Figure 1). To maximize the benefit of using dampers while still paying good attention to the cost induced, strategic placement of dampers is a must.

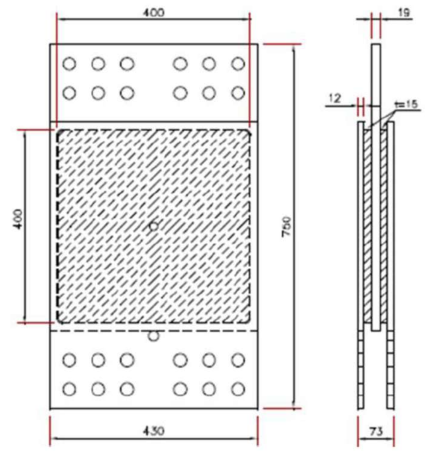

Figure 1. VSL-Gensui Damper

Strategic Placement of the dampers

Two damper placement strategies are used in this study. As the first strategy, Simplified Sequential Search Algorithm (SSSA) [7] is adopted. In this study, the original damper placement indicator of SSSA is modified by only using story drift and neglecting story velocity, and hereafter is called as MSSSA. Optimum Damper Allocation Method (ODAM) [8] is used for the second strategy. Uniform placement of damper in all stories of selected frames is also conducted for comparison against the previous two methods. This uniform placement method is identical to the initial step of the ODAM method. Andini and Goenawan have researched three methods mentioned above, on a simple structure [9].

In the ODAM, the total number of dampers used is decided at the beginning, and typically the dampers are placed at every story of selected frames. Then the dampers in the story with minimum drift will be moved to the floor with maximum drift. This process is repeated until certain acceptance criteria are met, or the last two damper relocations indicate swaps between the same two stories. In the MSSSA method, each damper addition is placed at the story with the largest drift in the selected frames. The damper addition is stopped when certain acceptance criteria are met. In this study, the maximum story drift ratio of the structure is targeted to be less than 0.4%. Meanwhile, the average damage index of the structure is targeted to be reduced as much as 25% and 35% for earthquakes with scheme Y and scheme X, respectively. Y and X represent the dominant earthquake direction corresponding to the building. For a comparable comparison between the methods, the number of the dampers on all method is determined. Dampers installed on all method will be 44 dampers.

Considered Structure

In this study, an existing hotel located in Mataram is chosen. This 14 meters high five-story building has 62.3 meters by 15.5 meters floor plan dimension resulting to span-to-depth ratio larger than 3.0. The floor plan can be seen in Figures 2 to 4. When analyzing earthquake which direction perpendicular to larger building horizontal dimension, according to SNI 1726:2012, semi-rigid floor assumption should be used to obtain accurate building deformation. Performance of the structure will be improved to a certain condition.

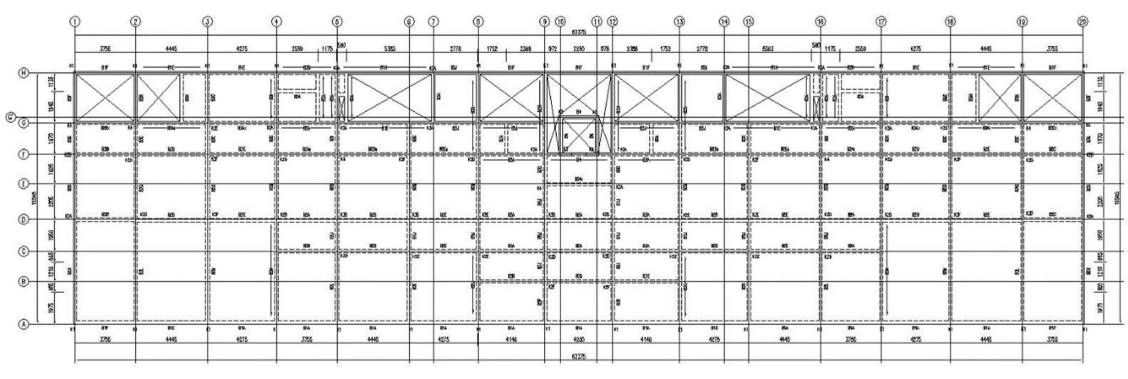

Figure 2. Typical Floor Plan (1st floor – 3rd floor)

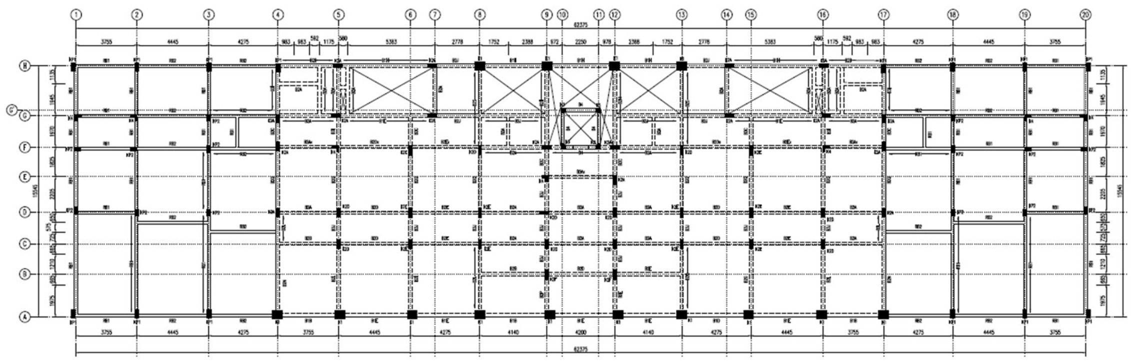

Figure 3. Floor Plan of the 4th floor

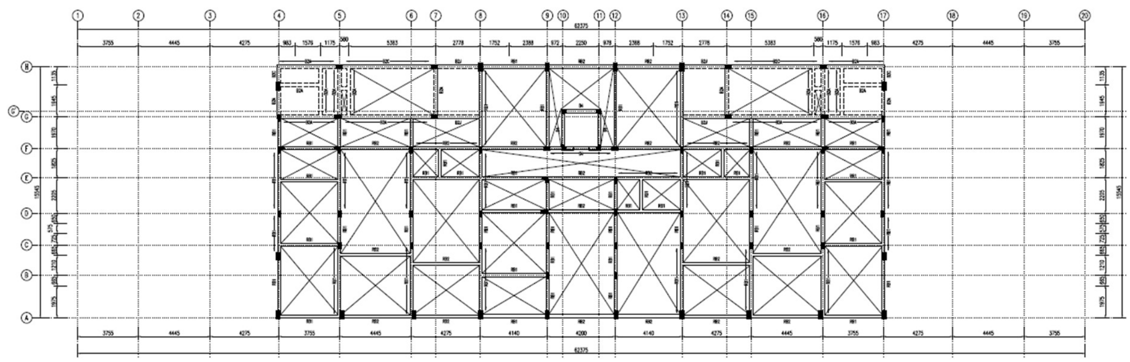

Figure 4 Floor Plan of the roof floor

Modelling of the Structure and Analysis

In this study, computer software SAP2000 is used to remodel the existing structure, as shown in Figure 5. The auto-hinge feature of SAP2000 is used to determine the non-linear hinges properties of all beams and columns.

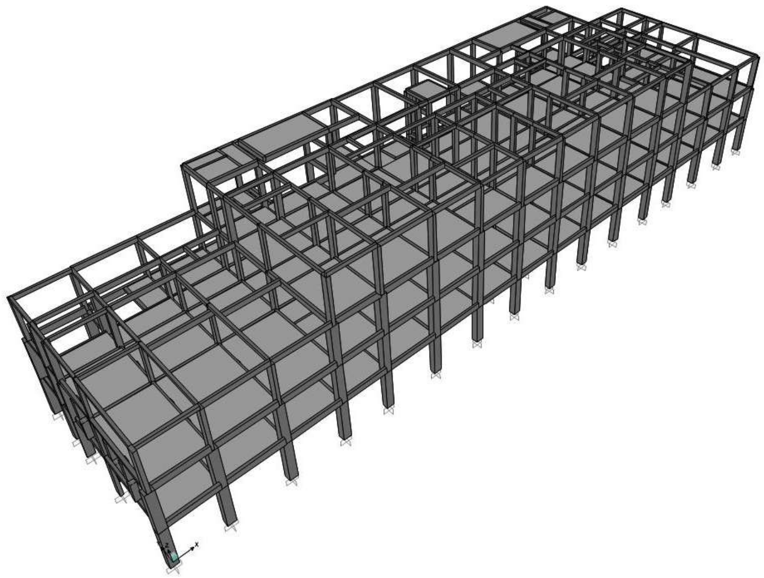

Figure 5. Modelling of Existing Building in SAP2000

The ground-motions records used for the analysis are obtained from the Pacific Earthquake Engineering Research (PEER). The Imperial Valley earthquake (recorded at El Centro station) is used in this study. Ground-motion obtained from PEER is matched to Mataram's Maximum Considered Earthquake (MCE) response spectrum. MCE is a 2500-year return period earthquake and is 1.5 times greater than the Elastic Design Earthquake (EDE), which required by SNI 1726:2012 for designing an earthquake-resistant structure. Imperial Valley PGA in east-west (EW) and north-south (NS) direction are 0.58812 g and 0.83878 g, respectively, which can be seen in Figure 6. To maintain magnitude ratio of the Imperial Valley earthquake of both direction, during the spectral matching process, the larger value of PGA, in this case, the NS and EW component is match to 100% and 70% of Mataram's MCE, respectively. In this study, spectrum consistent EW and NS ground motions are subjected to the building twice. First, the NS and EW component is applied in the Y and X-axis of the building, respectively. Then the direction of the two components are switched to ensure the most severe case is analyzed in both orthogonal directions.

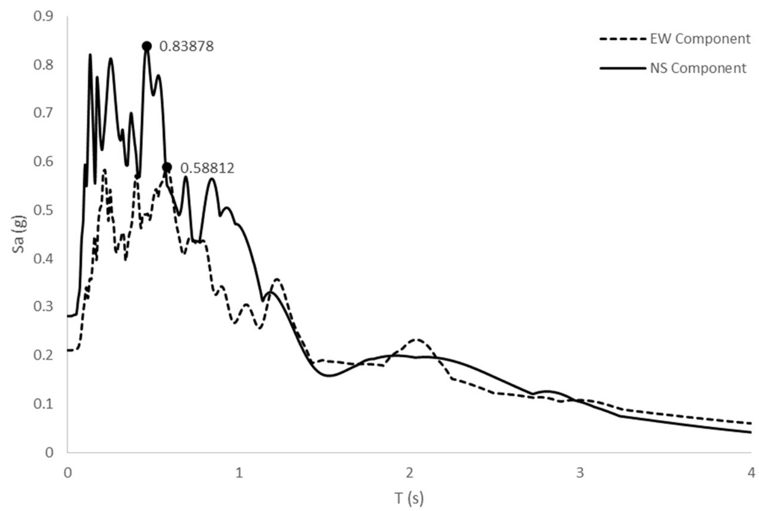

Figure 6. Imperial Valley Earthquake response spectrum of each component

VSL Gensui Damper is modelled as non-linear link property with plastic wen type. There are several parameters that need to be calculated, which are effective stiffness, effective damping stiffness, yield strength, and post-yield stiffness ratio. The parameters can be obtained by using several charts and equations [10].

Analysis Result

Structural performance can be determined from the story drift and damage index of the plastic hinges in the structure. Asia Concrete Model Code (ACMC) 2001 is used to determine the damage index classification of the plastic hinges [11]. The states of plastic hinge damage are Immediate Occupancy (IO), Life Safety (LS), Collapse Prevention (CP), and beyond CP, which correspond to damage index values of 0-10%, 10%-25%, 25%-40%, and 40%-100%, respectively. In this study, to give a brief idea of overall damage of the structural elements, the damage indices are averaged. Mid-range values of each damage states are used, which correspond to 5%, 17.5%, 32.5%, and 70% for damages below IO, between IO and LS, between LS and CP, and beyond CP, respectively. Figures 7 to 10 present the drifts of the structure. In the figures, labels "R" and "SR" indicate the assumption of rigid and semi-rigid floors used in the analysis, while labels "X" and "Y" indicate the direction of dominant NS earthquake component. MSSSA and ODAM indicate the strategic damper placement method used, while uniform and bare indicate the initial step of the ODAM method and original structure without any dampers installed. In Figures 7 to 10, "DR 0.4%" represents the 0.4% story drift ratio target of each floor.

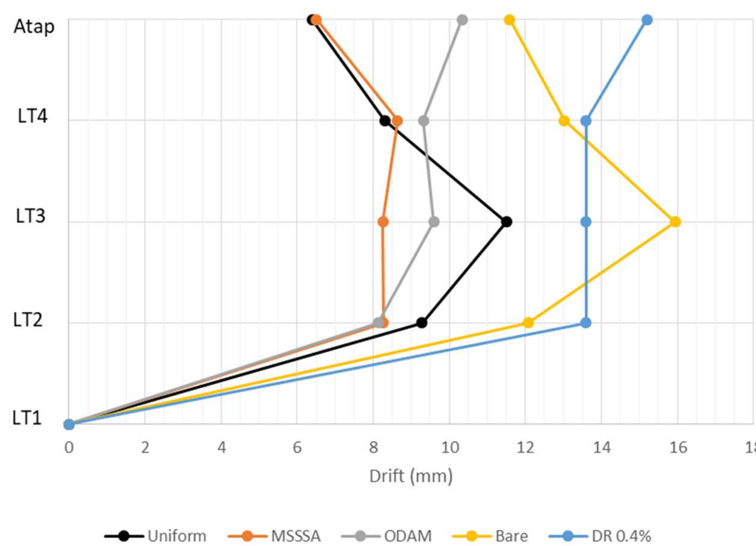

Figure 7. Drift in the X direction of the structure for R-X case

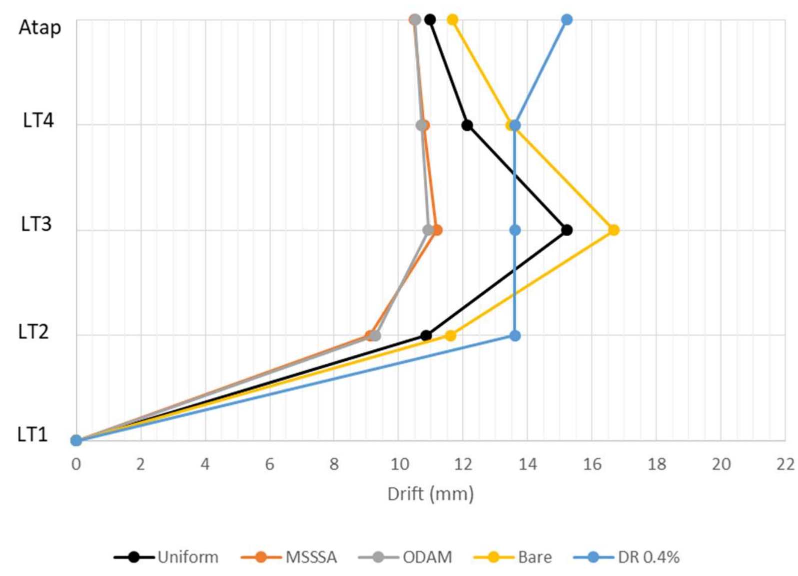

Figure 8. Drift in the Y direction of the structure for R-Y case

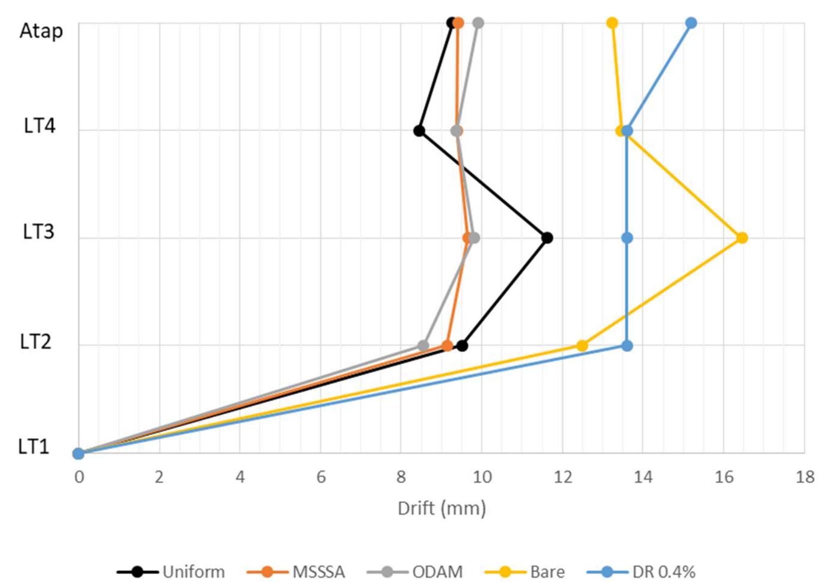

Figure 9. Drift in the X direction of the structure for SR-X case

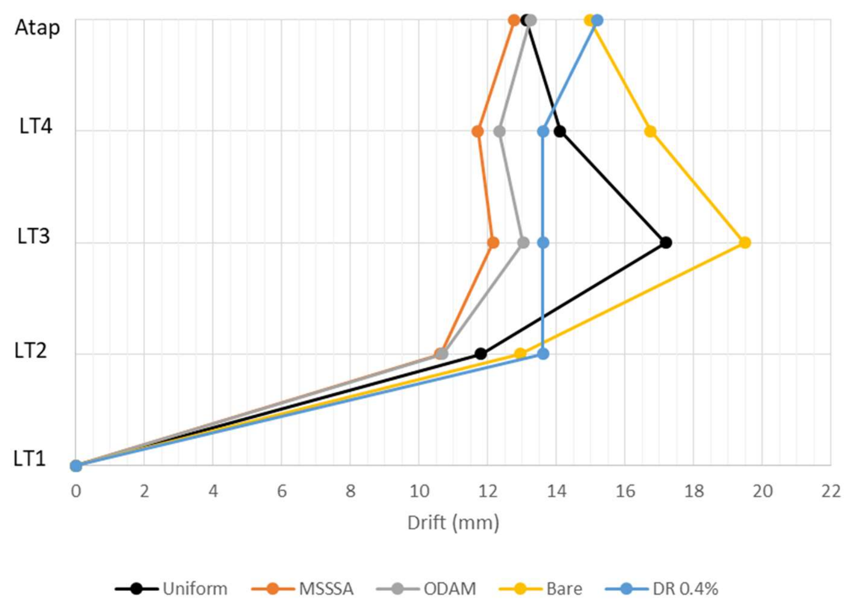

Figure 10. Drift in the Y direction of the structure for SR-Y case

For cases using semi-rigid assumption, the figures above are generated from the maximum drift of several frames perpendicular to the dominant direction of the earthquake. It can be seen from the figures that the strengthened building's performance increases against that of the original building. In ODAM and MSSSA methods, the drift of the structures can be reduced below the target. Despite of using the same number of dampers, in SR-Y and R-Y cases, Uniform placement method fail to reach the target. The final placement of dampers in each strategic placement methods is presented in Figures 11 to 21, where the marks **O** and **X** indicate damper positions by using MSSSA and ODAM strategic placement, respectively. In Figures 11 to 21, the dampers are always installed parallel to the marked frames.

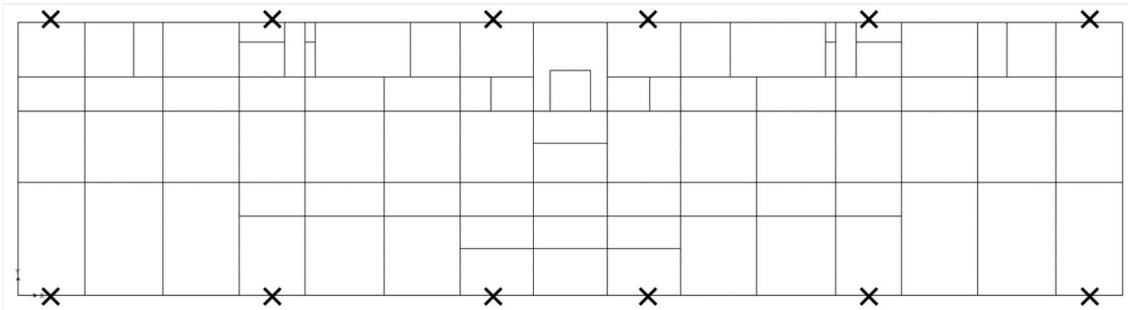

Figure 11. Damper Placement at 2nd floor (R-X)

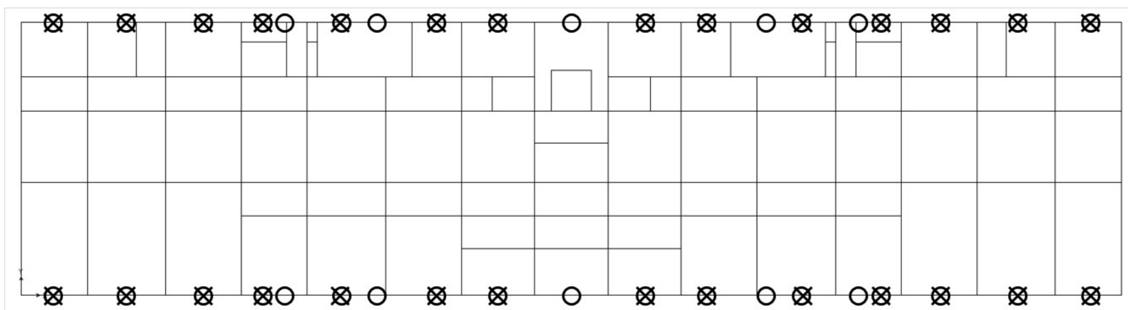

Figure 12. Damper Placement at 3rd floor (R-X)

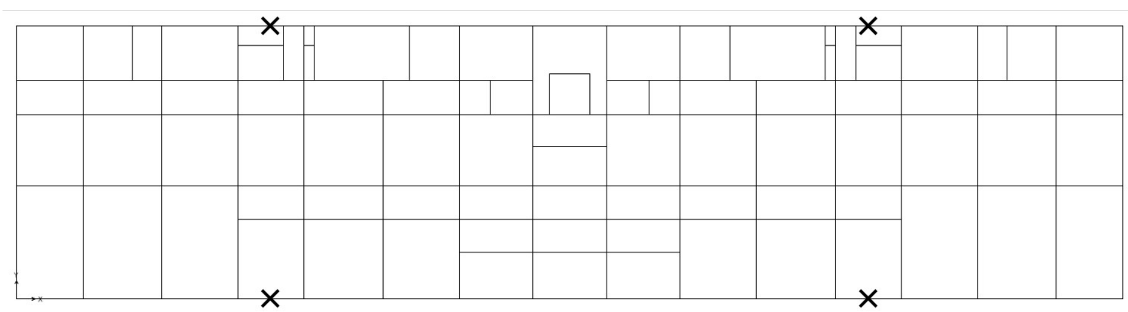

Figure 13. Damper Placement at 4th floor (R-X)

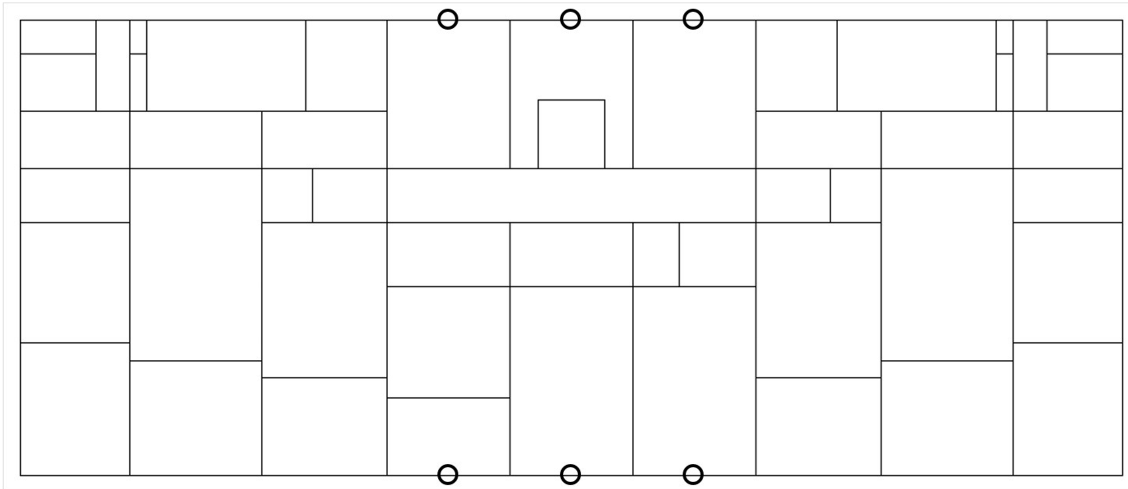

Figure 14. Damper Placement at roof floor (R-X)

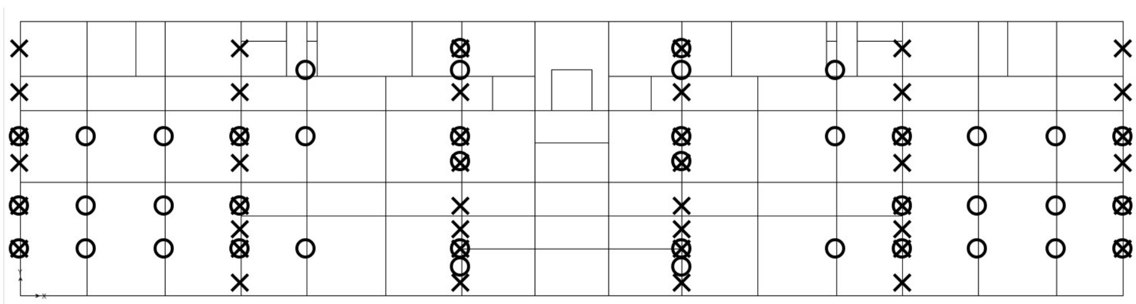

Figure 15. Damper Placement at 3rd floor (R-Y)

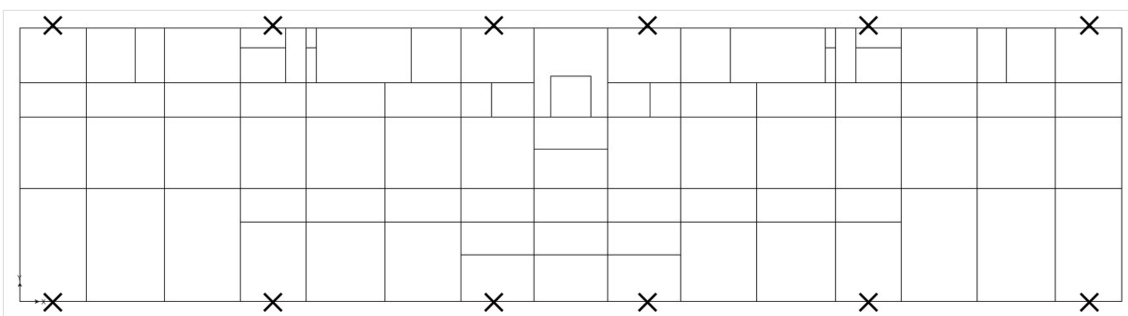

Figure 16. Damper Placement at 2nd floor (SR-X)

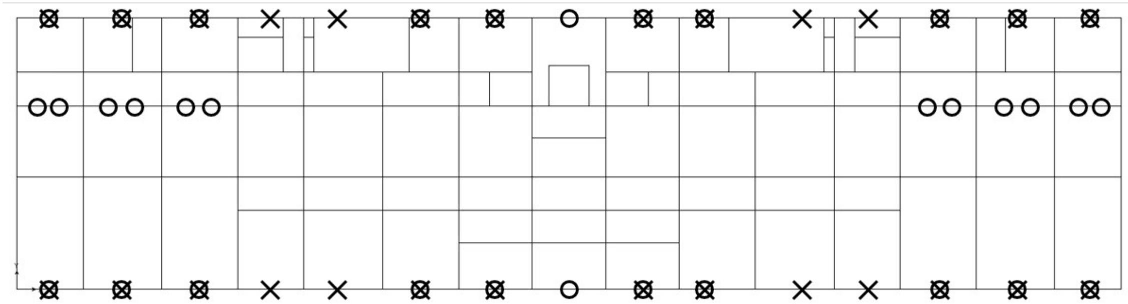

Figure 17. Damper Placement at 3rd floor (SR-X)

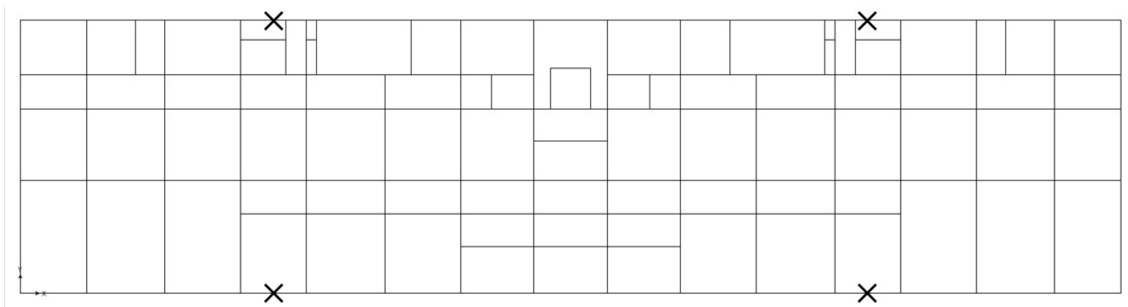

Figure 18. Damper Placement at 4th floor (SR-X)

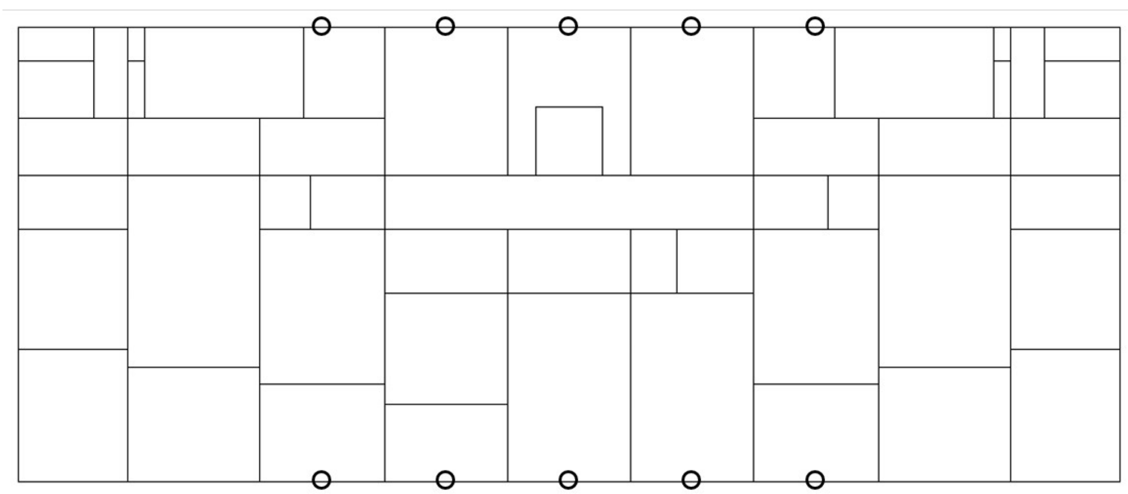

Figure 19. Damper Placement at roof floor (SR-X)

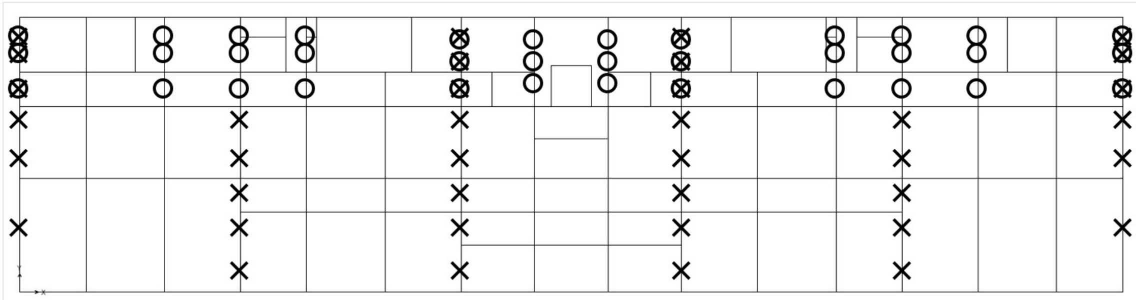

Figure 20. Damper Placement at 3rd floor (SR-Y)

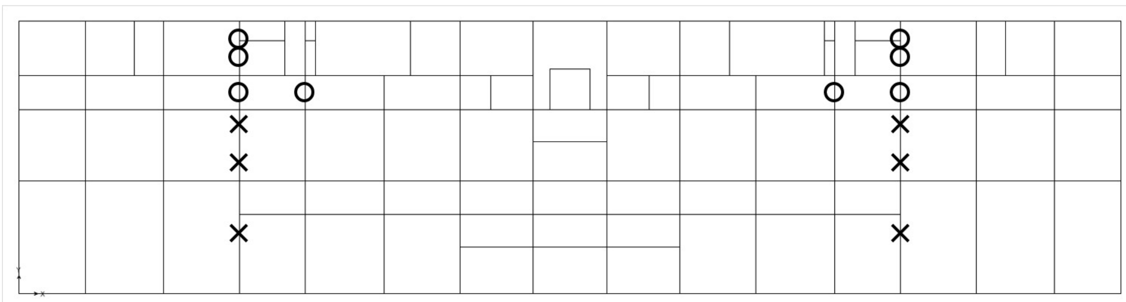

Figure 21. Damper Placement at 4th floor (SR-Y)

Table 1. Plastic Hinges (R-X)

Plastic Hinges (B-IO)

	Bare				Uniform				MSSSA				ODAM			
Step	Beam	Column	Total	DI	Beam	Column	Total	DI	Beam	Column	Total	DI	Beam	Column	Total	DI
Bare	155	46	201	0.480%												
1					84	35	119	0.284%	72	41	113	0.270%	[redacted]			
2									63	36	99	0.236%	83	31	114	0.272%
3									58	33	91	0.217%	79	30	109	0.260%
4									60	35	95	0.227%	77	29	106	0.253%
5									63	32	95	0.227%	71	30	101	0.241%
							Improvement % :	40.80%			Improvement % :	52.74%			Improvement % :	49.75%

Table 2. Plastic Hinges (R-Y)

Plastic Hinges (B-IO)

	Bare				Uniform				MSSSA				ODAM			
Step	Beam	Column	Total	DI	Beam	Column	Total	DI	Beam	Column	Total	DI	Beam	Column	Total	DI
Bare	155	44	199	0.475%												
1					126	40	166	0.396%	150	44	194	0.463%	[redacted]			
2									142	40	182	0.435%	116	39	155	0.370%
3									137	40	177	0.423%	110	38	148	0.353%
4									127	40	167	0.399%	85	39	124	0.296%
5									122	39	161	0.384%	87	40	127	0.303%
6									113	39	152	0.363%	84	39	123	0.294%
7									88	38	126	0.301%	76	39	115	0.275%
							Improvement % :	16.58%			Improvement % :	36.68%			Improvement % :	42.21%

Table 3. Plastic Hinges (SR-X)

	Plastic Hinges (B-IO)															
	Bare				Uniform				MSSSA				ODAM			
Step	Beam	Column	Total	DI	Beam	Column	Total	DI	Beam	Column	Total	DI	Beam	Column	Total	DI
Bare	266	47	313	0.747%												
1					160	35	195	0.466%	171	41	212	0.506%	[redacted]			
2									160	36	196	0.468%	168	32	200	0.478%
3									166	37	203	0.485%	162	31	193	0.461%
4									160	35	195	0.466%	163	29	192	0.458%
5									156	36	192	0.458%	153	30	183	0.437%
6													165	33	198	0.473%
							Improvement % :	37.70%			Improvement % :	38.66%			Improvement % :	36.74%

Table 4. Plastic Hinges (SR-Y)

	Plastic Hinges (B-IO)															
	Bare				Uniform				MSSSA				ODAM			
Step	Beam	Column	Total	DI	Beam	Column	Total	DI	Beam	Column	Total	DI	Beam	Column	Total	DI
Bare	244	44	288	0.688%												
1					201	40	241	0.575%	235	45	280	0.669%	[redacted]			
2									228	49	277	0.661%	192	39	231	0.552%
3									220	46	266	0.635%	185	39	224	0.535%
4									217	60	277	0.661%	131	52	183	0.437%
5									216	41	257	0.614%	157	40	197	0.470%
6									188	40	228	0.544%	156	39	195	0.466%
7									172	40	212	0.506%	154	38	192	0.458%
8									173	42	215	0.513%				
						Improvement % :		16.32%		Improvement % :		25.35%		Improvement % :		33.33%

The damage severity of the plastic hinges is presented in Tables 1 to 4. In the tables, only B-IO hinges are displayed because there is no more severe hinge state than B-IO. Overall, there are 2094 points of non-linear hinges. From these tables, it can be seen that the number of plastic hinges decreases when compared to the bare model. However, at certain steps, the number of plastic hinges may increase, especially in ODAM, because the dampers are not added but moved among stories of the building. It can be seen is earthquake scheme Y, where the deformations are still relatively large, ODAM and MSSA methods show much better performance compared to the Uniform method.

In this structure, there are significant differences from the results with semi-rigid and rigid floor assumption analysis. It is obvious that in a relatively large horizontal span dimension compared to its perpendicular, the concrete slab may not rigid enough to simulate rigid body movement of the whole floor diaphragm. The results of the analysis with the semi-rigid model produce more severe drifts compared to that of the rigid floor model. The drift of frames in the same story may differ significantly in semi-rigid floor assumption, which is not the case in rigid floor assumption. The drift of frames information is very useful to determine damper placement throughout the study.

Conclusion

In this study, the effort to improve the seismic performance of a structure is conducted by installing VSL Gensui Dampers. The analyzed building has a large diaphragm span to depth ratio that it should use semi-rigid floor assumption. From non-linear time history analysis results, some conclusion can be made as follows:

1. More extreme story drifts are observed in structure analyzed by using semi-rigid floor assumption in the direction perpendicular to a larger floor plan dimension. This assumption is imperative since different drift of frames in the same story can be obtained. This is important for strategic damper placement in the floor plan since drifts are used as placement indicator. Story drifts in the direction of larger floor plan dimension obtained from either rigid or semi-rigid floor assumptions show in-significant differences.

2. In this study, the MSSSA damper placement method shows the most consistent performance in reducing the story drifts as well as element damages. Even though the final result of damper placement is similar, the ODAM placement method has its limitation compared to MSSSA method that number of dampers used must be determined in the beginning, and dampers can only be swapped among stories of initially chosen frames.

3. In this study, it can be seen that both MSSSA and ODAM placement can improve the structure damage index and drift to meet the targeted performance.

4. Despite of using the same number of dampers as in MSSSA and ODAM methods, Uniform damper placement show less effective in improving the seismic performance of the structure.

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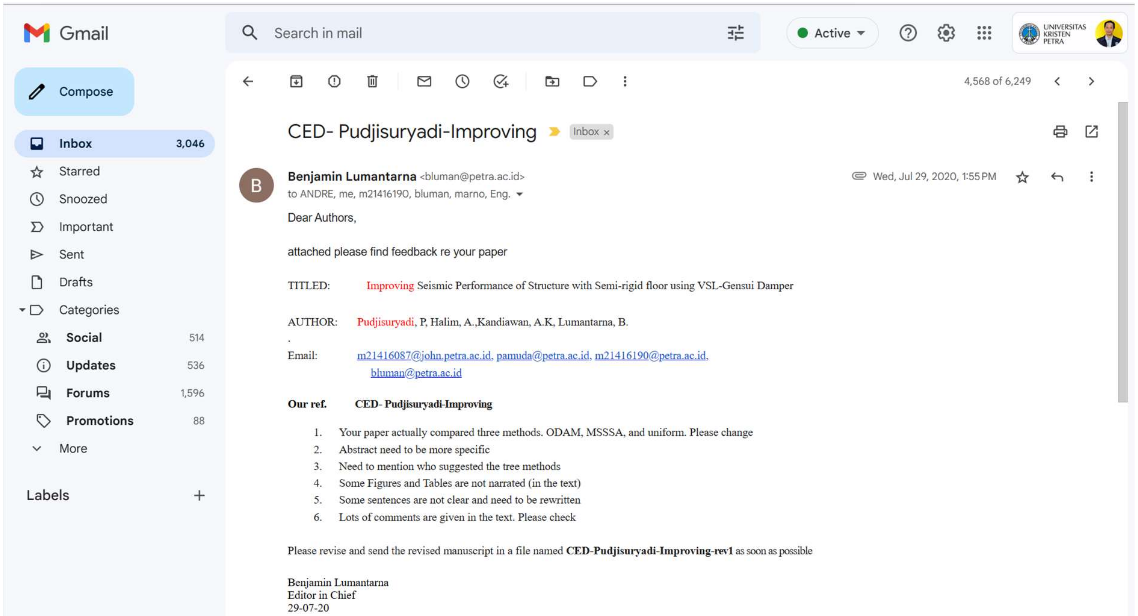

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3. Need to mention who suggested the tree methods
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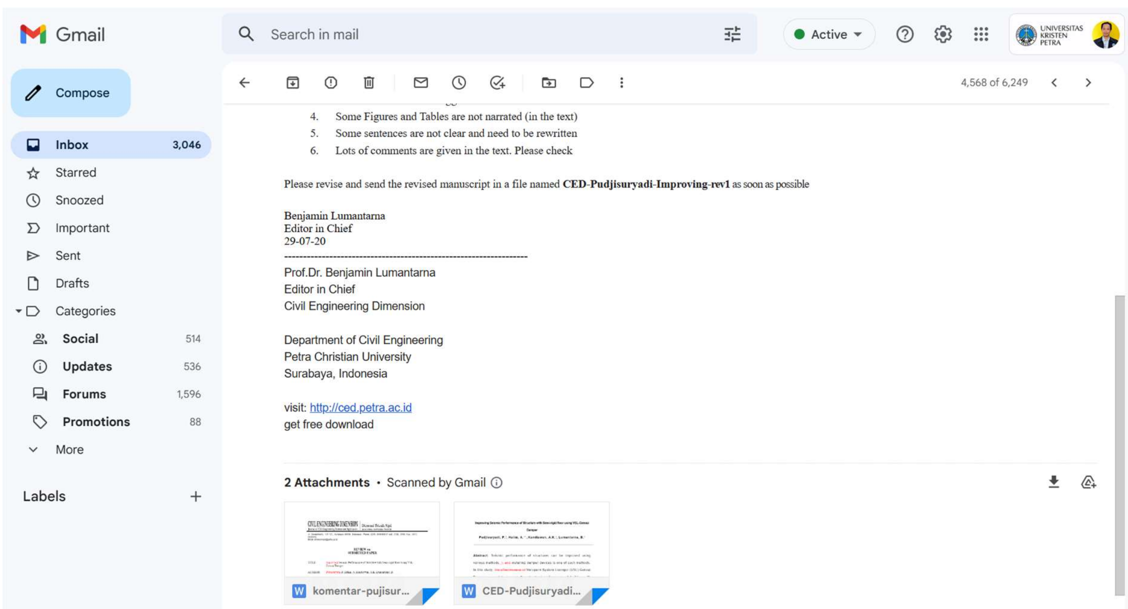

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TITLE: Improving Seismic Performance of Structure with Semi-rigid floor using VSL-Gensui Damper

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Our ref. **CED- Pudjisuryadi-Improving**

Followings are feedback for the above captioned paper:

1. Your paper actually compared three methods. ODAM, MSSSA, and uniform. Please change
2. Abstract need to be more specific
3. Need to mention who suggested the tree methods
4. Some Figures and Tables are not narrated (in the text)
5. Some sentences are not clear and need to be rewritten
6. Lots of comments are given in the text. Please check

Please revise and send the revised manuscript in a file named **CED-Pudjisuryadi-Improving-rev1** as soon as possible

Benjamin Lumantarna
Editor in Chief
29-07-20

Improving Seismic Performance of Structure with Semi-rigid floor using VSL-Gensui Damper

Pudjisuryadi, P.[1], Halim, A.[1]*.,Kandiawan, A.K.[1], Lumantarna, B.[1]

Abstract: Seismic performance of structures can be improved using various methods. I~~, and i~~nstalling damper devices is one of such methods. In this study, ~~the effectiveness of~~ Vorspann System Losinger (VSL) Gensui Damper is used to improve the structural performance of building with semi-rigid floors ~~is investigated~~. The considered building is subjected to spectrum consistent ground accelerations generated from El Centro 18 May 1940 earthquake N-S and E-W components per Indonesian Seismic Code (SNI 1726:2012) for Mataram City. Modified Simplified Sequential Search Algorithm (MSSSA) and Optimum Damper Allocation Method (ODAM) methods are used to efficiently place the dampers on the building until certain criteria are met. Results show that installation of VSL Gensui Dampers can effectively reduce structural drifts. Furthermore, it should be noted that the placement of dampers must be well distributed among frames in the same story, since their drifts may differ significantly in building with semi-rigid floors.

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Keywords: Drift; damper placement method; Non-Linear Time History Analysis; semi-rigid floors; strengthening; VSL Gensui damper.

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Introduction

In seismically active countries such as Indonesia, consideration of earthquake load in building design is imperative. Indonesia has SNI 1726:2012 [1], as its guidelines for designing building structures to withstand earthquake load. In conjunction with structural codes such as concrete design code (SNI 2847:2013) [2] and steel design code (SNI 1729:2015), the Indonesian Seismic Code (SNI 1726:2012) should be used to ensure buildings capability to withstand earthquakes.

One of the most common criteria that are not accurately assumed is floor rigidity. In SNI 1726:2012, there is a clause which states, "Diaphragms of concrete slabs or concrete filled metal deck with span-to-depth ratios of 3 or less in structures that have no horizontal irregularities are permitted to be idealized as rigid" [1,3]. However, in buildings with concrete slabs, rigid floor diaphragm is usually assumed regardless of the large diaphragm span-to-depth ratio. This may cause inaccurate story drifts in the building model [4].

In the effort of improving the seismic performance of existing structures, many techniques can be used, and one of them is by installing dampers. A damper is an energy dissipation system that can be installed in a structure. The use of energy dissipation systems for an earthquake-resistant structure is useful for improving the seismic performance of a structure [5,6]. In this study, a type of damper produced by Vorspann System Losinger (VSL), namely VSL Gensui Damper, is used to improve the seismic performance of an elongated structure. VSL Gensui Damper is a wall type viscoelastic damper that consists of multilayer of rubber and steel that has 400x400x15mm in dimension (Figure 1~~Figure 1~~). To maximize the benefit of using dampers while still paying good attention to the cost induced, strategic placement of dampers is a must.

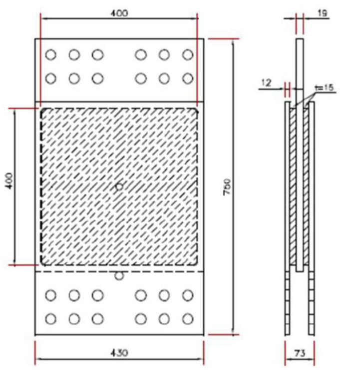

Figure 1. VSL-Gensui Damper

Strategic Placement of the dampers

Two damper placement strategies are used in this study. As the first strategy, Simplified Sequential Search Algorithm (SSSA) [7] is adopted. In this study, the original damper placement indicator of SSSA is modified by only using story drift and neglecting story velocity, and hereafter is called as MSSSA. Optimum Damper Allocation Method (ODAM) [8] is used for the second strategy. Uniform placement of damper in all stories of selected frames is also conducted for comparison against the previous two methods. This uniform placement method is identical to the initial step of the ODAM method. Andini and Goenawan have researched the three methods mentioned above, on a simple structure and concluded that ??? [9].

In ~~the~~ ODAM, the total number of dampers used is decided at the beginning, and typically the dampers are placed at every story of selected frames. Then the dampers in the story with minimum drift will be moved to the floor with maximum drift. This

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process is repeated until certain acceptance criteria are met, or the last two damper relocations indicate swaps between the same two stories. In the MSSSA method, each damper addition is placed at the story with the largest drift in the selected frames. The damper addition is stopped when certain acceptance criteria are met. In this study, the maximum story drift ratio of the structure is targeted to be less than 0.4%. Meanwhile, the average damage index of the structure is targeted to be reduced as much as 25% and 35% for earthquakes with scheme Y and scheme X, respectively. Y and X represent the dominant earthquake direction corresponding to the building. For a comparable comparison between the methods, the number of the dampers on all method is determined to be~~. Dampers installed on all method will be~~ 44 dampers.

Considered Structure

An~~In this study, an~~ existing hotel located in Mataram is chosen to be studied. This 14 meters high five-story building has 62.3 meters by 15.5 meters floor plan dimension resulting to span-to-depth ratio larger than 3.0. The floor plan can be seen in Figures 2 to 4. When analyzing earthquake which direction perpendicular to larger building horizontal dimension, according to SNI 1726:2012, semi-rigid floor assumption should be used to obtain accurate building deformation. Performance of the structure will be improved to a certain condition.

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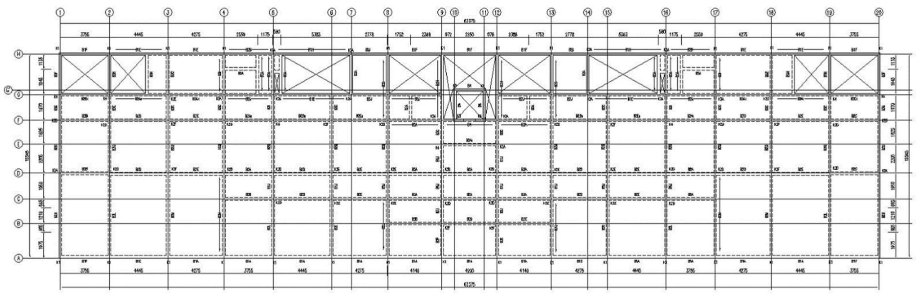

Figure 2. Typical Floor Plan (1st floor – 3rd floor)

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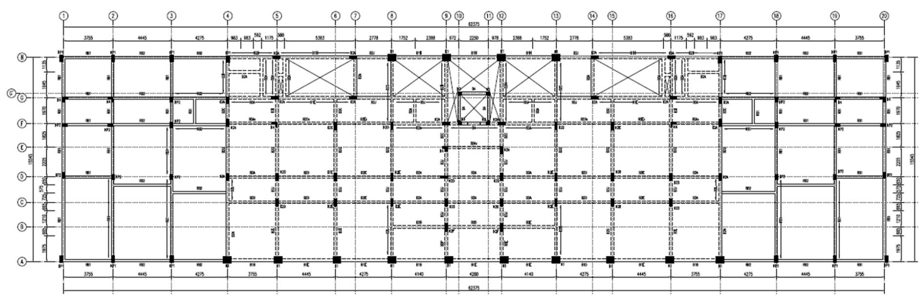

Figure 3. Floor Plan of the 4th floor

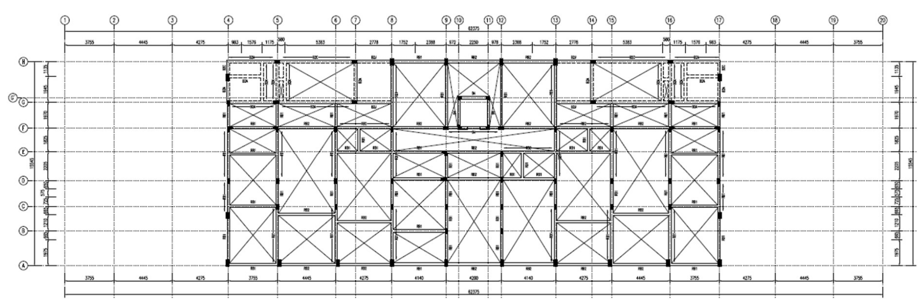

Figure 4 Floor Plan of the roof floor

Modelling of the Structure and Analysis

~~In this study, ~~C~~c~~omputer software SAP2000 [ref??] is used to ~~re~~model the existing structure, as shown in Figure 5~~Figure 5~~. The auto-hinge feature of SAP2000 is used to determine the non-linear hinges properties of all beams and columns.

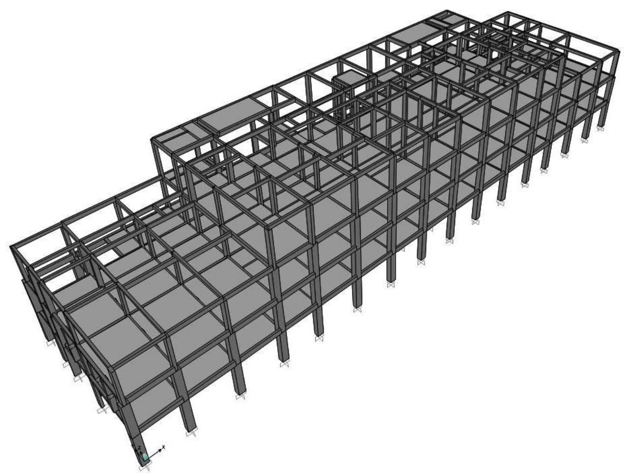

Figure 5. Modelling of Existing Building in SAP2000

The ground-motions records used for the analysis are The Imperial Valley earthquake (recorded at El Centro station,) obtained from the Pacific Earthquake Engineering Research (PEER)~~. The Imperial Valley earthquake (recorded at El Centro station) is used in this study~~. These Ground-motions~~ obtained from PEER~~ are~~is~~ matched to Mataram's Maximum Considered Earthquake (MCE) response spectrum. MCE is a 2500-year return period earthquake and is 1.5 times greater than the Elastic Design Earthquake (EDE), which is required by SNI 1726:2012 for designing an earthquake-resistant structure. Imperial Valley's PGA in E~~e~~ast-W~~w~~est (EW) and N~~n~~orth-S~~s~~outh (NS) direction are 0.58812 g and 0.83878 g, respectively, which can be seen in Figure 6~~Figure 6~~. To maintain magnitude ratio of the Imperial Valley earthquake of both direction, during the spectral matching process, the larger

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value of PGA, in this case, the NS and EW component is match to 100% and 70% of Mataram's MCE, respectively. In this study, spectrum consistent EW and NS ground motions are subjected to the building twice. First, the NS and EW component is applied in the Y and X-axis of the building, respectively. Then the direction of the two components are switched to ensure the most severe case is analyzed in both orthogonal directions.

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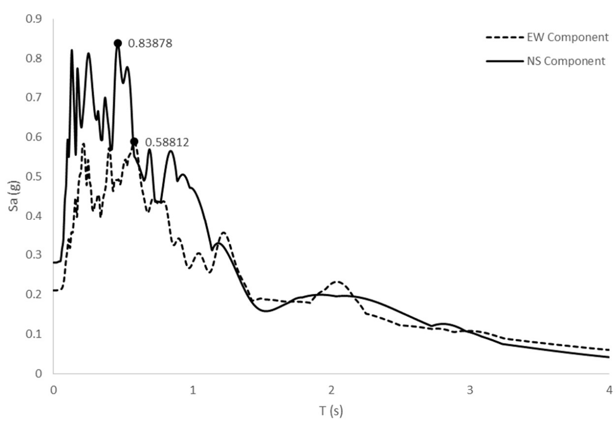

Figure 6. Imperial Valley Earthquake response spectrum of each component

VSL Gensui Damper is modelled as non-linear link property with plastic wen type. There are several parameters that need to be calculated, which are effective stiffness, effective damping stiffness, yield strength, and post-yield stiffness ratio. The parameters can be obtained by using several charts and equations [10].

Analysis Result

Structural performance can be determined from the story drift and damage index of the plastic hinges in the structure. Asia Concrete Model Code (ACMC) 2001 is used to determine the damage index classification of the plastic hinges [11]. The states of plastic hinge damages are Immediate Occupancy (IO), Life Safety (LS), Collapse

Prevention (CP), and beyond CP, which correspond to damage index values of 0-10%, 10%-25%, 25%-40%, and 40%-100%, respectively. In this study, to give a brief idea of overall damage of the structural elements, the damage indices are averaged. Mid-range values of each damage states are used, which correspond to 5%, 17.5%, 32.5%, and 70% for damages below IO, between IO and LS, between LS and CP, and beyond CP, respectively. Figures 7 to 10 present the drifts of the structure (with…44 damper?). In these figures, labels "R" and "SR" indicate the assumption of rigid and semi-rigid floors used in the analysis, while labels "X" and "Y" indicate the direction of dominant NS earthquake component. MSSSA and ODAM indicate the ~~strategic~~ damper placement method used, while uniform and bare indicate the initial step of the ODAM method and original structure without any dampers installed respectively. In Figures 7 to 10, "DR 0.4%" represents the 0.4% story drift ratio target of each floor used in this study.

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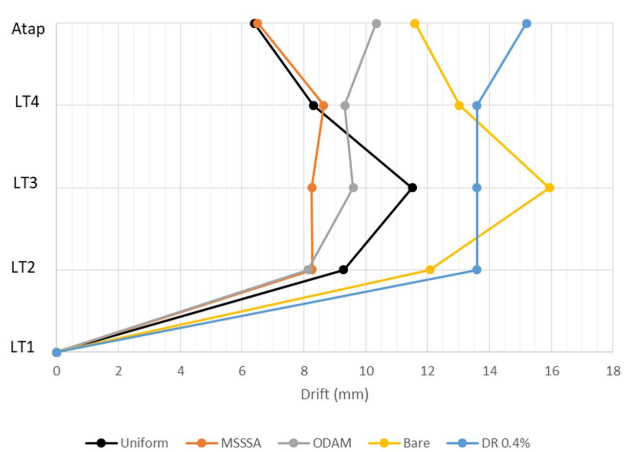

Figure 7. Drift in the X direction of the structure for R-X case

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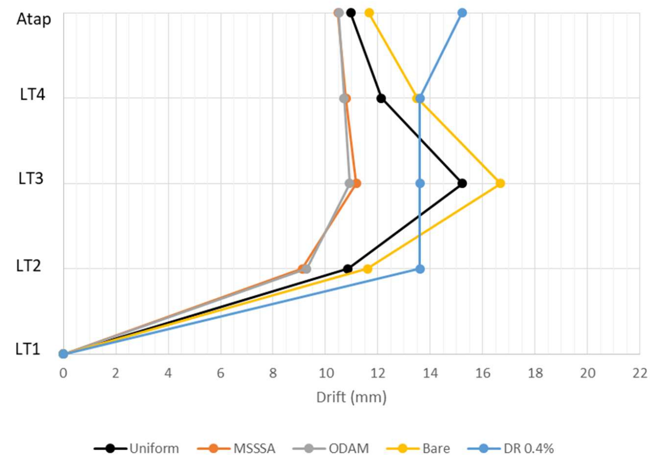

Figure 8. Drift in the Y direction of the structure for R-Y case

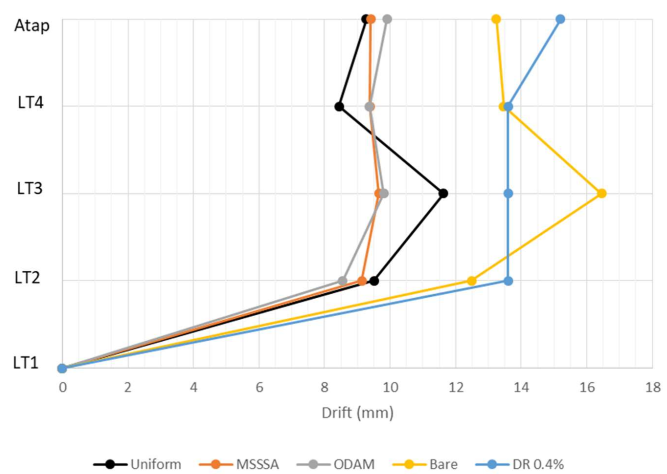

Figure 9. Drift in the X direction of the structure for SR-X case

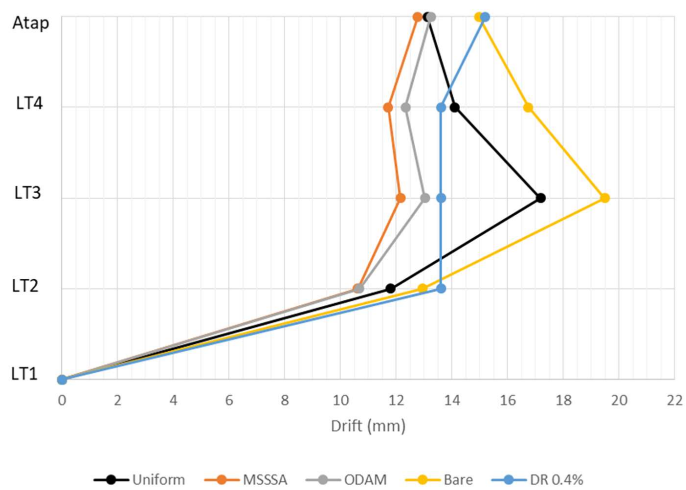

Figure 10. Drift in the Y direction of the structure for SR-Y case

For cases using semi-rigid assumption, the figures above are generated from the maximum drift of several frames perpendicular to the dominant direction of the earthquake. It can be seen from the figures that the strengthened building's performance increases against that of the original building. In ODAM and MSSSA methods, the drift of the structures can be reduced below the target. Despite of using the same number of dampers, in SR-Y and R-Y cases, Uniform placement method fail to reach the target. The final placement of dampers in each ~~strategic~~ placement methods is presented in Figures 11 to 21, where the marks **O** and **X** indicate damper positions by using MSSSA and ODAM ~~strategic~~ placement, respectively. In Figures 11 to 21, the dampers are always installed parallel to the marked frames.

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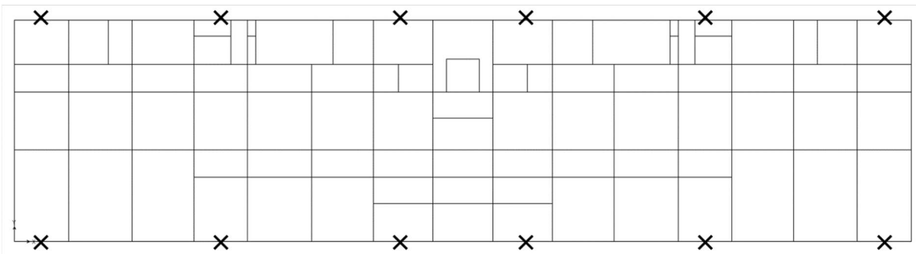

Figure 11. Damper Placement at 2nd floor (R-X)

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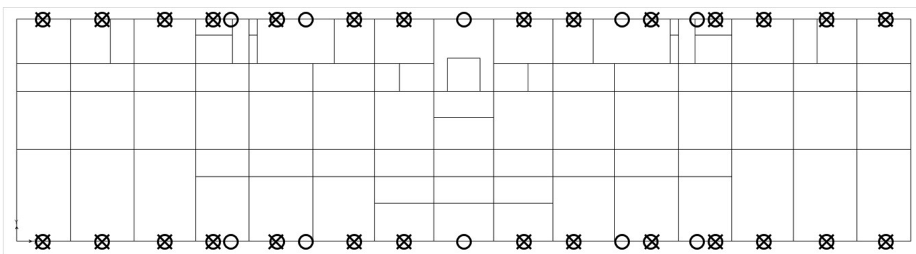

Figure 12. Damper Placement at 3rd floor (R-X)

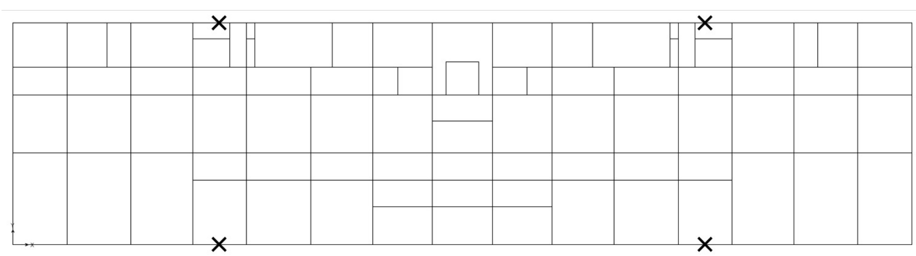

Figure 13. Damper Placement at 4th floor (R-X)

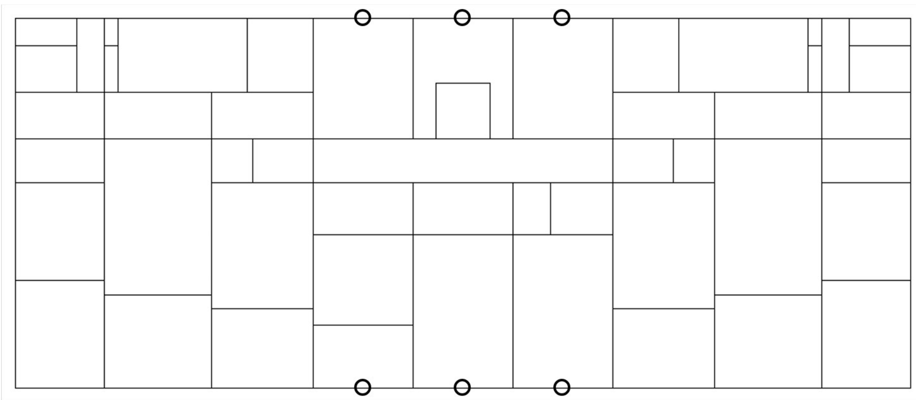

Figure 14. Damper Placement at roof floor (R-X)

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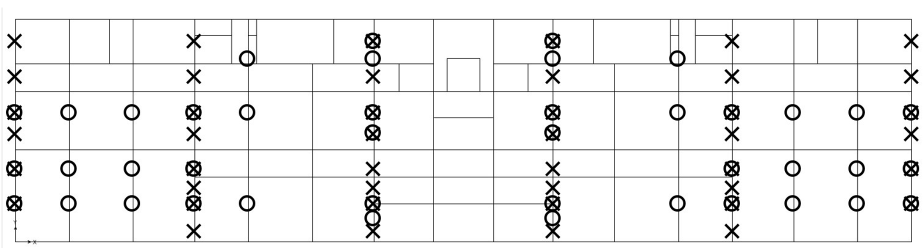

Figure 15. Damper Placement at 3rd floor (R-Y)

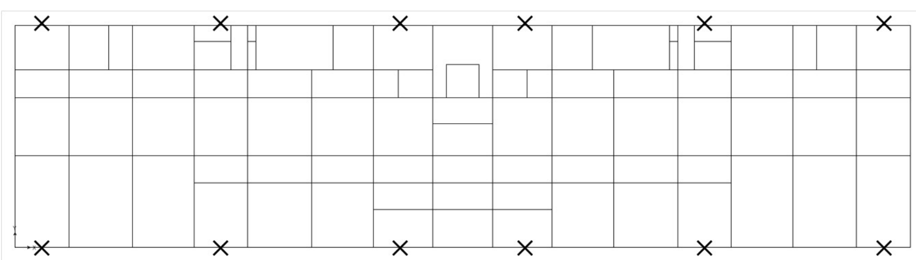

Figure 16. Damper Placement at 2nd floor (SR-X)

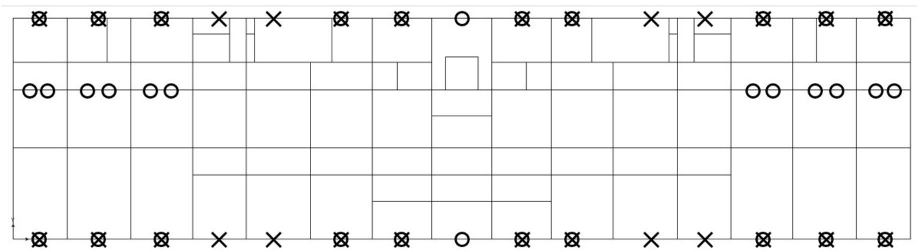

Figure 17. Damper Placement at 3rd floor (SR-X)

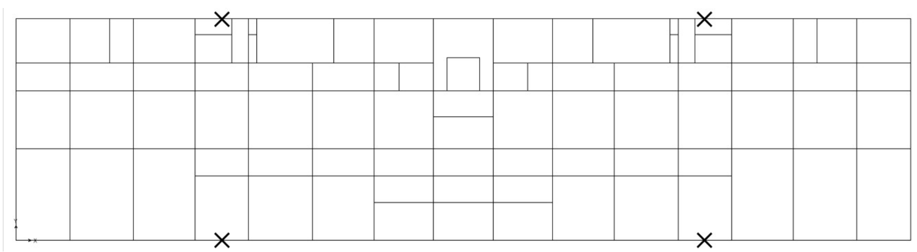

Figure 18. Damper Placement at 4th floor (SR-X)

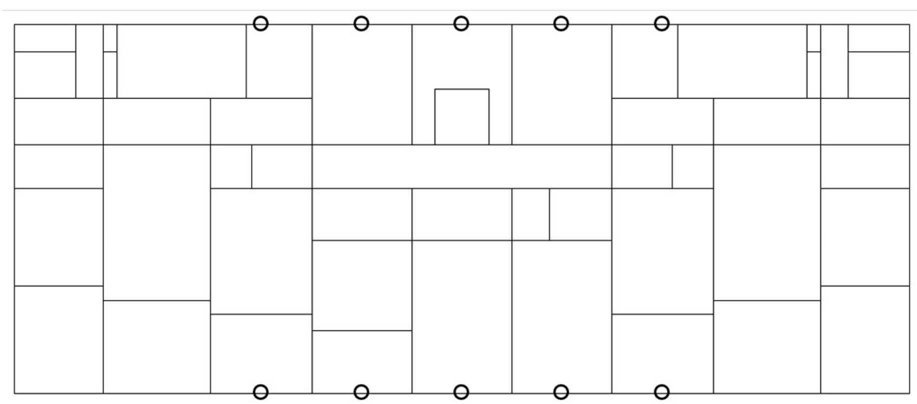

Figure 19. Damper Placement at roof floor (SR-X)

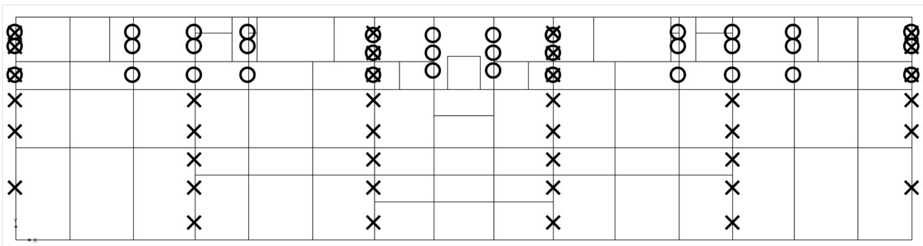

Figure 20. Damper Placement at 3rd floor (SR-Y)

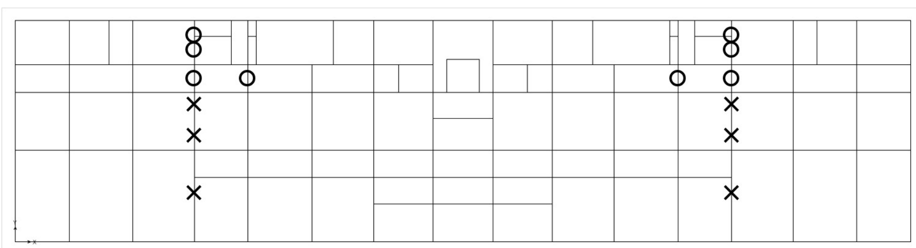

Figure 21. Damper Placement at 4th floor (SR-Y)

Table 1. Plastic Hinges (R-X)

Plastic Hinges (B-IO)

	Bare				Uniform				MSSSA				ODAM			
Step	Beam	Column	Total	DI	Beam	Column	Total	DI	Beam	Column	Total	DI	Beam	Column	Total	DI
Bare	155	46	201	0.480%												
1					84	35	119	0.284%	72	41	113	0.270%	[redacted]			
2									63	36	99	0.236%	83	31	114	0.272%
3									58	33	91	0.217%	79	30	109	0.260%
4									60	35	95	0.227%	77	29	106	0.253%
5									63	32	95	0.227%	71	30	101	0.241%
							Improvement % :	40.80%			Improvement % :	52.74%			Improvement % :	49.75%

Table 2. Plastic Hinges (R-Y)

Plastic Hinges (B-IO)

	Bare				Uniform				MSSSA				ODAM			
Step	Beam	Column	Total	DI	Beam	Column	Total	DI	Beam	Column	Total	DI	Beam	Column	Total	DI
Bare	155	44	199	0.475%												
1					126	40	166	0.396%	150	44	194	0.463%	[redacted]			
2									142	40	182	0.435%	116	39	155	0.370%
3									137	40	177	0.423%	110	38	148	0.353%
4									127	40	167	0.399%	85	39	124	0.296%
5									122	39	161	0.384%	87	40	127	0.303%
6									113	39	152	0.363%	84	39	123	0.294%
7									88	38	126	0.301%	76	39	115	0.275%
							Improvement % :	16.58%			Improvement % :	36.68%			Improvement % :	42.21%

Table 3. Plastic Hinges (SR-X)

Plastic Hinges (B-IO)

	Bare				Uniform				MSSSA				ODAM			
Step	Beam	Column	Total	DI	Beam	Column	Total	DI	Beam	Column	Total	DI	Beam	Column	Total	DI
Bare	266	47	313	0.747%												
1					160	35	195	0.466%	171	41	212	0.506%	[redacted]			
2									160	36	196	0.468%	168	32	200	0.478%
3									166	37	203	0.485%	162	31	193	0.461%
4									160	35	195	0.466%	163	29	192	0.458%
5									156	36	192	0.458%	153	30	183	0.437%
6													165	33	198	0.473%
						Improvement % :		37.70%		Improvement % :		38.66%		Improvement % :		36.74%

Table 4. Plastic Hinges (SR-Y)

Plastic Hinges (B-IO)

	Bare				Uniform				MSSSA				ODAM			
Step	Beam	Column	Total	DI	Beam	Column	Total	DI	Beam	Column	Total	DI	Beam	Column	Total	DI
Bare	244	44	288	0.688%												
1					201	40	241	0.575%	235	45	280	0.669%	[redacted]			
2									228	49	277	0.661%	192	39	231	0.552%
3									220	46	266	0.635%	185	39	224	0.535%
4									217	60	277	0.661%	131	52	183	0.437%
5									216	41	257	0.614%	157	40	197	0.470%
6									188	40	228	0.544%	156	39	195	0.466%
7									172	40	212	0.506%	154	38	192	0.458%
8									173	42	215	0.513%				
						Improvement % :		16.32%		Improvement % :		25.35%		Improvement % :		33.33%

The damage severity of the plastic hinges is presented in Tables 1 to 4. In the tables, only B-IO hinges are displayed because there is no more severe hinge state than B-IO. Overall, there are 2094 points of non-linear hinges. From these tables, it can be seen that the number of plastic hinges decreases when compared to the bare model. However, at certain steps, the number of plastic hinges may increase, especially in ODAM, because the dampers are not added but moved among stories of the building. It can be seen is earthquake scheme Y, where the deformations are still relatively large, ODAM and MSSA methods show much better performance compared to the Uniform method.

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In this structure, there are significant differences from the results with semi-rigid and rigid floor assumption analysis. It is obvious that in a relatively large horizontal span dimension compared to its perpendicular, the concrete slab may not be rigid enough to simulate rigid body movement of the whole floor diaphragm. The results of the analysis with the semi-rigid model produce more severe drifts compared to that of the rigid floor model. The drift of frames in the same story may differ significantly in semi-rigid floor assumption, which is not the case in rigid floor assumption. The drift of frames information is very useful to determine damper placement throughout the study.

Conclusion

In this study, the effort to improve the seismic performance of a structure is conducted by installing VSL Gensui Dampers. The analyzed building has a large diaphragm span to depth ratio that it should use semi-rigid floor assumption. From non-linear time history analysis results, some conclusion can be made as follows:

1. More extreme story drifts are observed in structure analyzed by using semi-rigid floor assumption in the direction perpendicular to a larger floor plan dimension. This assumption is imperative since different drift of frames in the same story can be obtained. This is important for strategic damper placement in the floor plan since drifts are used as placement indicator. Story drifts in the direction of larger floor plan dimension obtained from either rigid or semi-rigid floor assumptions show in-significant differences.

2. In this study, the MSSSA damper placement method shows the most consistent performance in reducing the story drifts as well as element damages. Even though the final result of damper placement is similar, the ODAM placement method has its limitation compared to MSSSA method that number of dampers used must be determined in the beginning, and dampers can only be swapped among stories of initially chosen frames.

3. In this study, it can be seen that both MSSSA and ODAM placement can improve the structure damage index and drift to meet the targeted performance.

4. Despite of using the same number of dampers as in MSSSA and ODAM methods, Uniform damper placement show less effective in improving the seismic performance of the structure.

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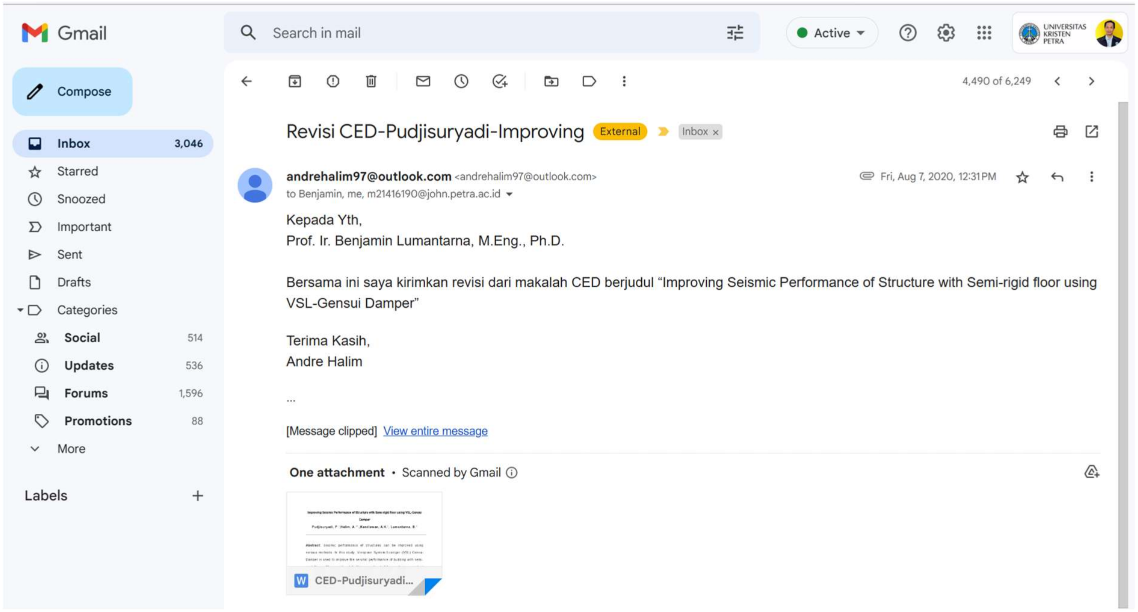

Improving Seismic Performance of Structure with Semi-rigid floor using VSL-Gensui Damper

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Abstract: Seismic performance of structures can be improved using various methods. In this study, Vorspann System Losinger (VSL) Gensui Damper is used to improve the seismic performance of building with semi-rigid floors. The considered building is subjected to spectrum consistent ground accelerations generated from El Centro May 19^{th,} 1940 earthquake per SNI 1726:2012 for Mataram City. Modified Simplified Sequential Search Algorithm (MSSSA) and Optimum Damper Allocation Method (ODAM) methods are used to efficiently place the dampers on the building until certain criteria are met. Results show that by using either of the methods can effectively reduce structural drifts and damages. MSSSA shows slightly better performance since ODAM has a limitation that dampers can only be swapped among stories of initially chosen frames. It should be noted that the dampers must be well distributed among frames in the same story, since their drifts may differ significantly in building with semi-rigid floors.

Keywords:Drift; damper placement method; Non-Linear Time History Analysis;semi-rigid floors; strengthening; VSL Gensui damper.

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Introduction

In seismically active countries such as Indonesia, consideration of earthquake load in building design is imperative. Indonesia has SNI 1726:2012 [1],as its guidelines for designing building structures to withstand earthquake load. In conjunction with structural codes such as concrete design code (SNI 2847:2013) [2] and steel design code (SNI 1729:2015), the Indonesian Seismic Code (SNI 1726:2012) should be used to ensure buildings capability to withstand earthquakes.

One of the most common criteria that are not accurately assumed is floor rigidity. In SNI 1726:2012, there is a clause which states "Diaphragms of concrete slabs or concrete filled metal deck with span-to-depth ratios of 3 or less in structures that have no horizontal irregularities are permitted to be idealized as rigid" [1,3]. However, in buildings with concrete slabs, rigid floor diaphragm is usually assumed regardless of the large diaphragm span-to-depth ratio. This may cause inaccurate story drifts in the building model [4].

In the effort of improving the seismic performance of existing structures, many techniques can be used, and one of them is by installing dampers. Damper is an energy dissipation system that can be installed in a structure. The use of energy dissipation systems for an earthquake-resistant structure is useful for improving the seismic performance of a structure [5,6]. In this study, a type of damper produced by Vorspann System Losinger (VSL), namely VSL Gensui Damper, is used to improve the seismic performance of an elongated structure. VSL Gensui Damper is a wall type viscoelastic damper that consists of a multilayer of rubber and steel that has 400x400x15mm in dimension (Figure 1). To maximize the benefit of using dampers while still paying good attention to the cost induced, strategic placement of dampers is a must.

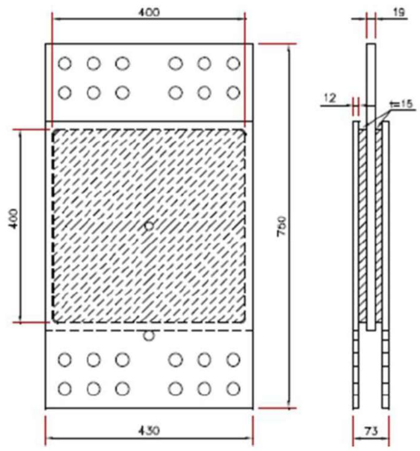

Figure 1. VSL-Gensui Damper

Strategic Placement of the dampers

Two damper placement strategies are used in this study. As the first strategy, Simplified Sequential Search Algorithm (SSSA) [7] is adopted. In this study, proposed modification of SSSA by Angkasaputra and Sebastiano [8] is used. The original damper placement indicator of SSSA is modified by only using story drift and neglecting story velocity, and hereafter is called as MSSSA. Optimum Damper Allocation Method (ODAM) [9] is used for the second strategy. Common uniform placement of damper in all stories of selected frames is also conducted for comparison against the previous two methods. This uniform damper placement happens to be the initial step of the ODAM method. In previous research by Andini and Goenawan [10], the two methods were studied on a simple structure and concluded that both ODAM and MSSSA are effective in reducing interstory drift.

In ODAM, the total number of dampers used is decided at the beginning, and typically the dampers are placed at every story of selected frames. Then the dampers in the story with minimum drift will be moved to the floor with maximum drift. This process is repeated until certain acceptance criteria are met, or the last two damper relocations indicate swaps between the same two stories. In the MSSSA method, each damper addition is placed at the story with the largest drift in the selected frames. The damper addition is stopped when certain acceptance criteria are met. In this study, the maximum story drift ratio of the structure is targeted to be less than 0.4%. Meanwhile, the average damage index of the structure is targeted to be reduced as much as 25% and 35% for earthquakes with scheme Y and scheme X, respectively. Y and X represent the dominant earthquake direction corresponding to the building. For a comparable comparison between the methods, the number of the dampers on all method is determined to be 44 dampers.

Considered Structure

An existing hotel located in Mataram is chosen to be studied. This five-story building has 14 meters height and 62.3 meters by 15.5 meters floor plan dimension resulting in span-to-depth ratio larger than 3.0 which requires semi-rigid floor assumption to obtain accurate building deformation [1]. The floor plan of the typical 1st to 3rd floor, 4th floor, and roof floor can be seen in Figures 2, 3 and 4, respectively.

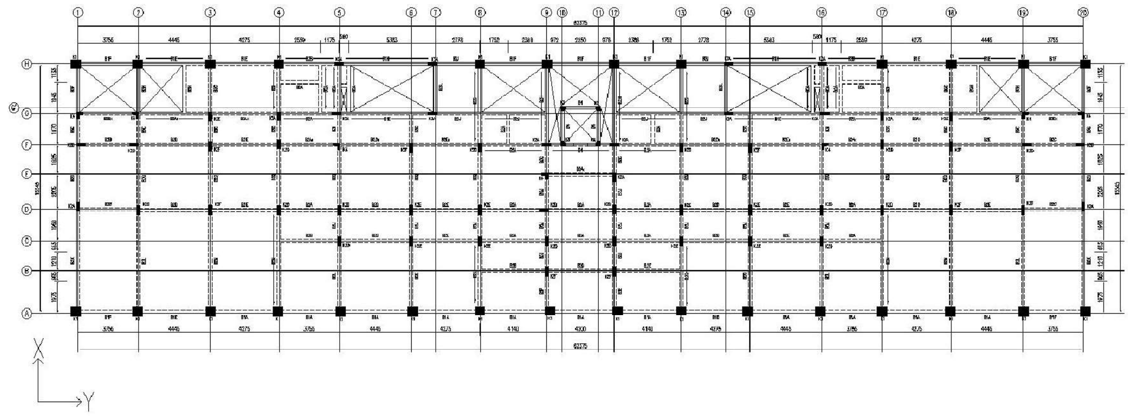

Figure 2. Typical Floor Plan (1st floor – 3rd floor)

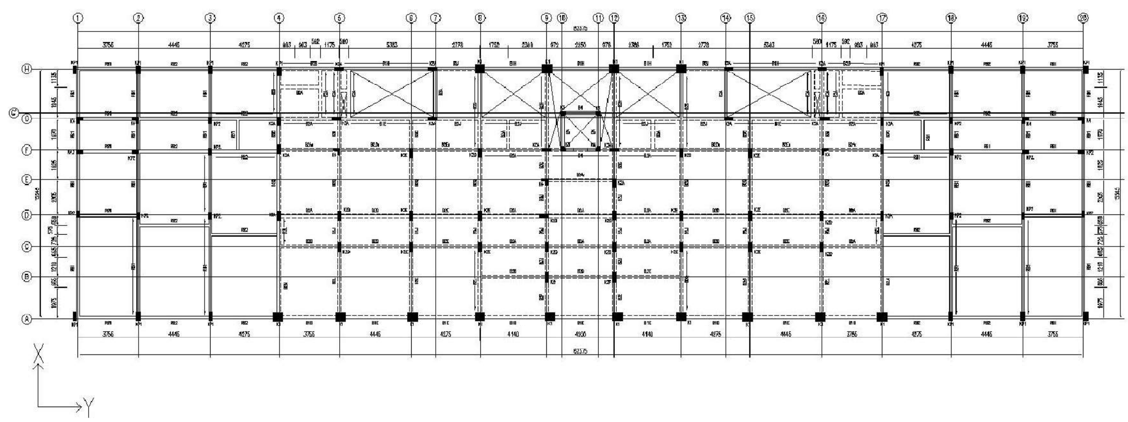

Figure 3.Floor Plan of the 4th floor

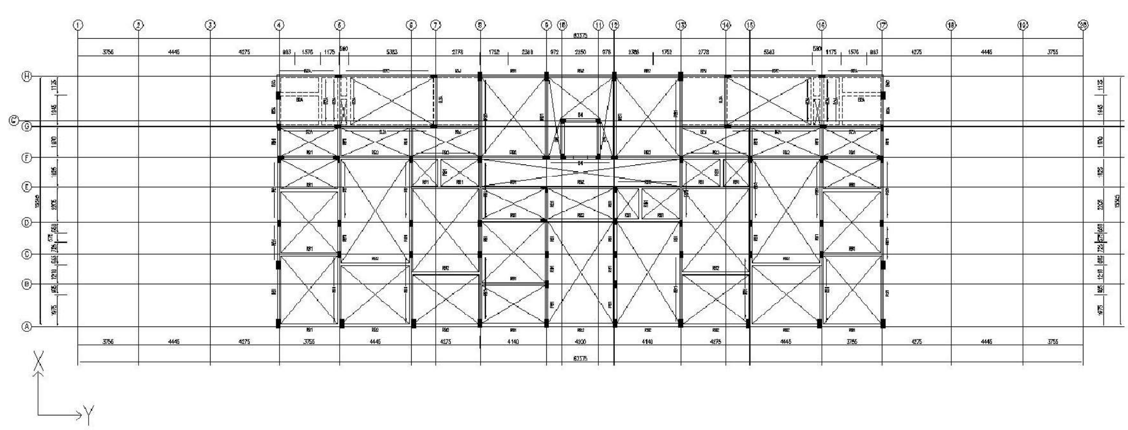

Figure 4 Floor Plan of the roof floor

Modelling of the Structure and Analysis

Computer software SAP2000 [11] is used to model the existing structure, as shown in Figure 5. The auto-hinge feature of SAP2000 is used to determine the non-linear hinges properties of all beams and columns.

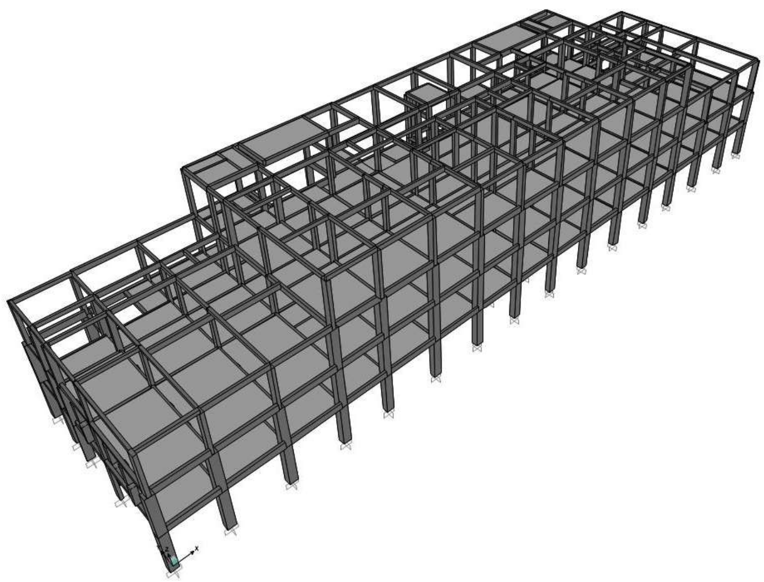

Figure 5. Modeling of Existing Building in SAP2000

The ground-motions records used for the analysis are The Imperial Valley earthquake (recorded at El Centro station, May 19^{th,} 1940) obtained from the Pacific Earthquake Engineering Research (PEER). These Ground-motions are matched to Mataram's Maximum Considered Earthquake (MCE) response spectrum. MCE is a 2500-year return period earthquake and is 1.5 times greater than the Elastic Design Earthquake (EDE), which is required by SNI 1726:2012 for designing an earthquake-resistant structure. Imperial Valley's PGA in East-West (EW) and North-South (NS) direction is 0.21 g and 0.281 g, respectively, which can be seen in Figure 6. To maintain the PGA ratio of the Imperial Valley earthquake in both directions, the original NS and EW ground accelerations are matched to 100% and 70% of Mataram's MCE, respectively.

The modified ground acceleration can be seen in Figure 7. In this study, spectrum consistent EW and NS ground motions are subjected to the building twice. First, the NS and EW component is applied in the Y and X-axis of the building, respectively. Then the directions of the two components are switched to ensure the most severe case is analyzed in both orthogonal directions.

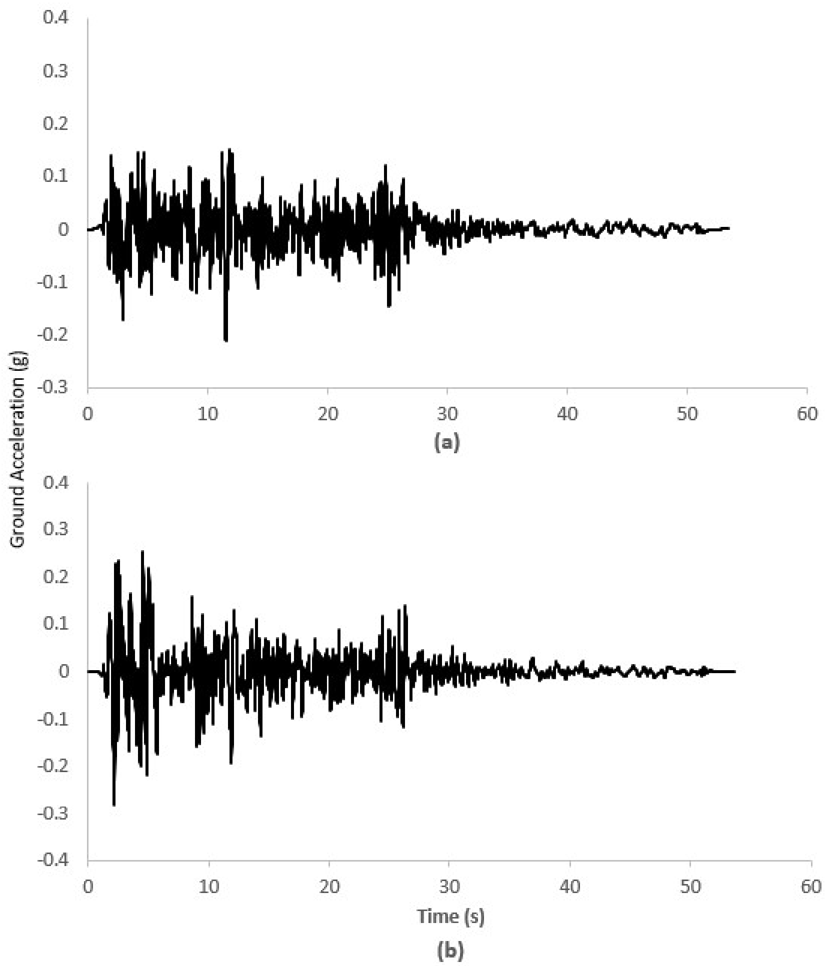

Figure 6. Imperial Valley Earthquake ground accelerations: (a) EW Component; (b) NS Component

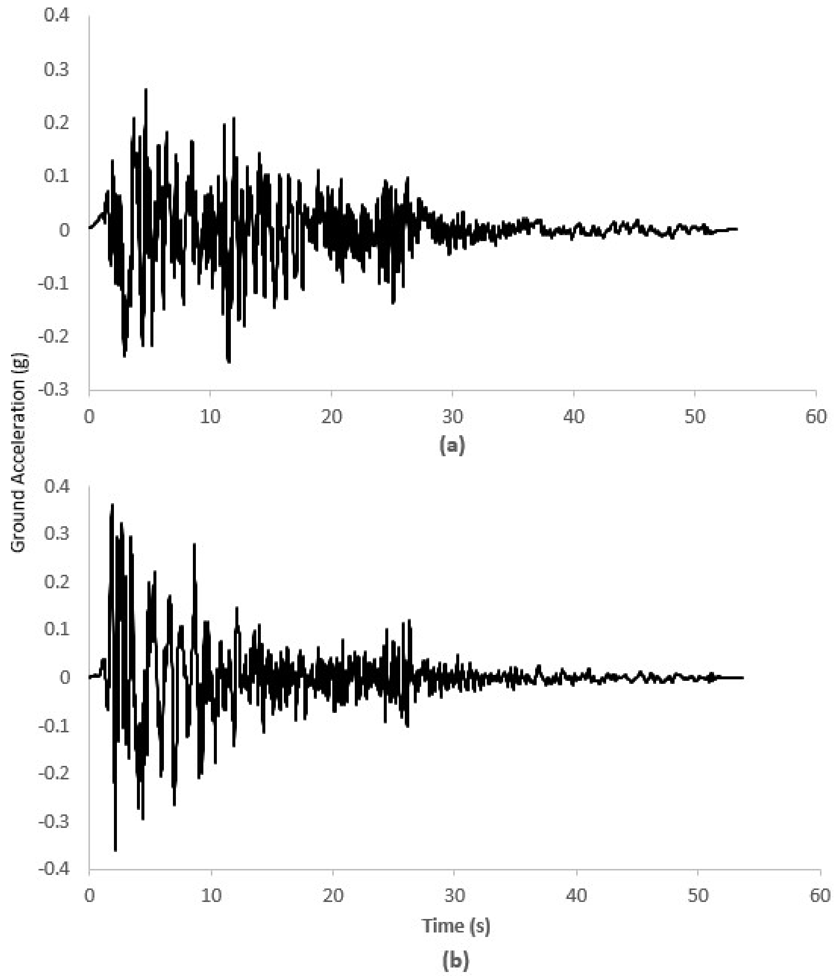

Figure 7.Modified Imperial Valley Earthquake ground accelerations: (a) EW Component; (b) NS Component

VSL Gensui Damper is modelled as non-linear link property with plastic wen type. There are several parameters that need to be calculated, which are effective stiffness, effective damping stiffness, yield strength, and post-yield stiffness ratio. The parameters can be obtained by using several chart sand equations [12].

Analysis Result

Structural performance can be determined from the story drift and damage index of the plastic hinges in the structure. Asia Concrete Model Code (ACMC) 2001 is used to determine the damage index classification of the plastic hinges [13]. The states of plastic hinge damages are Immediate Occupancy (IO), Life Safety (LS), Collapse Prevention (CP), and beyond CP, which correspond to damage index values of 0-10%, 10%-25%, 25%-40%, and 40%-100%, respectively. In this study, to give a brief idea of overall damage of the structural elements, the damage indices are averaged. Mid-range values of each damage states are used, which correspond to 5%, 17.5%, 32.5%, and 70% for damages below IO, between IO and LS, between LS and CP, and beyond CP, respectively. Figures 8 to 11 present the drifts of the structure with 44 dampers with MSSSA and ODAM placement strategies as well the 0.4% story drift ratio target of each floor used in this study (DR 0.4%). In these figures, drifts of original structure (bare) and structure with 44 dampers distributed in all stories of selected frames (uniform) are also shown as comparison. Labels "X" and "Y" indicate the direction of dominant NS earthquake component. Figure 8 and 9 shows drifts of structure with rigid (R) floor assumption due to dominant ground motion in the X and Y directions, respectively. Figures 10 and 11 show drifts of structure with semi-rigid (SR) floor assumption due to dominant ground motion in the X and Y directions, respectively. MSSSA and ODAM indicate the damper placement method used, while uniform and bare indicate the initial step of the ODAM method and original structure without any dampers installed, respectively. In Figures 8 to 11, "DR 0.4%" represents the 0.4% story drift ratio target of each floor used in this study.

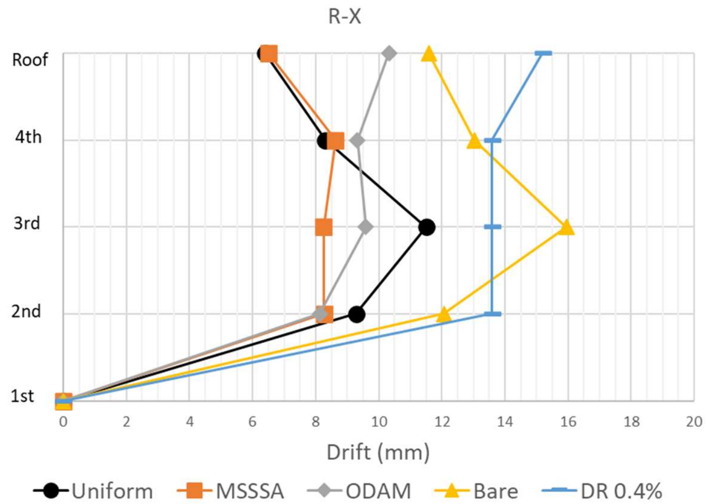

Figure 8.Drift in the X direction of the structure for R-X case

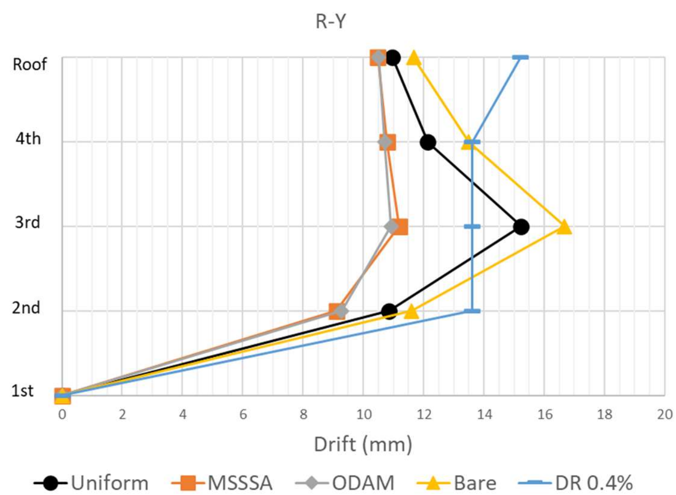

Figure 9. Drift in the Y direction of the structure for R-Y case

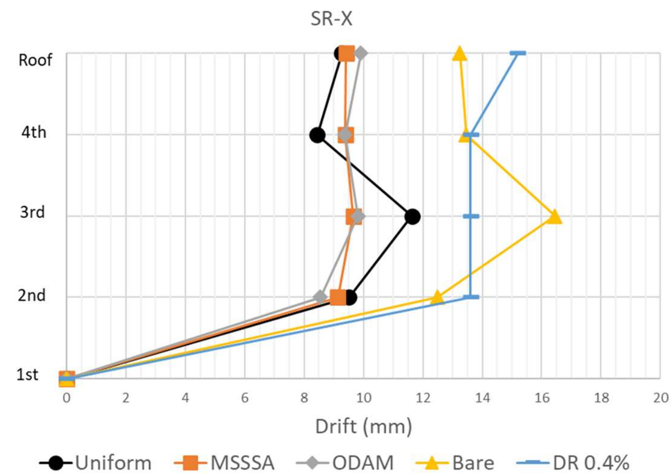

Figure 10. Drift in the X direction of the structure for SR-X case

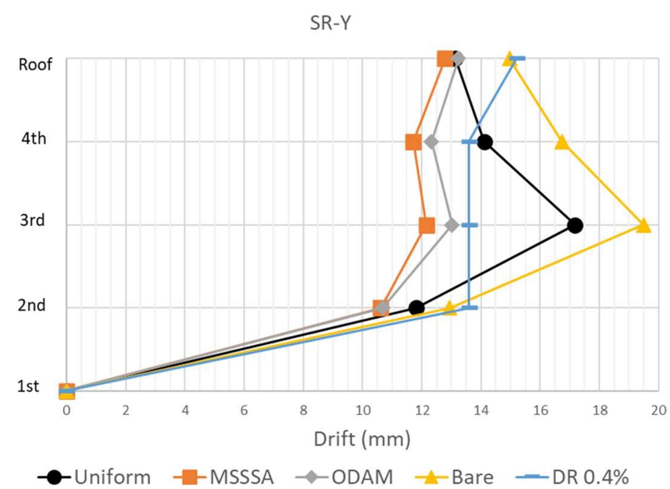

Figure 11. Drift in the Y direction of the structure for SR-Y case

For cases using semi-rigid floor assumption (Figures 10 and 11), the plotted drifts are the maximum drift values among all frames of the structure. It can be seen from the figures that the building with application of VSL Gensui damper have better performance against the original building. In ODAM and MSSSA methods, the drift of the structures can be reduced below the target. Despite using the same number of dampers, in SR-Y and R-Y cases, building with uniformly distributed dampers in all stories fails to reach the target. The final placement of dampers in each placement methods is presented in Figures 12 to 22, where the marks **O** and **X** indicate damper positions by using MSSSA and ODAM placement, respectively. In Figures 12 to 22, the dampers are always installed parallel to the marked frames. While the number of dampers installed on each floor can be seen on the caption of the figures shown.

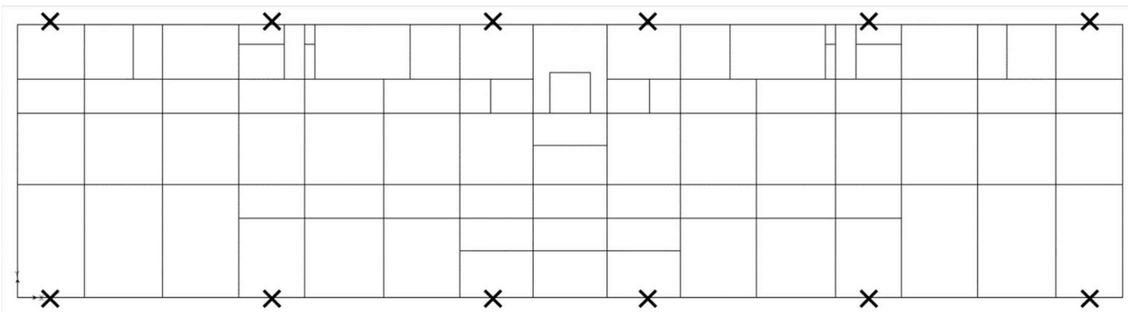

Figure 12.Damper Placement at 2nd floor (R-X); ODAM: 12 dampers

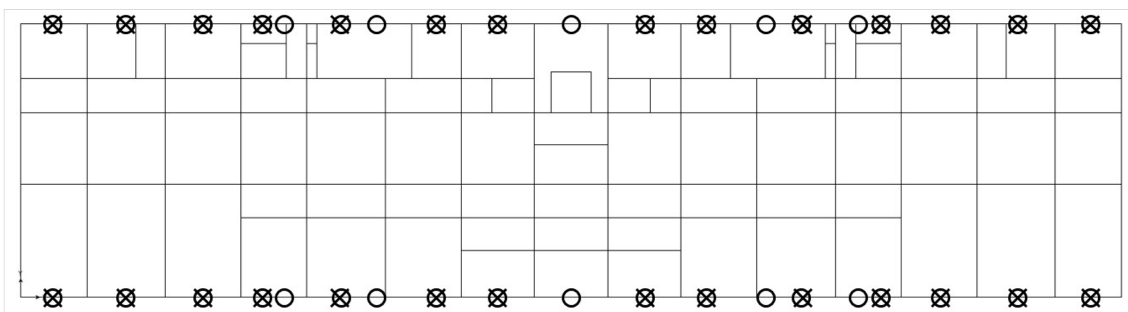

Figure 13.Damper Placement at 3rd floor (R-X); MSSSA: 38 dampers;

ODAM: 28 dampers

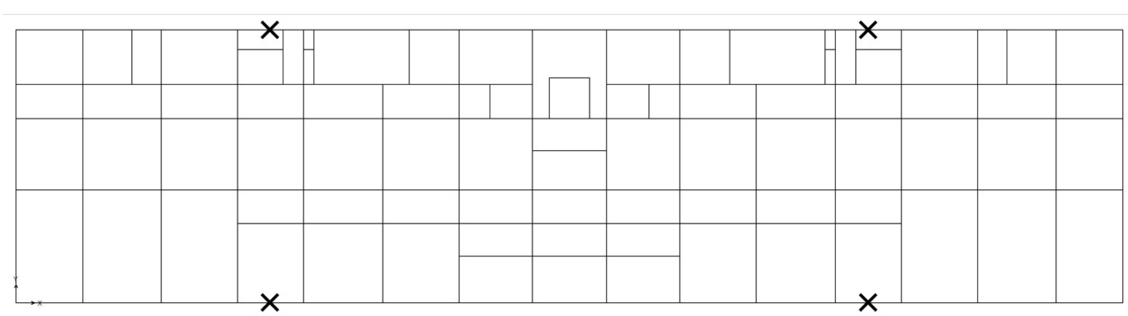

Figure 14.Damper Placement at 4th floor (R-X); ODAM: 4 dampers

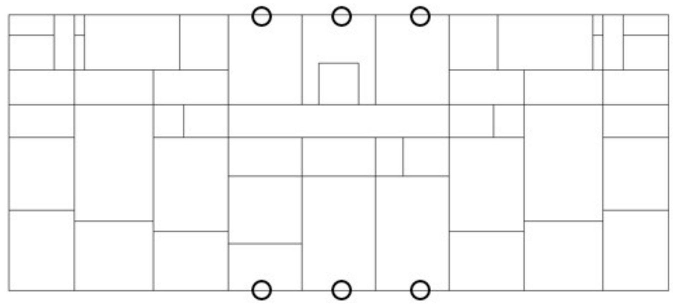

Figure 15.Damper Placement at roof floor (R-X); MSSSA: 6 dampers

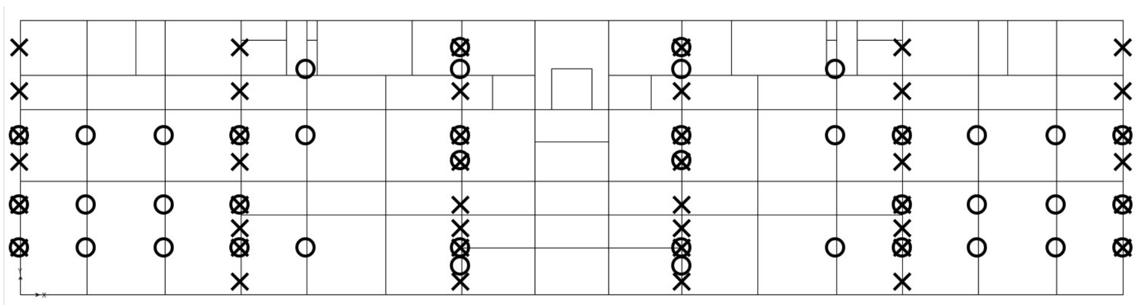

Figure 16. Damper Placement at 3rd floor (R-Y); MSSSA: 44 dampers;

ODAM: 44 dampers

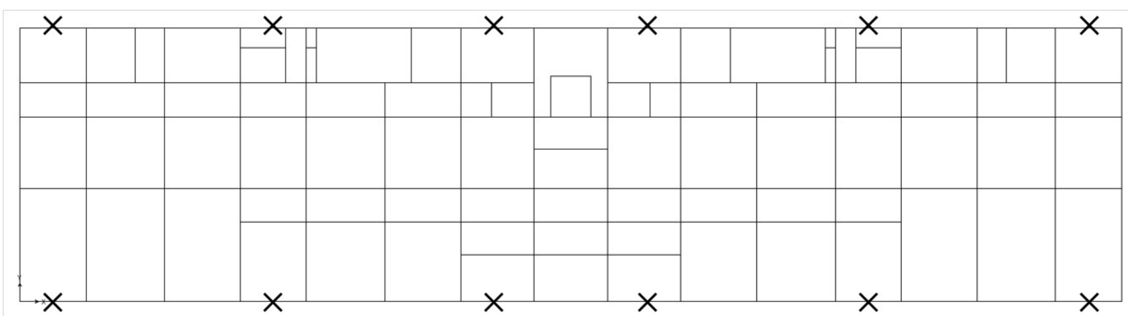

Figure 17.Damper Placement at 2nd floor (SR-X); ODAM: 12 dampers

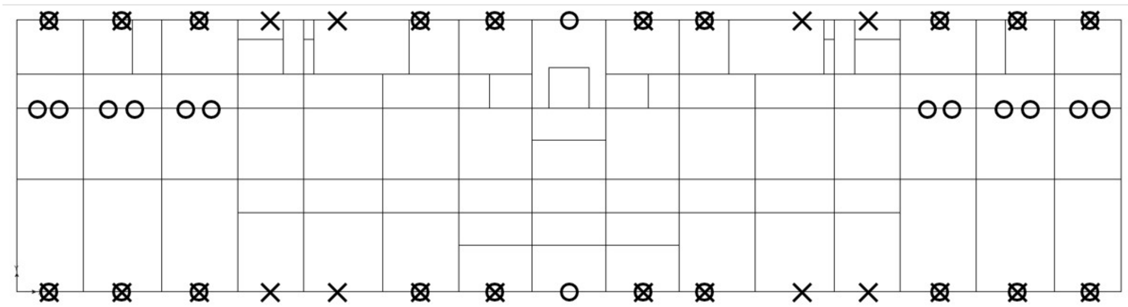

Figure 18.Damper Placement at 3rd floor (SR-X); MSSSA: 34 dampers;

ODAM: 28 dampers

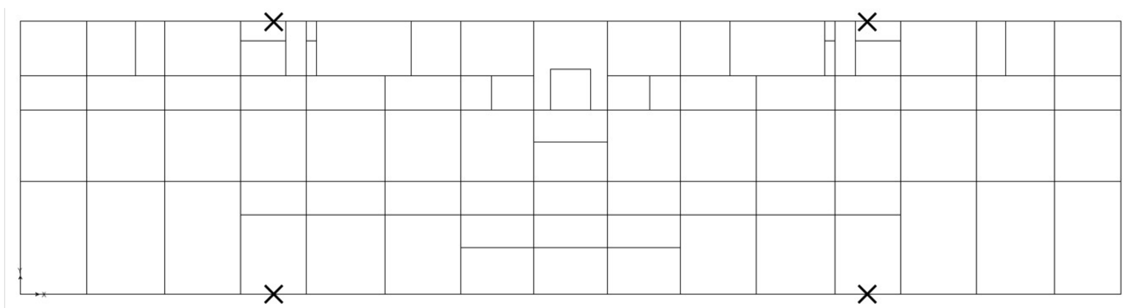

Figure 19.Damper Placement at 4th floor (SR-X); ODAM: 4 dampers

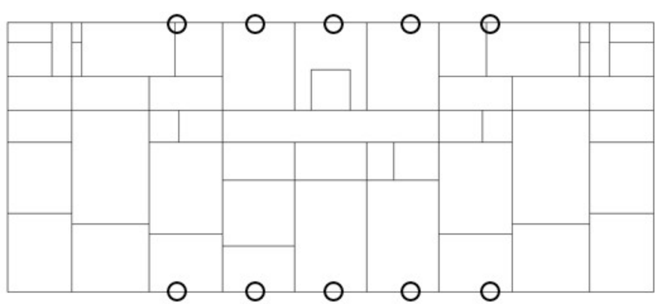

Figure 20.Damper Placement at roof floor (SR-X); MSSSA: 10 dampers

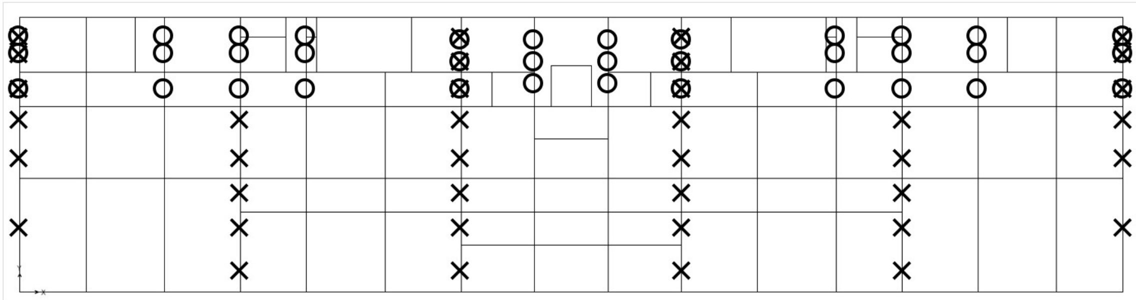

Figure 21.Damper Placement at 3rd floor (SR-Y); MSSSA: 36 dampers; ODAM: 38 dampers

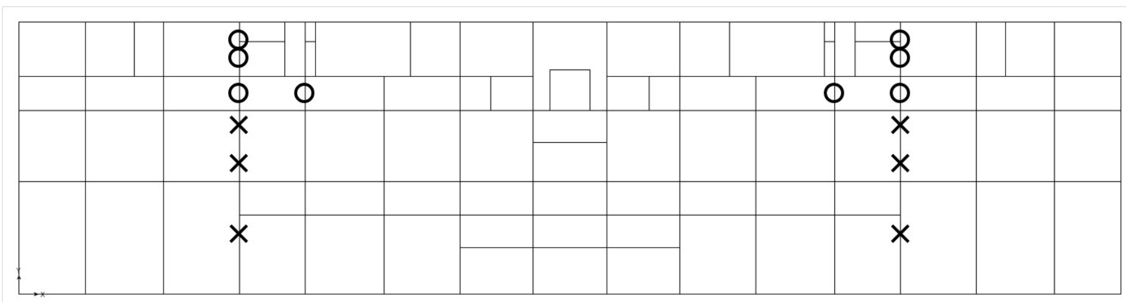

Figure 22.Damper Placement at 4th floor (SR-Y); MSSSA: 8 dampers; ODAM: 6 dampers

It can be seen in Figure 12, Figure 14, Figure 17, and Figure 19, that there are no dampers placed for MSSSA strategic placement, because there is always larger drift on floor other than 2nd and 4th floors in every step of damper addition. However, some dampers may still exist on those floors for ODAM method since dampers are installed on each floor in its initial placement.

Table 1. Plastic Hinges (R-X)

Plastic Hinges (B-IO)

	Bare				Uniform				MSSSA				ODAM			
Step	Beam	Column	Total	DI	Beam	Column	Total	DI	Beam	Column	Total	DI	Beam	Column	Total	DI
Bare	155	46	201	0.480%												
1					84	35	119	0.284%	72	41	113	0.270%	[redacted]			
2									63	36	99	0.236%	83	31	114	0.272%
3									58	33	91	0.217%	79	30	109	0.260%
4									60	35	95	0.227%	77	29	106	0.253%
5									63	32	95	0.227%	71	30	101	0.241%
							Improvement % :	40.80%			Improvement % :	52.74%			Improvement % :	49.75%

Table 2. Plastic Hinges (R-Y)

Plastic Hinges (B-IO)

	Bare				Uniform				MSSSA				ODAM			
Step	Beam	Column	Total	DI	Beam	Column	Total	DI	Beam	Column	Total	DI	Beam	Column	Total	DI
Bare	155	44	199	0.475%												
1					126	40	166	0.396%	150	44	194	0.463%	[redacted]			
2									142	40	182	0.435%	116	39	155	0.370%
3									137	40	177	0.423%	110	38	148	0.353%
4									127	40	167	0.399%	85	39	124	0.296%
5									122	39	161	0.384%	87	40	127	0.303%
6									113	39	152	0.363%	84	39	123	0.294%
7									88	38	126	0.301%	76	39	115	0.275%
							Improvement % :	16.58%			Improvement % :	36.68%			Improvement % :	42.21%

Table 3. Plastic Hinges (SR-X)

Plastic Hinges (B-IO)

	Bare				Uniform				MSSSA				ODAM			
Step	Beam	Column	Total	DI	Beam	Column	Total	DI	Beam	Column	Total	DI	Beam	Column	Total	DI
Bare	266	47	313	0.747%												
1					160	35	195	0.466%	171	41	212	0.506%	[redacted]			
2									160	36	196	0.468%	168	32	200	0.478%
3									166	37	203	0.485%	162	31	193	0.461%
4									160	35	195	0.466%	163	29	192	0.458%
5									156	36	192	0.458%	153	30	183	0.437%
6													165	33	198	0.473%
							Improvement % :	37.70%			Improvement % :	38.66%			Improvement % :	36.74%

Table 4. Plastic Hinges (SR-Y)

Plastic Hinges (B-IO)

	Bare				Uniform				MSSSA				ODAM			
Step	Beam	Column	Total	DI	Beam	Column	Total	DI	Beam	Column	Total	DI	Beam	Column	Total	DI
Bare	244	44	288	0.688%												
1					201	40	241	0.575%	235	45	280	0.669%	[redacted]			
2									228	49	277	0.661%	192	39	231	0.552%
3									220	46	266	0.635%	185	39	224	0.535%
4									217	60	277	0.661%	131	52	183	0.437%
5									216	41	257	0.614%	157	40	197	0.470%
6									188	40	228	0.544%	156	39	195	0.466%
7									172	40	212	0.506%	154	38	192	0.458%
8									173	42	215	0.513%				
						Improvement % :		16.32%		Improvement % :		25.35%		Improvement % :		33.33%

The damage severity of the plastic hinges is presented in Tables 1 to 4. In the tables, only B-IO hinges are displayed because there is no more severe hinge state than B-IO. In total, there are 2094 points of potential non-linear hinges assigned in the structure. More severe damages of structures using semi-rigid floor assumption are observed if compared to structures using rigid floor assumption indicated by increase of plastic damages. Due to dominant earthquake in Y direction, the total number of plastic damages increases from 199 to 288, 166 to 241, 126 to 215, and 115 to 192 in the case of bare, uniformly distributed dampers, MSSSA, and ODAM models, respectively (see Tables 2 and 4). This fact is also true in the case with dominant earthquake in X direction (see Tables 1 and 3). Tables 1 to 4 also show that application of dampers clearly reduces damages of the structure. For example, in the case of SR-Y (Table 4), the number of plastic hinges decreases from 288 in bare model to 215 and 192, in MSSSA and ODAM, respectively. However, at certain steps, the number of plastic hinges may increase, especially in ODAM, because the dampers are not added but moved among stories of the building. Uniformly distributed dampers do not reduce the damage as effective as both placement methods, as there are still 241 total plastic damages. It can be seen is earthquake scheme Y, where the deformations are still relatively large, ODAM and MSSA methods show much better performance compared to the structure with uniformly distributed dampers.

In this structure, there are significant differences from the results with semi-rigid and rigid floor assumption analysis. It is obvious that in a relatively large horizontal span dimension compared to its perpendicular, the concrete slab may not be rigid enough to simulate rigid body movement of the whole floor diaphragm. The results of the analysis with the semi-rigid model produce more severe drifts compared to that of the rigid floor model. The drift of frames in the same story may differ significantly in semi-rigid floor assumption, which is not the case in rigid floor assumption. The drift of frames information is very useful to determine damper placement throughout the study.

Conclusion

In this study, the effort to improve the seismic performance of a structure is conducted by installing VSL Gensui Dampers. The analyzed building has a large diaphragm span to depth ratio that it should use semi-rigid floor assumption. From non-linear time history analysis results, some conclusion can be made as follows:

1. More extreme story drifts are observed in structure analyzed by using semi-rigid floor assumption in the direction perpendicular to a larger floor plan dimension. This assumption is imperative since different drift of frames in the same story can be obtained. This is important for strategic damper placement in the floor plan since drifts are used as placement indicator. Story drifts in the direction of larger floor plan dimension obtained from either rigid or semi-rigid floor assumptions show in-significant differences.

2. In this study, the MSSSA damper placement method shows the most consistent performance in reducing the story drifts as well as element damages. Even though the final result of damper placement is similar, the ODAM placement method has its limitation compared to MSSSA method that number of dampers used must be determined in the beginning, and dampers can only be swapped among stories of initially chosen frames.

3. Both MSSSA and ODAM damper placement methods can improve the structure damage index and drift to meet the targeted performance.

4. Despite using the same number of dampers as in MSSSA and ODAM methods, uniform damper placement is less effective in improving the seismic performance of the structure.

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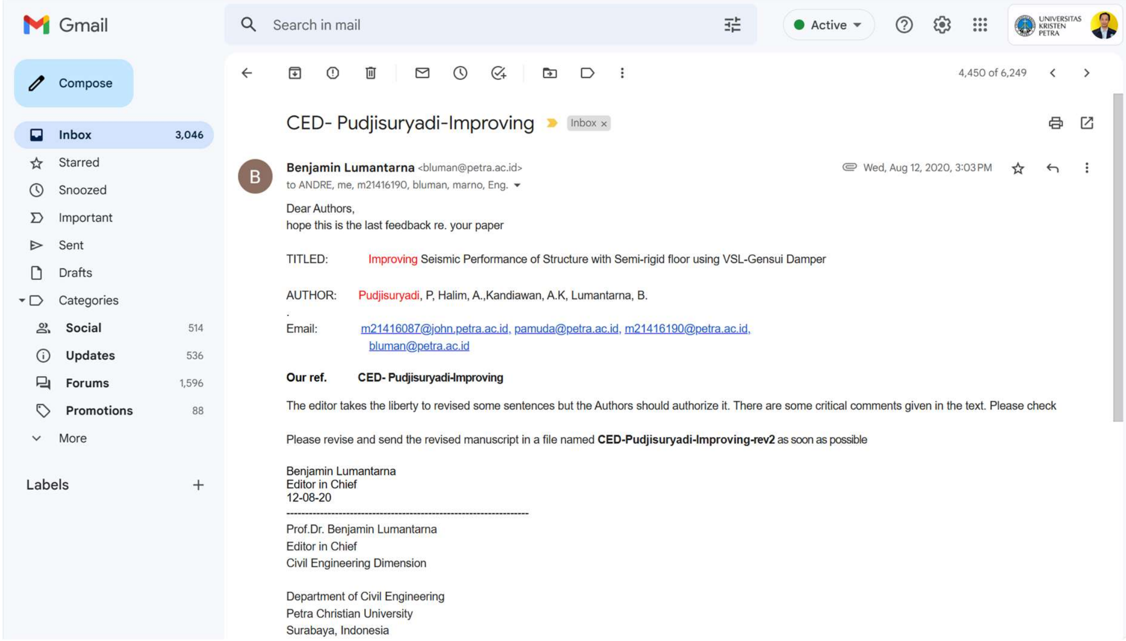

CED- Pudjisuryadi-Improving

Benjamin Lumantarna <bluman@petra.ac.id>
to ANDRE, me, m21416190, bluman, marno, Eng.
Wed, Aug 12, 2020, 3:03 PM

Dear Authors,
hope this is the last feedback re. your paper

TITLED: Improving Seismic Performance of Structure with Semi-rigid floor using VSL-Gensui Damper

AUTHOR: Pudjisuryadi, P, Halim, A.,Kandiawan, A.K, Lumantarna, B.

Email: m21416087@john.petra.ac.id, pamuda@petra.ac.id, m21416190@petra.ac.id, bluman@petra.ac.id

Our ref. **CED- Pudjisuryadi-Improving**

The editor takes the liberty to revised some sentences but the Authors should authorize it. There are some critical comments given in the text. Please check

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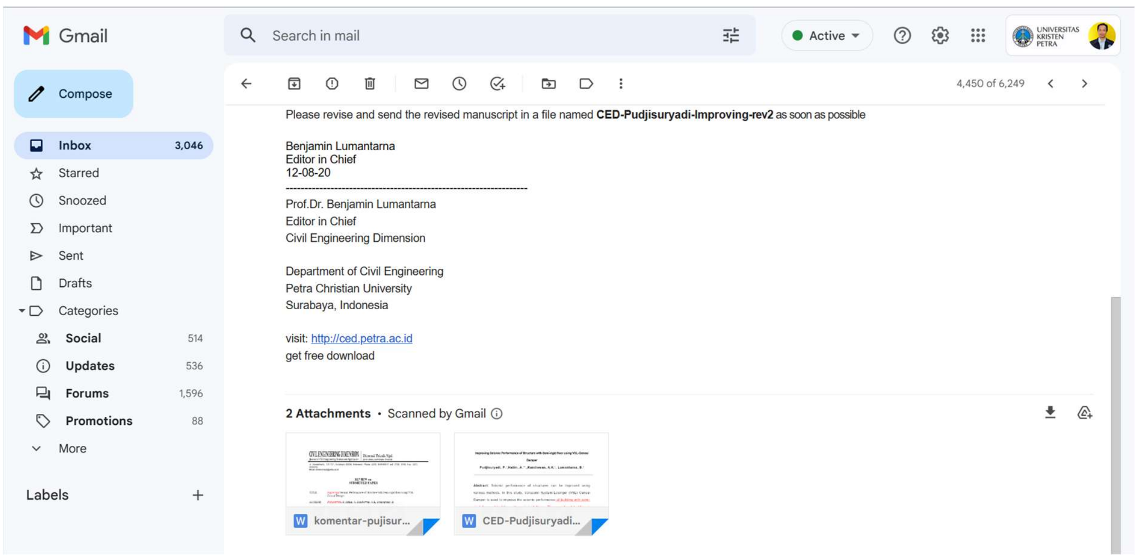

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REVIEW on
SUBMITTED PAPER

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AUTHOR: Pudjisuryadi, P, Halim, A.,Kandiawan, A.K, Lumantarna, B.
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Editor in Chief
12-08-20

Improving Seismic Performance of Structure with Semi-rigid floor using VSL-Gensui Damper

Pudjisuryadi, P.[1], Halim, A.[1]*., Kandiawan, A.K.[1], Lumantarna, B.[1]

Abstract: Seismic performance of structures can be improved using various methods. In this study, Vorspann System Losinger (VSL) Gensui Damper is used to improve the seismic performance of building with semi-rigid floors~~ of building with semi-rigid floors. The considered building is subjected to~~. S~~s~~pectrum consistent ground accelerations is generated from El Centro May 19th, 1940 earthquake per SNI 1726:2012 for Mataram, West Timor, Indonesia~~ City~~. Modified Simplified Sequential Search Algorithm (MSSSA) and Optimum Damper Allocation Method (ODAM) ~~methods~~ are used to efficiently place the dampers on the building to meet~~until~~ certain ~~criteria are met.~~criteria. Uniform placement which is used as the first step of ODAM is used for comparison. The Results show that both~~by using either of the~~ methods can effectively reduce structural drifts and damages. MSSSA shows slightly better performance since ODAM has a limitation that dampers can only be swapped among stories of the initially chosen frames. It is also~~should be~~ noted that the dampers must be well distributed among frames in the same story, to take care the different drifts ~~since~~in building with semi-rigid floors.~~ their drifts may differ significantly in building with semi-rigid floors.~~

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Keywords:Drift; damper placement method; Non-Linear Time History Analysis;_semi-rigid floors; strengthening; VSL Gensui damper.

Introduction

In seismically active countries such as Indonesia, consideration of earthquake load in building design is imperative. Indonesia has SNI 1726:2012 [1],_as its guidelines for designing ~~building~~ structures to withstand earthquake load. In conjunction with structural codes such as concrete design code (SNI 2847:2013) [2] and steel design code (SNI 1729:2015), the Indonesian Seismic Code (SNI 1726:2012) should be used to ensure buildings capability to withstand earthquakes.

One of the most common criteria that are not accurately assumed is floor rigidity. In SNI 1726:2012, there is a clause which states "Diaphragms of concrete slabs or concrete filled metal deck with span-to-depth ratios of 3 or less in structures that have no horizontal irregularities are permitted to be idealized as rigid" [1,3]. However, in buildings with concrete slabs, rigid floor diaphragm is usually assumed regardless of the large diaphragm span-to-depth ratio. This may cause inaccurate story drifts in the building model [4].

In the effort of improving the seismic performance of existing structures, many techniques can be used, and one of them is by installing dampers. Damper is an energy dissipation system that can be installed in a structure. The use of energy dissipation systems for an earthquake-resistant structure is useful for improving the seismic performance of a structure [5,6]. In this study, a type of damper produced by Vorspann System Losinger (VSL), namely VSL Gensui Damper, is used to improve the seismic performance of an elongated structure. VSL Gensui Damper is a wall type viscoelastic damper that consists of ~~a~~ multilayers of rubber and steel that has 400x400x15mm in dimension (Figure 1~~Figure 1~~). To maximize the benefit of using dampers while still paying good attention to the cost induced, strategic placement of dampers is a must.

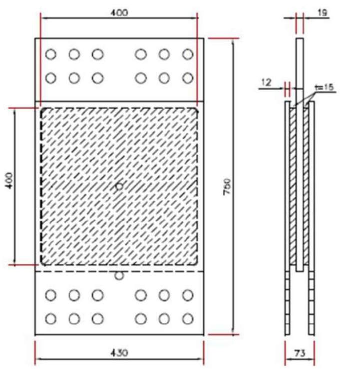

Figure 1. VSL-Gensui Damper

Strategic Placement of ~~the~~ dampers

Two damper placement strategies are used in this study. As the first strategy, Simplified Sequential Search Algorithm (SSSA) [7] is adopted. The~~In this study,~~ proposed modification of SSSA by Angkasaputra and Sebastiano [8] is used, i~~.~~n which~~T~~ the original damper placement indicator of SSSA is modified by only using story drift and neglecting story velocity. H~~, and h~~ereafter the modification is called as Modified Simplified Sequential Search Algorithm (MSSSA). The second strategy used is Optimum Damper Allocation Method (ODAM) [9]~~ is used for the second strategy~~. The uniform damper placement which is the initial step of the ODAM method is used ~~Common uniform placement of damper in all stories of selected frames is also conducted~~ for comparison against the previous two methods.~~ This uniform damper placement happens to be the initial step of the ODAM method~~. In a previous research ~~by~~ Andini and Goenawan [10], studied the two methods ~~were studied~~ on a simple structure and concluded that both ODAM and MSSSA are effective in reducing interstory drift.

In ODAM, the total number of dampers used is decided at the beginning, and typically the dampers are placed at every story of selected frames. Then the dampers in the story with minimum drift will be moved to the floor with maximum drift. This process is repeated until certain acceptance criteria are met, or the last two damper relocations indicate swaps between the same two stories. In the MSSSA method, each damper addition is placed at the story with the largest drift in the selected frames. The damper addition is stopped when certain acceptance criteria are met. In this study, the maximum story drift ratio of the structure is targeted to be less than 0.4%. Meanwhile, the average damage index of the structure is targeted to be reduced as much as 25% and 35% for earthquakes with scheme Y and scheme X, respectively. Y and X represent the dominant earthquake direction corresponding to the building. For a comparable comparison between the methods, the number of the dampers on all method is determined to be 44 dampers.

Commented [B1]: Since you have this target. It is only fair to mention how many dampers needed by MSSRA to achieve this target both in X and Y scheme, while ODAM could not reduce the number of dampers assigned by uniform placement.

Considered Structure

An existing hotel located in Mataram, West Timor, Indonesia, is chosen to be studied. This five-story building has 14 meters height and 62.3 meters by 15.5 meters floor plan dimension resulting in span-to-depth ratio larger than 3.0 which requires semi-rigid floor assumption to obtain accurate building deformation [1]. The floor plan of the typical 1^{st} to 3^{rd} floor, 4^{th} floor, and roof floor can be seen in Figures 2, 3, and 4, respectively.

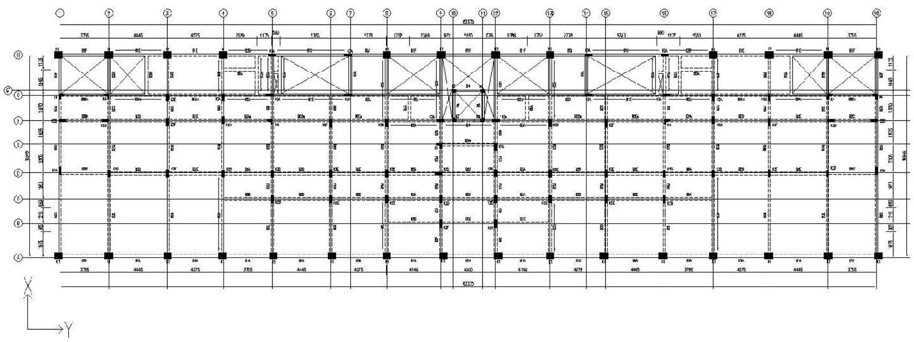

Figure 2. Typical Floor Plan (1st floor – 3rd floor)

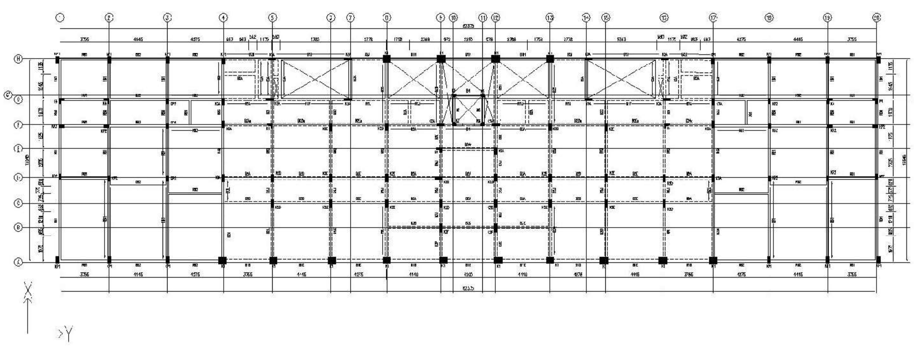

Figure 3.Floor Plan of the 4th floor

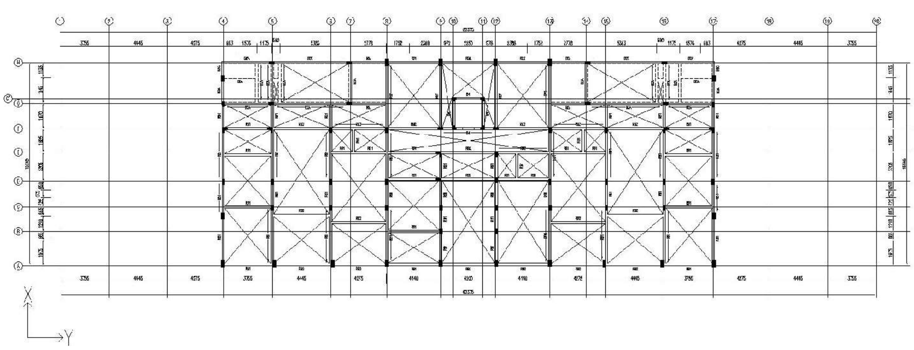

Figure 4 Floor Plan of the roof floor

Modelling of the Structure and Analysis

Computer software SAP2000 [11] is used to model the existing structure, as shown in Figure 5~~Figure 5~~. The auto-hinge feature of SAP2000 is used to determine the non-linear hinges properties of all beams and columns.

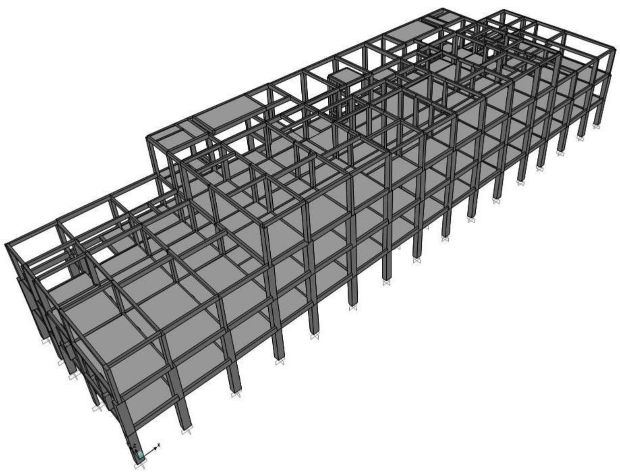

Figure 5. Modeling of Existing Building in SAP2000

The ground-motions records used for the analysis are The Imperial Valley earthquake,~~(~~ recorded at El Centro station, May $19^{th,}$ 1940,~~)~~ obtained from the Pacific Earthquake Engineering Research (PEER). These Ground-motions are matched to Mataram's Maximum Considered Earthquake (MCE) response spectrum. MCE is a 2500-year return period earthquake and is 1.5 times greater than the Elastic Design Earthquake (EDE), which is required by SNI 1726:2012 for designing an earthquake-resistant structure. Imperial Valley's PGA in East-West (EW) and North-South (NS) direction is 0.21 g and 0.281 g, respectively, which can be seen in Figure 6~~Figure 6~~. To maintain the PGA ratio of the Imperial Valley earthquake in both directions, the original NS and EW ground accelerations are matched to 100% and 70% of

Mataram's MCE, respectively. The modified ground acceleration can be seen in Figure 7~~Figure 7~~. In this study, spectrum consistent EW and NS ground motions are subjected to the building twice. First, the NS and EW component is applied in the Y and X-axis of the building, respectively. Then the directions of the two components are switched to ensure the most severe case is analyzed in both orthogonal directions.

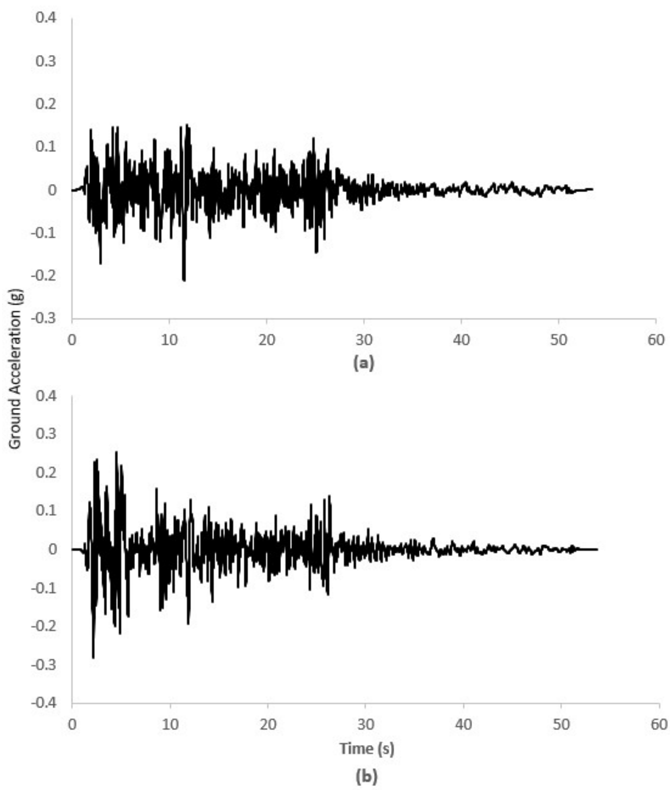

Figure 6. Imperial Valley Earthquake ground accelerations: (a) EW Component; (b) NS Component

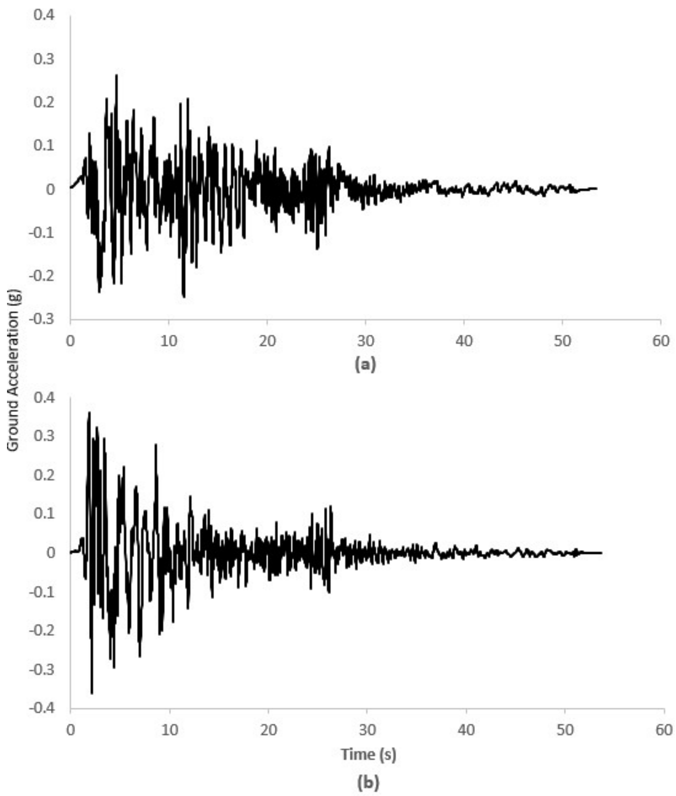

Figure 7.Modified Imperial Valley Earthquake ground accelerations: (a) EW Component; (b) NS Component

VSL Gensui Damper is ~~modelled~~modeled as non-linear link property with plastic wen type. There are several parameters that need to be calculated, which are effective stiffness, effective damping stiffness, yield strength, and post-yield stiffness ratio. The parameters can be obtained by using several charts and equations [12].

Analysis Result

Structural performance can be determined from the story drift and damage index of the plastic hinges in the structure. Asian Concrete Model Code (ACMC) 2001 is used to determine the damage index classification of the plastic hinges [13]. The states of plastic hinge damages are Immediate Occupancy (IO), Life Safety (LS), Collapse Prevention (CP), and beyond CP, which correspond to damage index values of 0-10%, 10%-25%, 25%-40%, and 40%-100%, respectively. In this study, to give a brief idea of overall damage of the structural elements, the damage indices are averaged. Mid-range values of each damage states are used, which correspond to 5%, 17.5%, 32.5%, and 70% for damages below IO, between IO and LS, between LS and CP, and beyond CP, respectively. Figures 8 to 11 present the drifts of the structure with 44 dampers with MSSSA and ODAM placement strategies as well the 0.4% story drift ratio target of each floor used in this study (DR 0.4%). In these figures, drifts of original structure (bare) and structure with 44 dampers distributed in all stories of selected frames (uniform) are also shown as comparison. Labels "X" and "Y" indicate the direction of the dominant NS earthquake component. Figure 8~~Figures 8~~ and 9 shows drifts of structure with rigid (R) floor assumption due to dominant ground motion in the X and Y directions, respectively. Figures 10 and 11 show drifts of structure with semi-rigid (SR) floor assumption due to dominant ground motion in the X and Y directions, respectively. MSSSA and ODAM indicate the damper placement method used, while uniform and bare indicate the initial step of the ODAM method and original structure without any dampers installed, respectively. In Figures 8 to 11, "DR 0.4%" represents the 0.4% story drift ratio target of each floor used in this study.

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Commented [B3]: Please note that although a two dimensional earthquake is used. This study consider the structure in the X and Y direction separately.

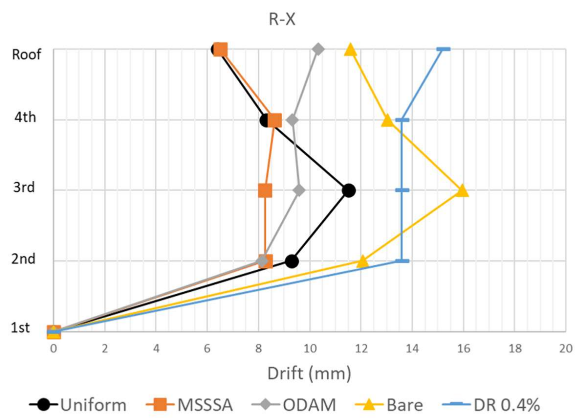

Figure 8.Drift in the X direction of the structure for R-X case

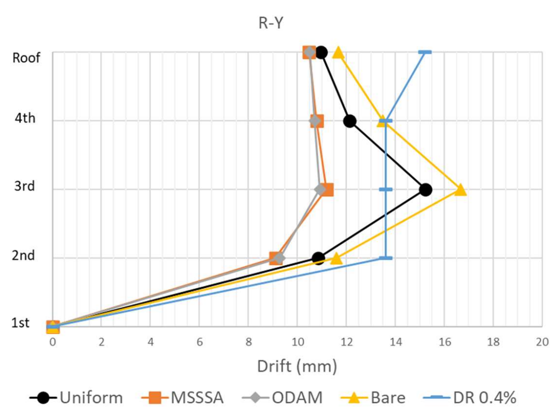

Figure 9. Drift in the Y direction of the structure for R-Y case

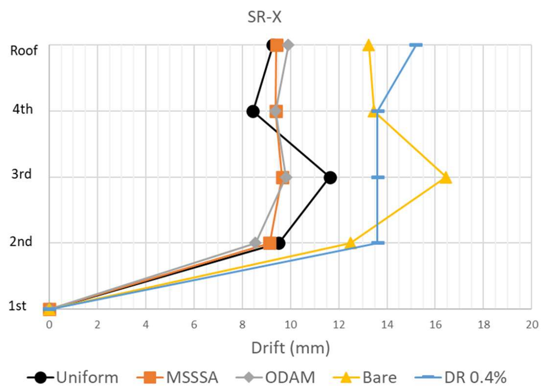

Figure 10. Drift in the X direction of the structure for SR-X case

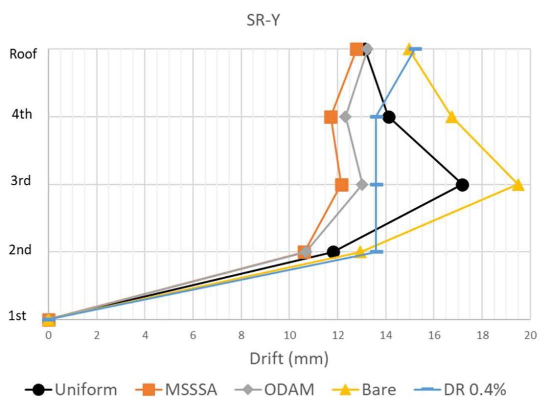

Figure 11. Drift in the Y direction of the structure for SR-Y case

For cases using semi-rigid floor assumption (Figures 10 and 11), the plotted drifts are the maximum drift values among all frames of the structure. It can be seen from the figures that both ODAM and MSSSA succeeded in reducing the drift below the target~~the building with application of VSL Gensui damper have better performance against the original building. In ODAM and MSSSA methods, the drift of the structures can be reduced below the target~~. Despite using the same number of dampers, in SR-Y and R-Y cases, building with uniformly distributed dampers in all stories fails to reach the target. The final placement of dampers in each placement methods is presented in Figures 12 to 22, where the marks **O** and **X** indicate damper positions ~~by~~ using MSSSA and ODAM placement, respectively. In Figures 12 to 22, the dampers are always installed parallel to the marked frames. While the number of dampers installed on each floor can be seen on the caption of the figures shown.

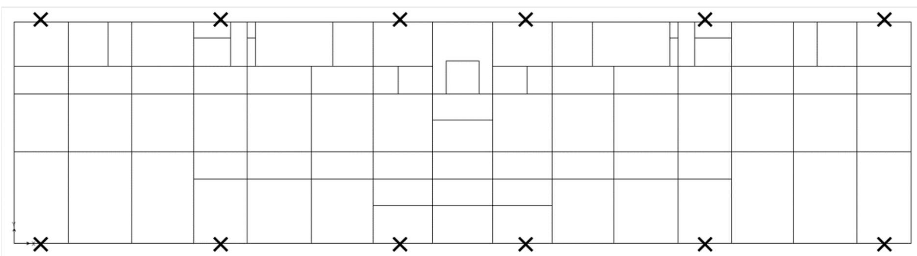

Figure 12.Damper Placement at 2nd floor (R-X); MSSSA; 0 damper, ODAM: 12 dampers

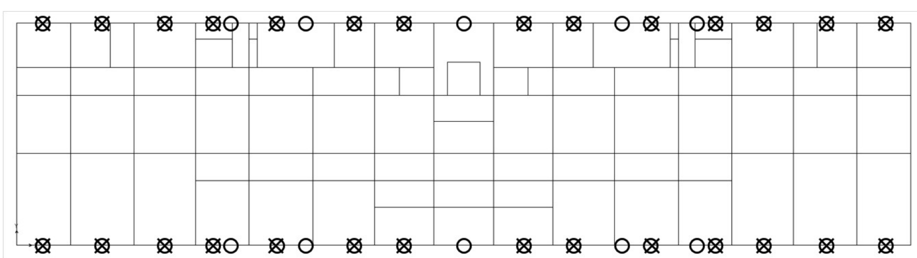

Figure 13.Damper Placement at 3rd floor (R-X); MSSSA: 38 dampers; ODAM: 28 dampers

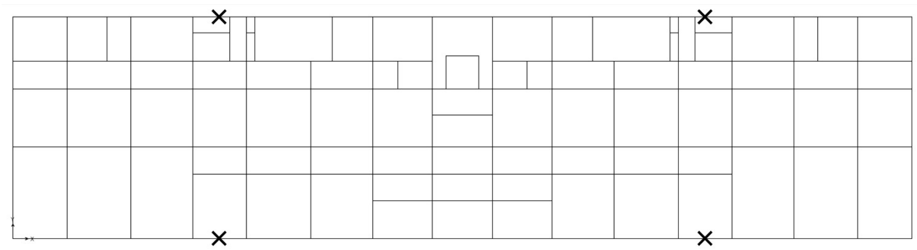

Figure 14.Damper Placement at 4th floor (R-X); MSSSA; 0 damper, ODAM: 4 dampers

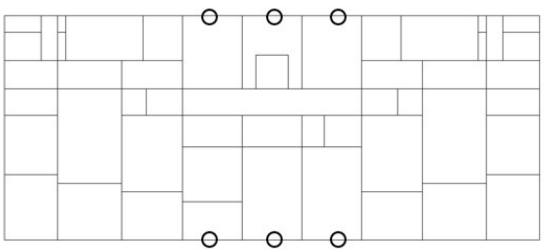

Figure 15.Damper Placement at roof floor (R-X); MSSSA: 6 dampers, ODAM: 0 damper

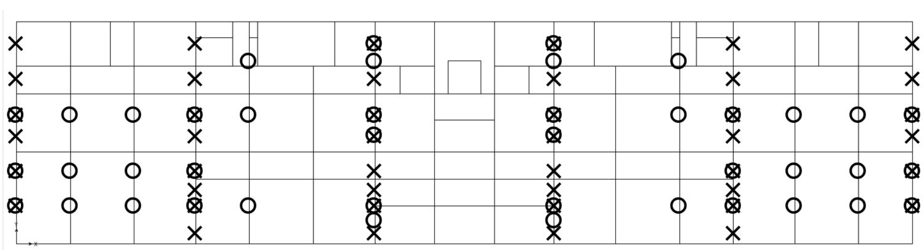

Figure 16. Damper Placement at 3rd floor (R-Y); MSSSA: 44 dampers; ODAM: 44 dampers

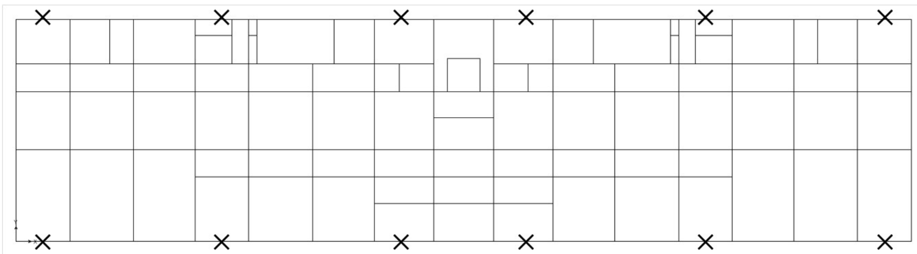

Figure 17.Damper Placement at 2nd floor (SR-X); ODAM: 12 dampers

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Revised others

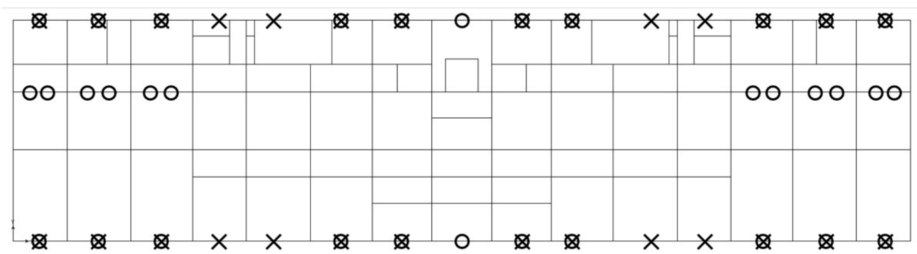

Figure 18.Damper Placement at 3rd floor (SR-X); MSSSA: 34 dampers; ODAM: 28 dampers

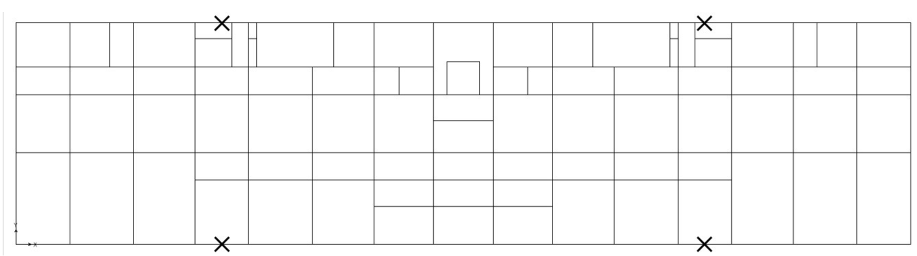

Figure 19.Damper Placement at 4th floor (SR-X); ODAM: 4 dampers

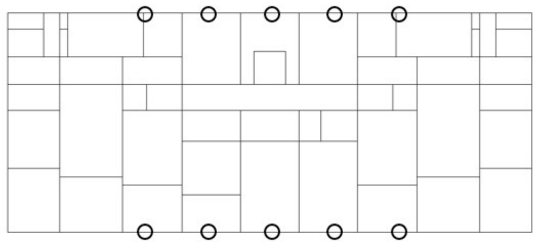

Figure 20.Damper Placement at roof floor (SR-X); MSSSA: 10 dampers

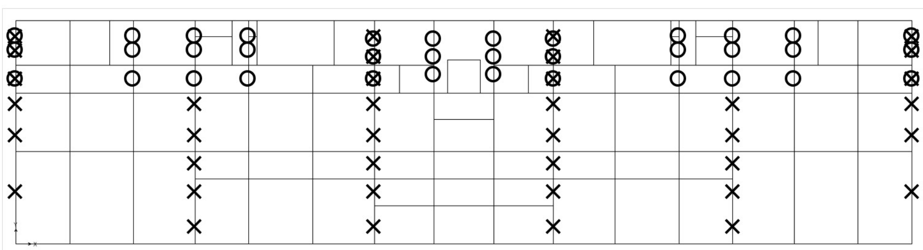

Figure 21.Damper Placement at 3rd floor (SR-Y); MSSSA: 36 dampers;

ODAM: 38 dampers

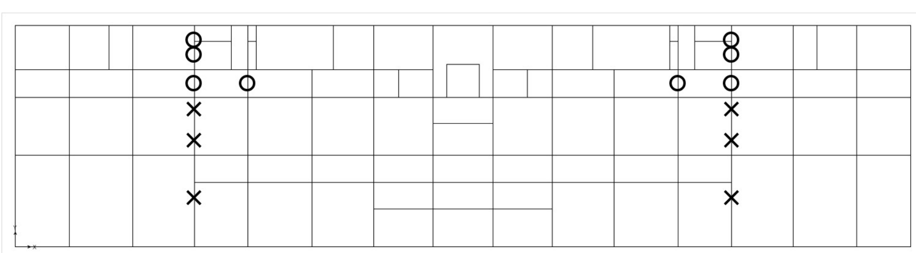

Figure 22.Damper Placement at 4th floor (SR-Y); MSSSA: 8 dampers;

ODAM: 6 dampers

It can be seen in Figure 12~~Figures 12~~, Figure 14~~14~~, Figure 17~~17~~, and Figure 19~~19~~, that there are no dampers placed for MSSSA strategic placement, because there is always larger drift on floor other than 2nd and 4th floors in every step of damper addition. However, some dampers may still exist on those floors for ODAM method since dampers are installed on each floor in its initial placement.

Table 1. Plastic Hinges (R-X)

Plastic Hinges (B-IO)																
	Bare				Uniform				MSSSA				ODAM			
Step	Beam	Column	Total	DI	Beam	Column	Total	DI	Beam	Column	Total	DI	Beam	Column	Total	DI
Bare	155	46	201	0.480%												
1					84	35	119	0.284%	72	41	113	0.270%	[redacted]			
2									63	36	99	0.236%	83	31	114	0.272%
3									58	33	91	0.217%	79	30	109	0.260%
4									60	35	95	0.227%	77	29	106	0.253%
5									63	32	95	0.227%	71	30	101	0.241%
							Improvement % :	40.80%			Improvement % :	52.74%			Improvement % :	49.75%

Table 2. Plastic Hinges (R-Y)

Plastic Hinges (B-IO)																
	Bare				Uniform				MSSSA				ODAM			
Step	Beam	Column	Total	DI	Beam	Column	Total	DI	Beam	Column	Total	DI	Beam	Column	Total	DI
Bare	155	44	199	0.475%												
1					126	40	166	0.396%	150	44	194	0.463%	[redacted]			
2									142	40	182	0.435%	116	39	155	0.370%
3									137	40	177	0.423%	110	38	148	0.353%
4									127	40	167	0.399%	85	39	124	0.296%
5									122	39	161	0.384%	87	40	127	0.303%
6									113	39	152	0.363%	84	39	123	0.294%
7									88	38	126	0.301%	76	39	115	0.275%
							Improvement % :	16.58%			Improvement % :	36.68%			Improvement % :	42.21%

Table 3. Plastic Hinges (SR-X)

Plastic Hinges (B-IO)																
	Bare				Uniform				MSSSA				ODAM			
Step	Beam	Column	Total	DI	Beam	Column	Total	DI	Beam	Column	Total	DI	Beam	Column	Total	DI
Bare	266	47	313	0.747%												
1					160	35	195	0.466%	171	41	212	0.506%	[redacted]			
2									160	36	196	0.468%	168	32	200	0.478%
3									166	37	203	0.485%	162	31	193	0.461%
4									160	35	195	0.466%	163	29	192	0.458%
5									156	36	192	0.458%	153	30	183	0.437%
6													165	33	198	0.473%
							Improvement % :	37.70%			Improvement % :	38.66%			Improvement % :	36.74%

Table 4. Plastic Hinges (SR-Y)

Plastic Hinges (B-IO)

	Bare				Uniform				MSSSA				ODAM			
Step	Beam	Column	Total	DI	Beam	Column	Total	DI	Beam	Column	Total	DI	Beam	Column	Total	DI
Bare	244	44	288	0.688%												
1					201	40	241	0.575%	235	45	280	0.669%	[redacted]			
2									228	49	277	0.661%	192	39	231	0.552%
3									220	46	266	0.635%	185	39	224	0.535%
4									217	60	277	0.661%	131	52	183	0.437%
5									216	41	257	0.614%	157	40	197	0.470%
6									188	40	228	0.544%	156	39	195	0.466%
7									172	40	212	0.506%	154	38	192	0.458%
8									173	42	215	0.513%				
						Improvement % :		16.32%		Improvement % :		25.35%		Improvement % :		33.33%

The damage severity of the plastic hinges is presented in Tables 1 to 4. In the tables, only B-IO hinges are displayed because there is no more severe hinge state than B-IO. In total, there are 2094 points of potential non-linear hinges assigned in the structure. More severe damages of structures using semi-rigid floor assumption are observed if compared to structures using rigid floor assumption indicated by increase of plastic damages. Due to dominant earthquake in Y direction, the total number of plastic damages increases from 199 to 288, 166 to 241, 126 to 215, and 115 to 192 in the case of bare, uniformly distributed dampers, MSSSA, and ODAM models, respectively (see Tables 2 and 4). This fact is also true in the case with dominant earthquake in X direction (see Tables 1 and 3). Tables 1 to 4 also show that application of dampers clearly reduces damages of the structure. For example, in the case of SR-Y (Table 4~~Table 4~~), the number of plastic hinges decreases from 288 in bare model to 215 and 192, in MSSSA and ODAM, respectively. However, at certain steps, the number of plastic hinges may increase, especially in ODAM, because the dampers are not added but moved among stories of the building. Uniformly distributed dampers do not reduce the damage as effective as both placement methods, as there are still 241 total plastic damages. It can be seen is earthquake scheme Y, where the deformations are still relatively large, ODAM and MSSA methods show much better performance compared to the structure with uniformly distributed dampers.

In this structure, there are significant differences from the results with semi-rigid and rigid floor assumption analysis. It is obvious that in a relatively large horizontal span dimension compared to its perpendicular, the concrete slab may not be rigid enough to simulate rigid body movement of the whole floor diaphragm. The results of the analysis with the semi-rigid model produce more severe drifts compared to that of the rigid floor model. The drift of frames in the same story may differ significantly in semi-rigid floor assumption, which is not the case in rigid floor assumption. The drift of frames information is very useful to determine damper placement throughout the study.

Conclusion

In this study, the effort to improve the seismic performance of a structure is conducted by installing VSL Gensui Dampers. The floor plan of the ~~analyzed~~ building has a large ~~diaphragm~~ span to depth ratio~~-~~ that it should be analysed as~~use~~ semi-rigid floor. ~~assumption.~~ From non-linear time history analysis results, some conclusion can be made as follows:

1. More extreme story drifts are observed in structure analyzed by using semi-rigid floor assumption in the direction perpendicular to a larger floor plan dimension. This

Commented [B5]: Or “longer”?

assumption is imperative since different drift of frames in the same story can be obtained. This is important for strategic damper placement in the floor plan since drifts are used as placement indicator. Story drifts in the direction of larger floor plan dimension obtained from either rigid or semi-rigid floor assumptions show in-significant differences.

2. In this study, the MSSSA damper placement method shows the most consistent performance in reducing the story drifts as well as element damages. Even though the final result of damper placement is similar, the ODAM placement method has its limitation compared to MSSSA method that number of dampers used must be determined in the beginning, and dampers can only be swapped among stories of initially chosen frames.

Commented [B6]: Mention here how many dampers is needed to obtained the targeted drift using MSSSA

3. Both MSSSA and ODAM damper placement methods can improve the structure damage index and drift to meet the targeted performance.

4. Despite using the same number of dampers as in MSSSA and ODAM methods, uniform damper placement is less effective in improving the seismic performance of the structure.

5

Commented [B7]: Mention that although calculated using two D earthquake. With two sceme the dampers should be superposed.
For EQ in the long direction, maybe you needn't to place 44 dampers in the first place, since unform placement already reduce the drift to the target drift.

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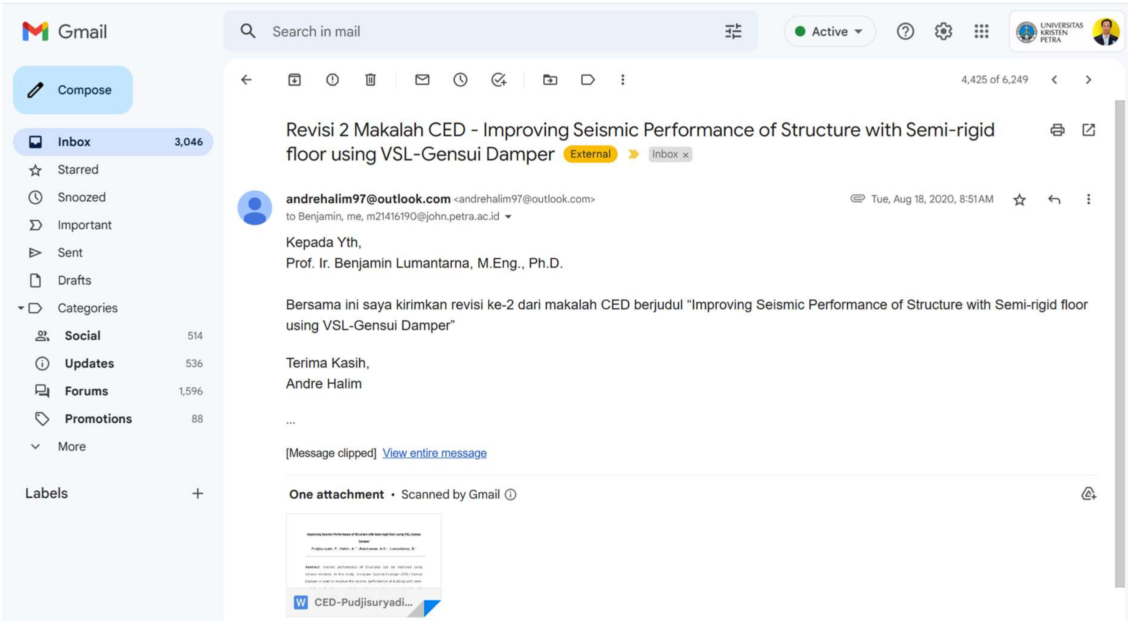

Improving Seismic Performance of Structure with Semi-rigid floor using VSL-Gensui Damper

Pudjisuryadi, P.[1],Halim, A.[1]*.,Kandiawan, A.K.[1], Lumantarna, B.[1]

Abstract: Seismic performance of structures can be improved using various methods. In this study, Vorspann System Losinger (VSL) Gensui Damper is used to improve the seismic performance of building with semi-rigid floors. Spectrum consistent ground accelerations is generated from El Centro May 19th, 1940 earthquake per SNI 1726:2012 for Mataram, West Timor, Indonesia. Modified Simplified Sequential Search Algorithm (MSSSA) and Optimum Damper Allocation Method (ODAM) are used to efficiently place the dampers on the building to meet certain criteria. Uniform placement which is used as the first step of ODAM is used for comparison. The Results show that both methods can effectively reduce structural drifts and damages. MSSSA shows slightly better performance since ODAM has a limitation that dampers can only be swapped among stories of the initially chosen frames. It is also noted that the dampers must be well distributed among frames in the same story, to take care the different drifts in building with semi-rigid floors.

Keywords:Drift; damper placement method; Non-Linear Time History Analysis; semi-rigid floors; strengthening; VSL Gensui damper.

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Introduction

In seismically active countries such as Indonesia, consideration of earthquake load in building design is imperative. Indonesia has SNI 1726:2012 [1], as its guidelines for designing structures to withstand earthquake load. In conjunction with structural codes such as concrete design code (SNI 2847:2013) [2] and steel design code (SNI 1729:2015), the Indonesian Seismic Code (SNI 1726:2012) should be used to ensure buildings capability to withstand earthquakes.

One of the most common criteria that are not accurately assumed is floor rigidity. In SNI 1726:2012, there is a clause which states "Diaphragms of concrete slabs or concrete filled metal deck with span-to-depth ratios of 3 or less in structures that have no horizontal irregularities are permitted to be idealized as rigid" [1,3]. However, in buildings with concrete slabs, rigid floor diaphragm is usually assumed regardless of the large diaphragm span-to-depth ratio. This may cause inaccurate story drifts in the building model [4].

In the effort of improving the seismic performance of existing structures, many techniques can be used, and one of them is by installing dampers. Damper is an energy dissipation system that can be installed in a structure. The use of energy dissipation systems for an earthquake-resistant structure is useful for improving the seismic performance of a structure [5,6]. In this study, a type of damper produced by Vorspann System Losinger (VSL), namely VSL Gensui Damper, is used to improve the seismic performance of an elongated structure. VSL Gensui Damper is a wall type viscoelastic damper that consists of multilayers of rubber and steel that has 400x400x15mm in dimension (Figure 1). To maximize the benefit of using dampers while still paying good attention to the cost induced, strategic placement of dampers is a must.

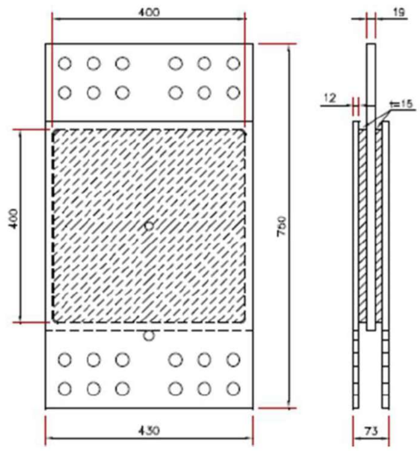

Figure 1. VSL-Gensui Damper

Strategic Placement of dampers

Two damper placement strategies are used in this study. As the first strategy, Simplified Sequential Search Algorithm (SSSA) [7] is adopted. The proposed modification of SSSA by Angkasaputra and Sebastiano [8] is used, in which the original damper placement indicator of SSSA is modified by only using story drift and neglecting story velocity. Hereafter the modification is called as Modified Simplified Sequential Search Algorithm (MSSSA). The second strategy used is Optimum Damper Allocation Method (ODAM) [9]. The uniform damper placement which is the initial step of the ODAM method is used for comparison against the previous two methods. In a previous research Andini and Goenawan [10], studied the two methods on a simple structure and concluded that both ODAM and MSSSA are effective in reducing interstory drift.

In ODAM, the total number of dampers used is decided at the beginning, and typically the dampers are placed at every story of selected frames. Then the dampers in the story with minimum drift will be moved to the floor with maximum drift. This process is repeated until certain acceptance criteria are met, or the last two damper relocations indicate swaps between the same two stories. In the MSSSA method, each damper addition is placed at the story with the largest drift in the selected frames. The damper addition is stopped when certain acceptance criteria are met. In this study, the maximum story drift ratio of the structure is targeted to be less than 0.4%. Meanwhile, the average damage index of the structure is targeted to be reduced as much as 25% and 35% for earthquakes with scheme Y and scheme X, respectively. Y and X represent the dominant earthquake direction corresponding to the building. For a comparable comparison between the methods, the number of the dampers on all method is determined to be 44 dampers and 16 dampers, for schemes Y and X, respectively. However, in some cases it is found that by using the MSSSA method, the number of dampers which is required to meet the targets are less.

Considered Structure

An existing hotel located in Mataram, West Timor, Indonesia, is chosen to be studied. This five-story building has 14 meters height and 62.3 meters by 15.5 meters floor plan dimension resulting in span-to-depth ratio larger than 3.0 which requires semi-rigid floor assumption to obtain accurate building deformation [1]. The floor plan of the typical 1st to 3rd floor, 4th floor, and roof floor can be seen in Figures 2, 3, and 4, respectively.

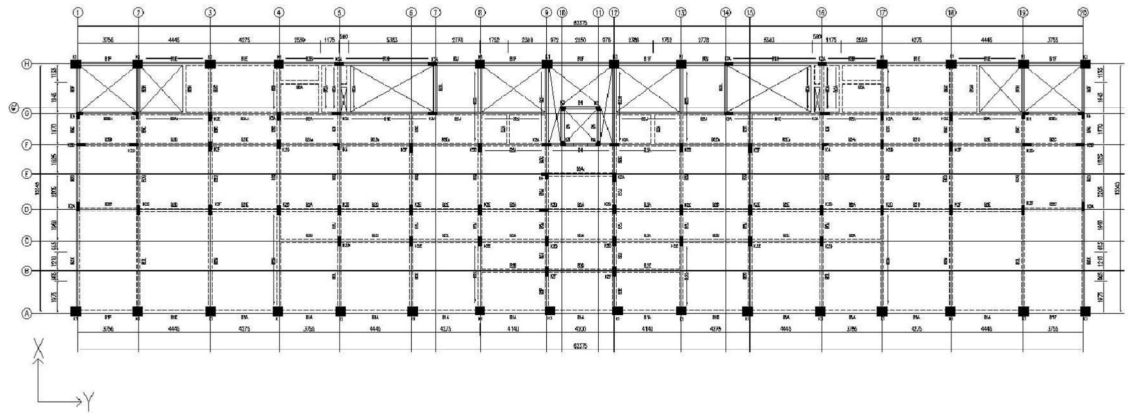

Figure 2. Typical Floor Plan (1st floor – 3rd floor)

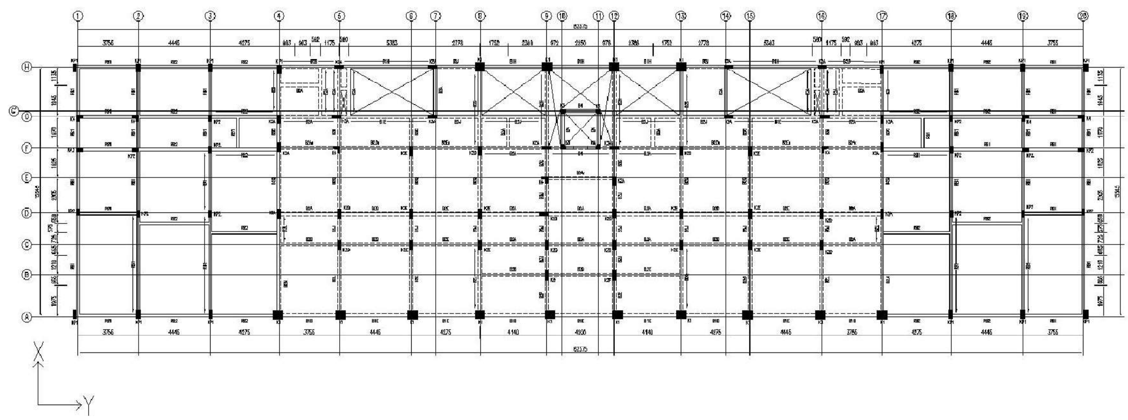

Figure 3.Floor Plan of the 4th floor

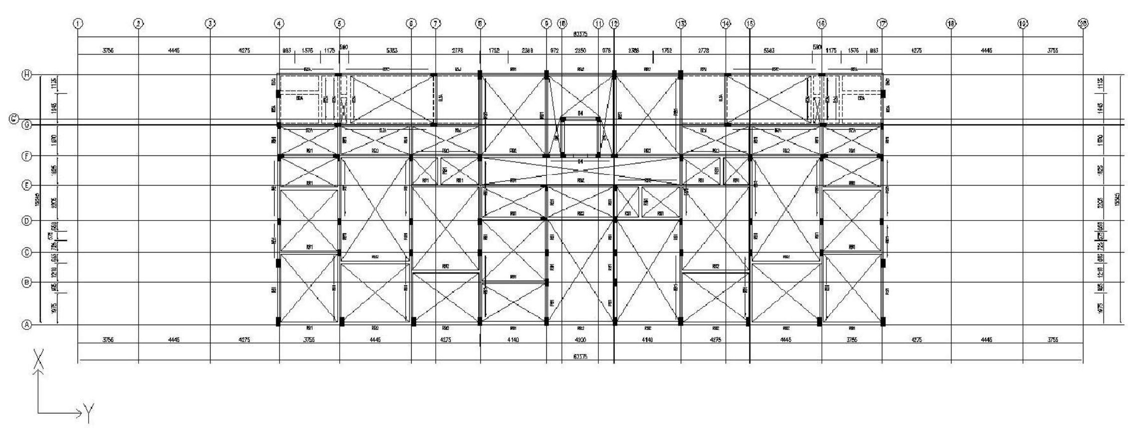

Figure 4 Floor Plan of the roof floor

Modelling of the Structure and Analysis

Computer software SAP2000 [11] is used to model the existing structure, as shown in Figure 5. The auto-hinge feature of SAP2000 is used to determine the non-linear hinges properties of all beams and columns.

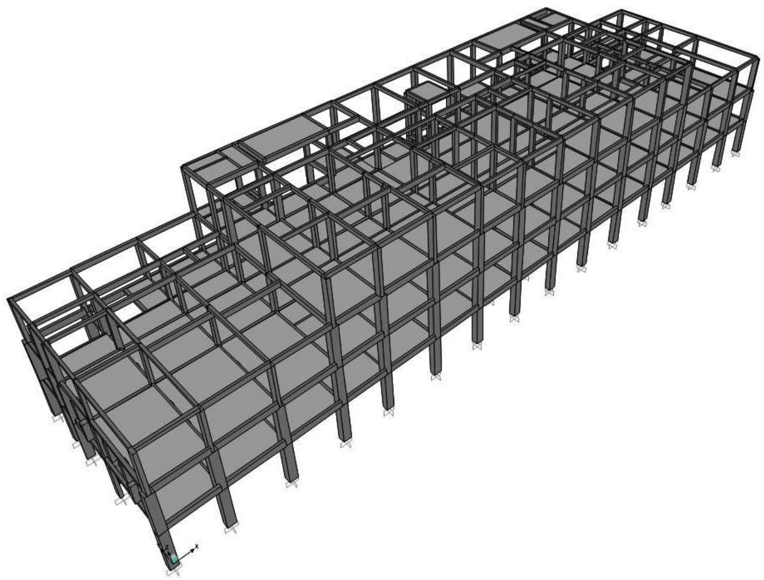

Figure 5. Modeling of Existing Building in SAP2000

The ground-motions records used for the analysis are The Imperial Valley earthquake, recorded at El Centro station, May 19^{th,} 1940, obtained from the Pacific Earthquake Engineering Research (PEER). These Ground-motions are matched to Mataram's Maximum Considered Earthquake (MCE) response spectrum. MCE is a 2500-year return period earthquake and is 1.5 times greater than the Elastic Design Earthquake (EDE), which is required by SNI 1726:2012 for designing an earthquake-resistant structure. Imperial Valley's PGA in East-West (EW) and North-South (NS) direction is 0.21 g and 0.281 g, respectively, which can be seen in Figure 6. To maintain the PGA ratio of the Imperial Valley earthquake in both directions, the original NS and EW ground accelerations are matched to 100% and 70% of Mataram's MCE, respectively.

The modified ground acceleration can be seen in Figure 7. In this study, spectrum consistent EW and NS ground motions are subjected to the building twice. First, the NS and EW component is applied in the Y and X-axis of the building, respectively. Then the directions of the two components are switched to ensure the most severe case is analyzed in both orthogonal directions.

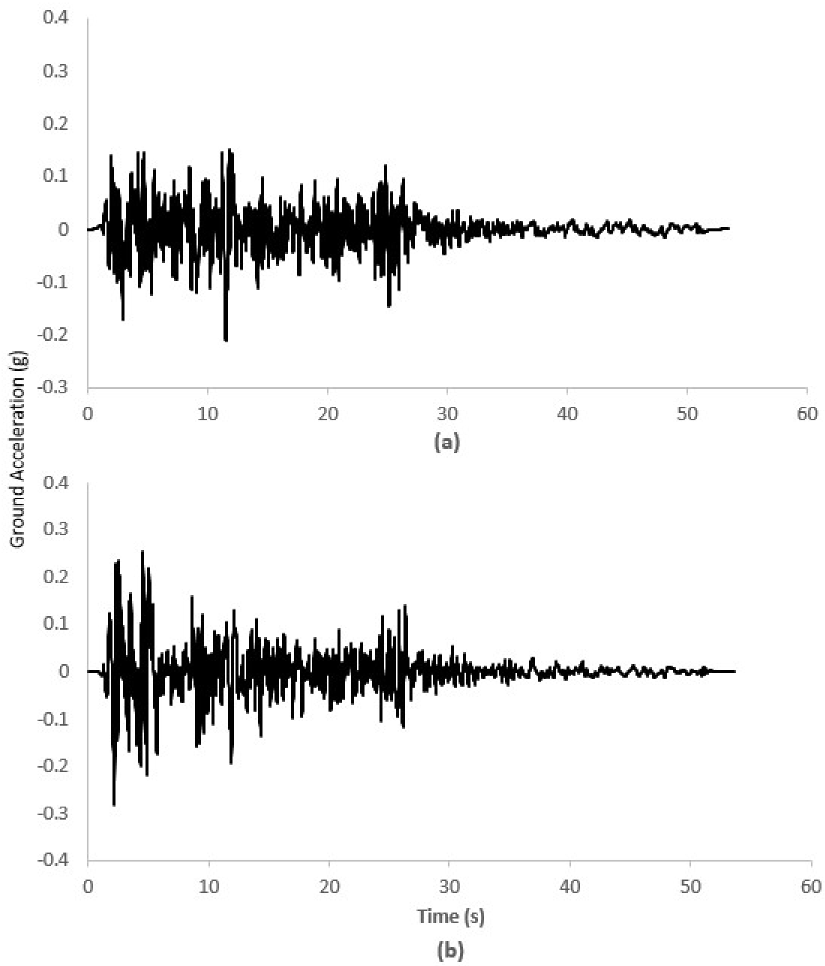

Figure 6. Imperial Valley Earthquake ground accelerations: (a) EW Component; (b) NS Component

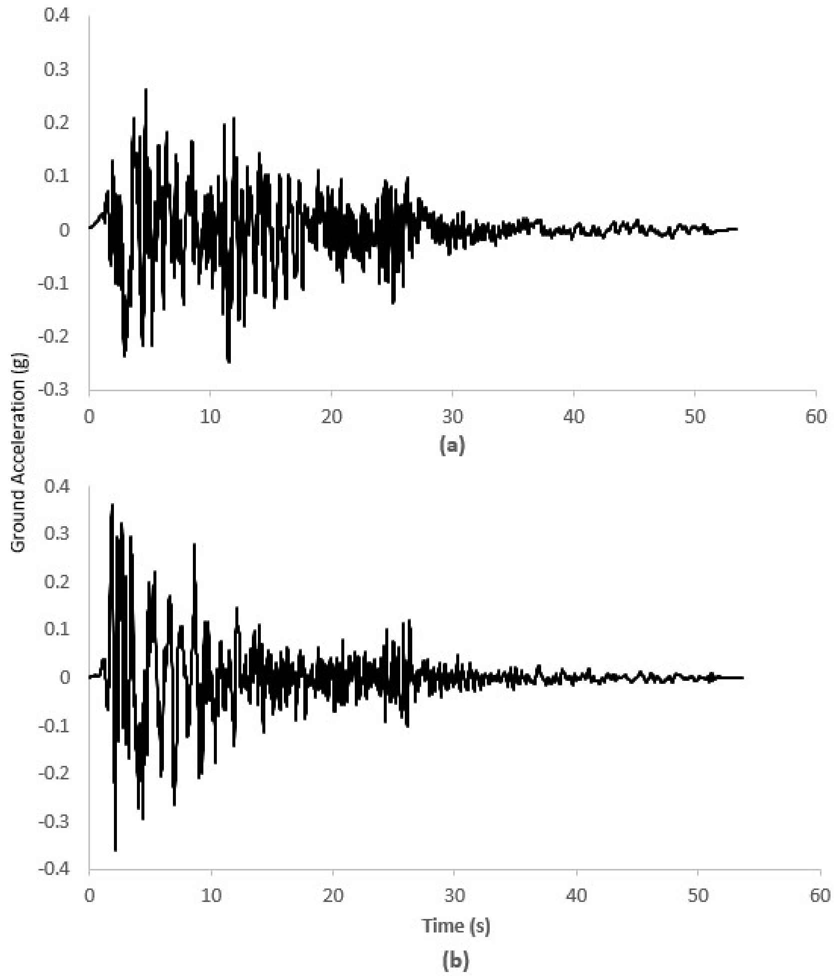

Figure 7.Modified Imperial Valley Earthquake ground accelerations: (a) EW Component; (b) NS Component

VSL Gensui Damper is modeled as non-linear link property with plastic wen type. There are several parameters that need to be calculated, which are effective stiffness, effective damping stiffness, yield strength, and post-yield stiffness ratio. The parameters can be obtained by using several charts and equations [12].

Analysis Result

Structural performance can be determined from the story drift and damage index of the plastic hinges in the structure. Asian Concrete Model Code (ACMC) 2001 is used to determine the damage index classification of the plastic hinges [13]. The states of plastic hinge damages are Immediate Occupancy (IO), Life Safety (LS), Collapse Prevention (CP), and beyond CP, which correspond to damage index values of 0-10%, 10%-25%, 25%-40%, and 40%-100%, respectively. In this study, to give a brief idea of overall damage of the structural elements, the damage indices are averaged. Mid-range values of each damage states are used, which correspond to 5%, 17.5%, 32.5%, and 70% for damages below IO, between IO and LS, between LS and CP, and beyond CP, respectively. Figures 8 to 11 present the drifts of the structure with a certain number of dampers with MSSSA and ODAM placement strategies as well the 0.4% story drift ratio target of each floor used in this study (DR 0.4%). In these figures, drifts of original structure (bare) and structure with a certain number of dampers which are distributed in all stories of selected frames (uniform) are also shown as comparison. Labels "X" and "Y" indicate the direction of the dominant NS earthquake component. Although a two-dimensional earthquake is used, dampers placement in schemes “X” and “Y” are analyzed separately. Figure 8 and 9 show drifts of structure with rigid (R) floor assumption due to dominant ground motion in the X and Y directions, respectively. Figures 10 and 11 show drifts of structure with semi-rigid (SR) floor assumption due to dominant ground motion in the X and Y directions, respectively. MSSSA and ODAM indicate the damper placement method used, while the numbers behind them show the number of dampers used. Uniform and Bare indicate the initial step of the ODAM method and original structure without any dampers installed, respectively. In Figures 8 to 11, "DR 0.4%" represents the 0.4% story drift ratio target of each floor used in this study. It can be seen in Figures 8 and 11, that the number of dampers required to meet the drift target by using MSSSA method is less than that of ODAM method. MSSSA12 and MSSSA42 indicate that 12 and 42 dampers are sufficient to reach the target instead of 16 and 44 dampers which are required by ODAM method.

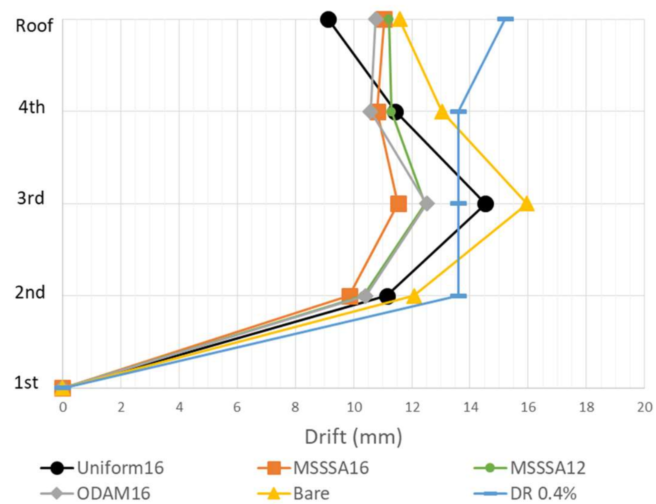

Figure 8.Drift in the X direction of the structure for R-X case

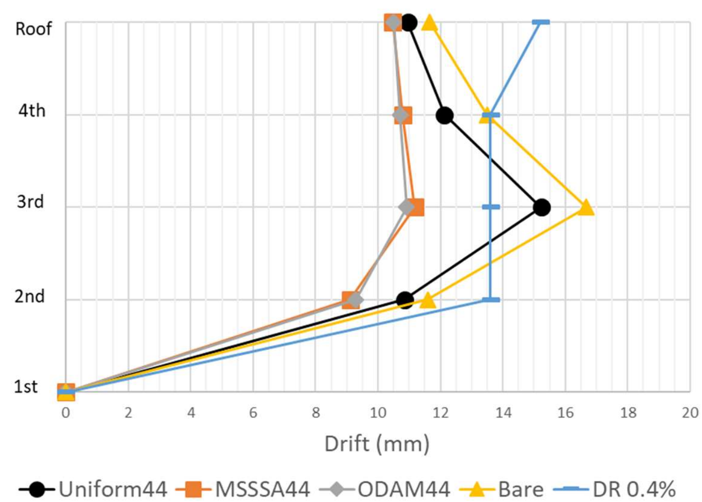

Figure 9. Drift in the Y direction of the structure for R-Y case

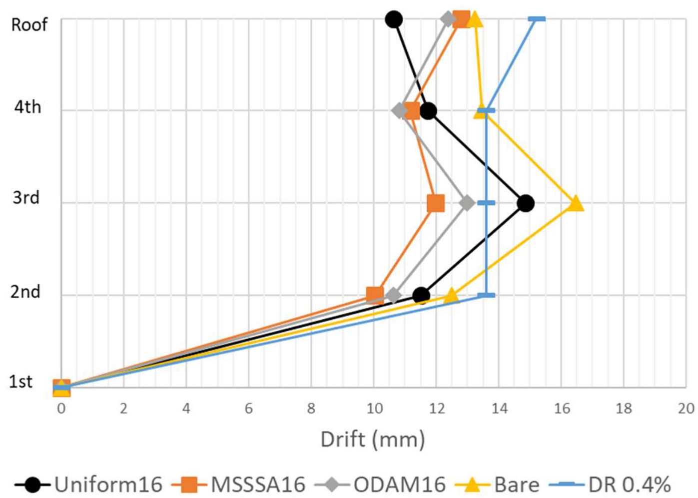

Figure 10. Drift in the X direction of the structure for SR-X case

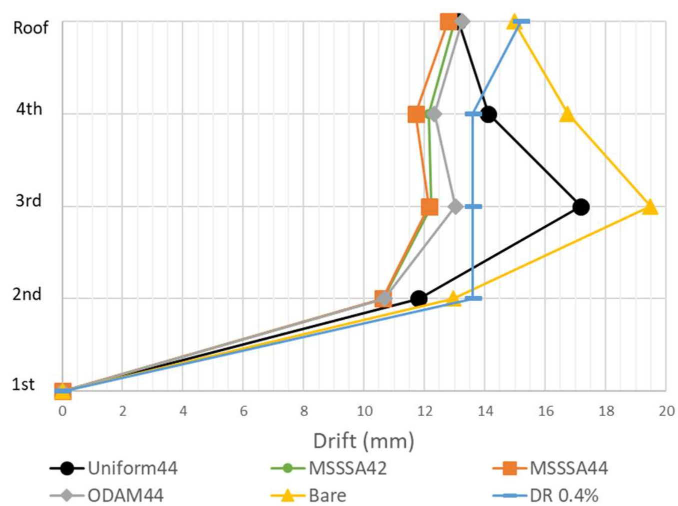

Figure 11. Drift in the Y direction of the structure for SR-Y case

For cases using semi-rigid floor assumption (Figures 10 and 11), the plotted drifts are the maximum drift values among all frames of the structure. It can be seen from the figures that both ODAM and MSSSA succeeded in reducing the drift below the target. Despite using the same number of dampers installed (44 dampers and 16 dampers for scheme Y and scheme X, respectively), building with uniformly distributed dampers in all stories fails to reach the target. The final placement of dampers in each placement method is presented in Figures 12 to 16, where the marks **O** and **X** indicate damper positions using MSSSA and ODAM placement, respectively. In Figures 12 to 16, the dampers are always installed parallel to the marked frames. While the number of dampers installed on each floor can be seen on the caption of the figures shown.

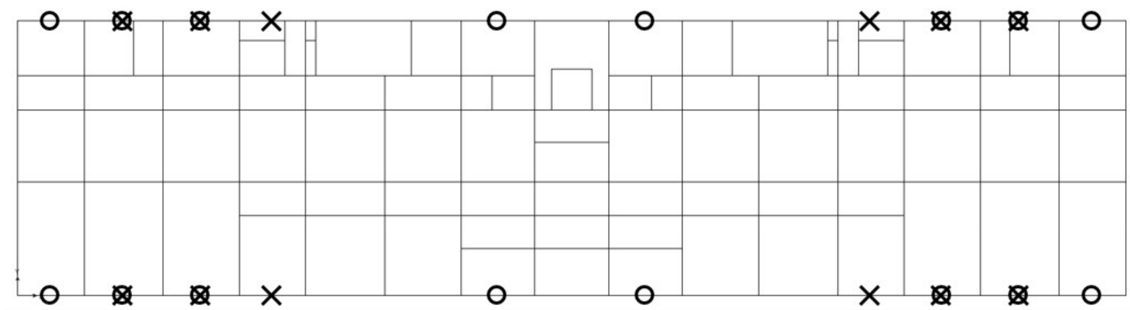

Figure 12. Damper Placement at 3rd floor (R-X and SR-X); MSSSA: 16 dampers; ODAM: 12 dampers

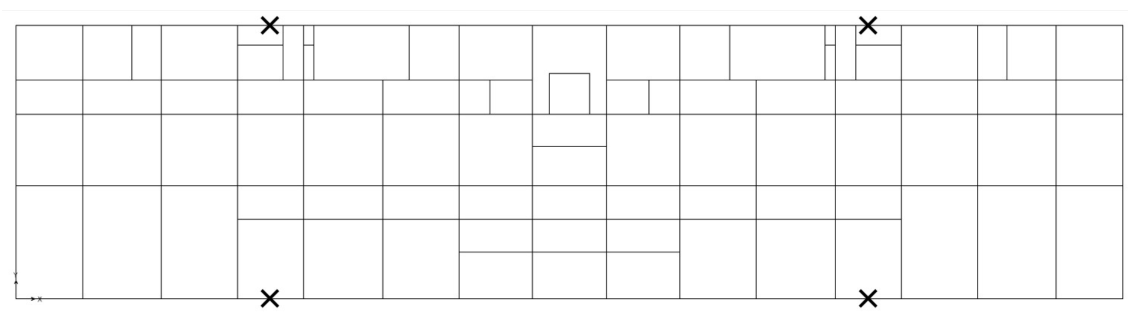

Figure 13. Damper Placement at 4th floor (R-X and SR-X); MSSSA: 0 damper; ODAM: 4 dampers

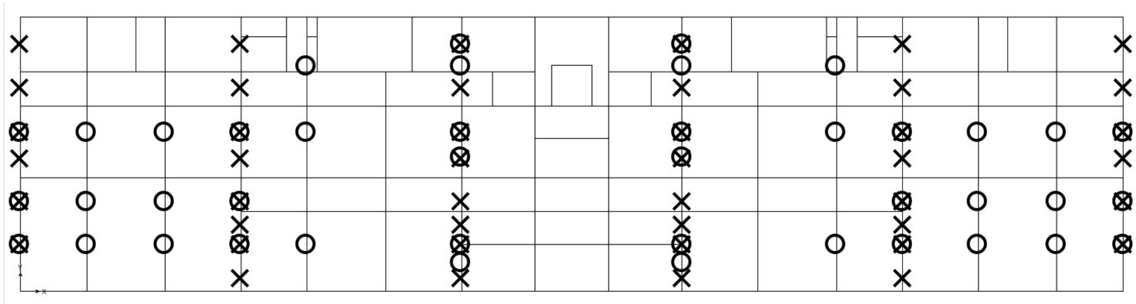

Figure 14. Damper Placement at 3rd floor (R-Y); MSSSA: 44 dampers; ODAM: 44 dampers

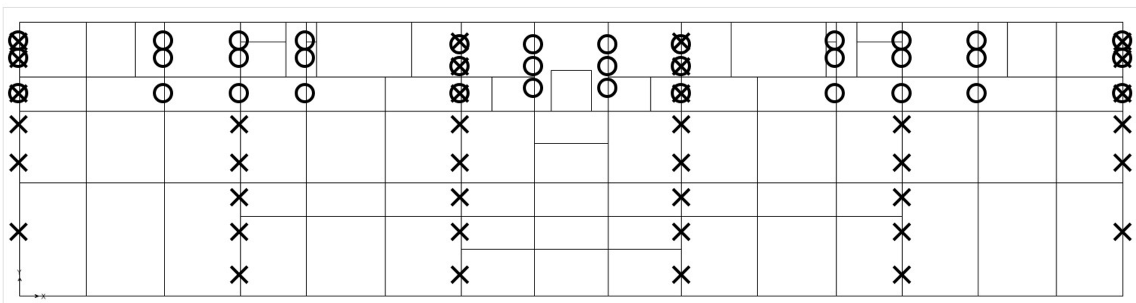

Figure 15.Damper Placement at 3rd floor (SR-Y); MSSSA: 36 dampers; ODAM: 38 dampers

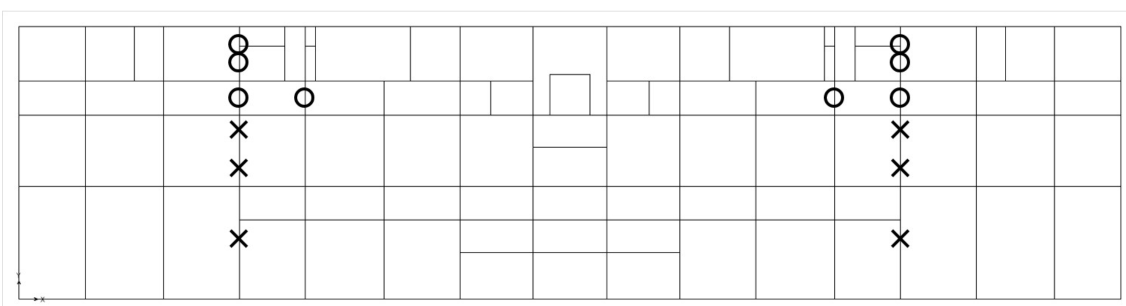

Figure 16.Damper Placement at 4th floor (SR-Y); MSSSA: 8 dampers; ODAM: 6 dampers

It can be seen in Figure 13 that there are no dampers placed for MSSSA strategic placement because there is always larger drift on floor other than 4th floors in every step of damper addition. However, some dampers may still exist on 4th floor for the ODAM method since dampers are installed on each floor in its initial placement.

Table 1. Plastic Hinges (R-X)

Plastic Hinges (B-IO)

	Bare				Uniform				MSSSA				ODAM			
Step	Beam	Column	Total	DI	Beam	Column	Structure	DI	Beam	Column	Structure	DI	Beam	Column	Structure	DI
Bare	155	46	201	0.480%												
1					116	44	160	0.382%	72	41	113	0.270%	[redacted]			
2									67	39	106	0.253%	84	41	125	0.298%
3													76	40	116	0.277%
						Improvement % :		20.40%		Improvement % :		47.26%		Improvement % :		42.29%

Table 2. Plastic Hinges (R-Y)

Plastic Hinges (B-IO)

	Bare				Uniform				MSSSA				ODAM			
Step	Beam	Column	Total	DI	Beam	Column	Total	DI	Beam	Column	Total	DI	Beam	Column	Total	DI
Bare	155	44	199	0.475%												
1					126	40	166	0.396%	150	44	194	0.463%	[redacted]			
2									142	40	182	0.435%	116	39	155	0.370%
3									137	40	177	0.423%	110	38	148	0.353%
4									127	40	167	0.399%	85	39	124	0.296%
5									122	39	161	0.384%	87	40	127	0.303%
6									113	39	152	0.363%	84	39	123	0.294%
7									88	38	126	0.301%	76	39	115	0.275%
							Improvement % :	16.58%			Improvement % :	36.68%			Improvement % :	42.21%

Table 3. Plastic Hinges (SR-X)

Plastic Hinges (B-IO)

	Bare				Uniform				MSSSA				ODAM			
Step	Beam	Column	Total	DI	Beam	Column	Structure	DI	Beam	Column	Structure	DI	Beam	Column	Structure	DI
Bare	266	47	313	0.747%												
1					215	46	261	0.623%	171	41	212	0.506%	[redacted]			
2									160	40	200	0.478%	179	43	222	0.530%
3													164	42	206	0.492%
						Improvement % :		16.61%		Improvement % :		36.10%		Improvement % :		34.19%

Table 4. Plastic Hinges (SR-Y)

Plastic Hinges (B-IO)

	Bare				Uniform				MSSSA				ODAM			
Step	Beam	Column	Total	DI	Beam	Column	Total	DI	Beam	Column	Total	DI	Beam	Column	Total	DI
Bare	244	44	288	0.688%												
1					201	40	241	0.575%	235	45	280	0.669%	[redacted]			
2									228	49	277	0.661%	192	39	231	0.552%
3									220	46	266	0.635%	185	39	224	0.535%
4									217	60	277	0.661%	131	52	183	0.437%
5									216	41	257	0.614%	157	40	197	0.470%
6									188	40	228	0.544%	156	39	195	0.466%
7									172	40	212	0.506%	154	38	192	0.458%
8									173	42	215	0.513%				
						Improvement % :		16.32%		Improvement % :		25.35%		Improvement % :		33.33%

The damage severity of the plastic hinges is presented in Tables 1 to 4. In the tables, only B-IO hinges are displayed because there is no more severe hinge state than B-IO. In total, there are 2094 points of potential non-linear hinges assigned in the structure. More severe damages of structures using semi-rigid floor assumption are observed if compared to structures using rigid floor assumption indicated by increase of plastic damages. Due to dominant earthquake in the Y direction, the total number of plastic damages increases from 199 to 288, 166 to 241, 126 to 215, and 115 to 192 in the case of bare, uniformly distributed dampers, MSSSA, and ODAM models, respectively (see Tables 2 and 4). This fact is also true in the case with dominant earthquake in the X direction (see Tables 1 and 3). Tables 1 to 4 also show that the application of dampers clearly reduces damages of the structure. For example, in the case of SR-Y (Table 4), the number of plastic hinges decreases from 288 in bare model to 215 and 192, in MSSSA and ODAM, respectively. However, at certain steps, the number of plastic hinges may increase, especially in ODAM, because the dampers are not added but moved among stories of the building. Uniformly distributed dampers do not reduce the damage as effective as both placement methods, as there are still 241 total plastic damages. It can be seen is earthquake scheme Y, where the deformations are still relatively large, ODAM and MSSA methods show much better performance compared to the structure with uniformly distributed dampers.

In this structure, there are significant differences from the results with semi-rigid and rigid floor assumption analysis. It is obvious that in a relatively large horizontal span dimension compared to its perpendicular, the concrete slab may not be rigid enough to simulate rigid body movement of the whole floor diaphragm. The results of the analysis with the semi-rigid model produce more severe drifts compared to that of the rigid floor model. The drift of frames in the same story may differ significantly in semi-rigid floor assumption, which is not the case in rigid floor assumption. The drift of frames information is very useful to determine damper placement throughout the study.

Conclusion

In this study, the effort to improve the seismic performance of a structure is conducted by installing VSL Gensui Dampers. The floor plan of the building has a large span to depth ratio that it should be analysed as semi-rigid floor. From non-linear time history analysis results, some conclusion can be made as follows:

1. More extreme story drifts are observed in structure analyzed by using semi-rigid floor assumption in the direction perpendicular to a longer floor plan dimension. This assumption is imperative since different drift of frames in the same story can be obtained. This is important for strategic damper placement in the floor plan since drifts are used as placement indicator. Story drifts in the direction of larger floor plan dimension obtained from either rigid or semi-rigid floor assumptions show in-significant differences.

2. In this study, the MSSSA damper placement method shows the most consistent performance in reducing the story drifts as well as element damages. Even though the final result of damper placement is similar, the ODAM placement method has its limitation compared to MSSSA method that number of dampers used must be determined in the beginning, and dampers can only be swapped among stories of initially chosen frames. In R-Y and SR-X cases, the required numbers of dampers are 44 and 16 for both methods. However, MSSSA method indicates that 12 and 42 dampers are sufficient in R-X and SR-Y, respectively compared to ODAM which requires 16 and 44 dampers.

3. Both MSSSA and ODAM damper placement methods can improve the structure damage index and drift to meet the targeted performance.

4. Despite using the same number of dampers as in MSSSA and ODAM methods, uniform damper placement is less effective in improving the seismic performance of the structure.

5. It should be noted that the damper requirements in each direction are analyzed separately, despite that 2D earthquake is used. The final behavior of the structure should be represented with dampers in both directions installed.

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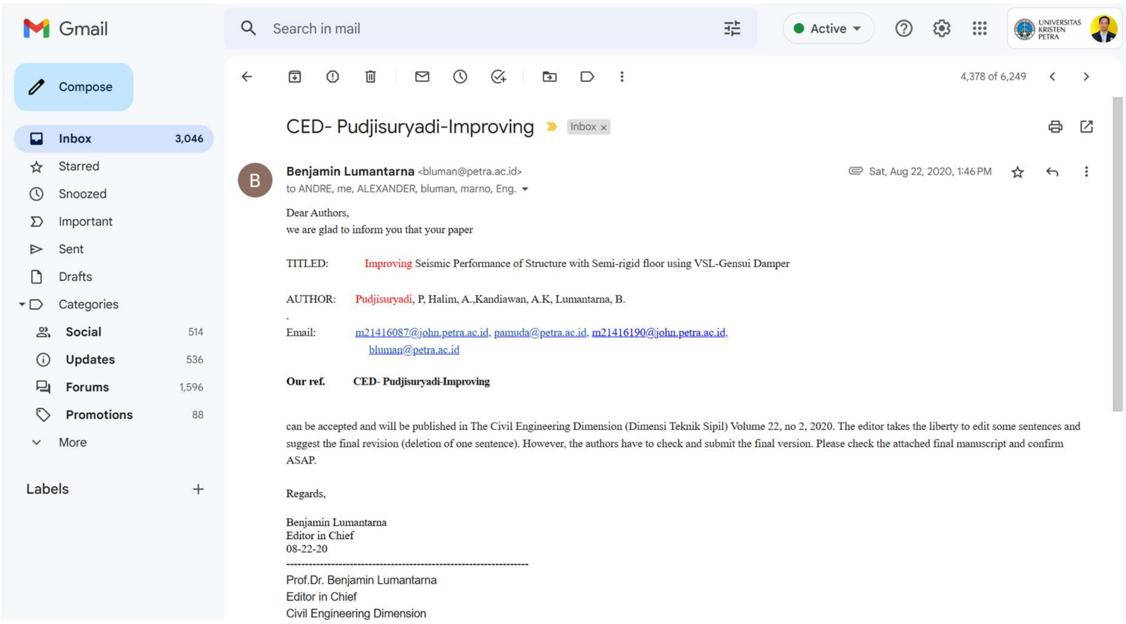

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Benjamin Lumantarna <bluman@petra.ac.id>
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AUTHOR: Pudjisuryadi, P, Halim, A.,Kandiawan, A.K, Lumantarna, B.

Email: m21416087@john.petra.ac.id, pamuda@petra.ac.id, m21416190@john.petra.ac.id, bluman@petra.ac.id

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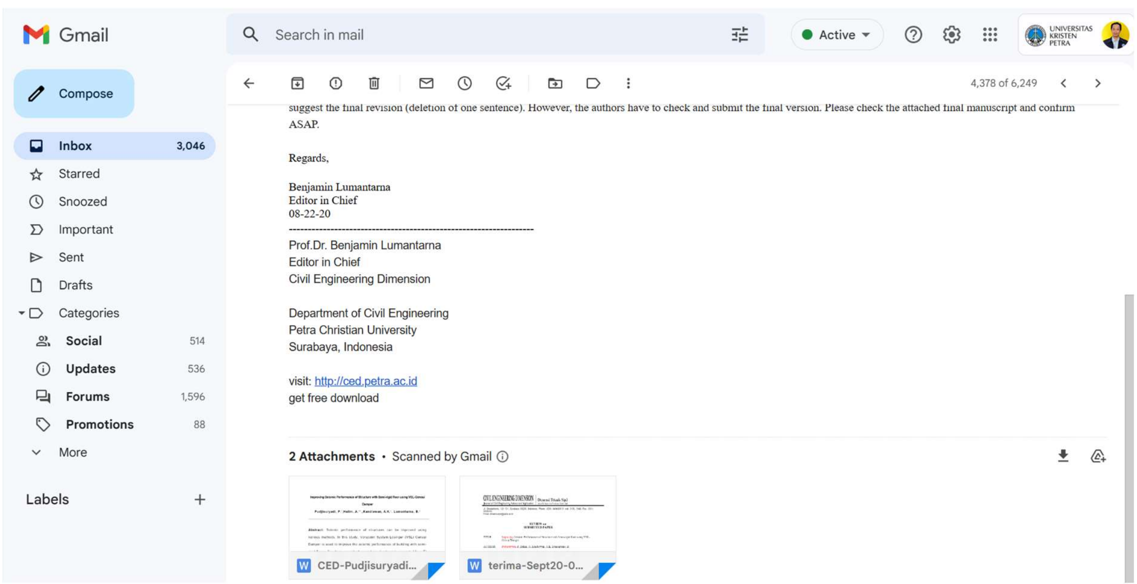

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REVIEW on
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TITLE: Improving Seismic Performance of Structure with Semi-rigid floor using VSL-Gensui Damper

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Improving Seismic Performance of Structure with Semi-rigid floor using VSL-Gensui Damper

Pudjisuryadi, P.[1],Halim, A.[1]*.,Kandiawan, A.K.[1], Lumantarna, B.[1]

Abstract: Seismic performance of structures can be improved using various methods. In this study, Vorspann System Losinger (VSL) Gensui Damper is used to improve the seismic performance of building with semi-rigid floors. Spectrum consistent ground accelerations is generated from El Centro May 19th, 1940 earthquake per SNI 1726:2012 for Mataram, West Timor, Indonesia. Modified Simplified Sequential Search Algorithm (MSSSA) and Optimum Damper Allocation Method (ODAM) are used to efficiently place the dampers on the building to meet certain criteria. Uniform placement which is used as the first step of ODAM is used for comparison. The Results show that both methods can effectively reduce structural drifts and damages. MSSSA shows slightly better performance since ODAM has a limitation that dampers can only be swapped among stories of the initially chosen frames. It is also noted that the dampers must be well distributed among frames in the same story, to take care the different drifts in building with semi-rigid floors.

Keywords:Drift; damper placement method; Non-Linear Time History Analysis; semi-rigid floors; strengthening; VSL Gensui damper.

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Introduction

In seismically active countries such as Indonesia, consideration of earthquake load in building design is imperative. Indonesia has SNI 1726:2012 [1], as its guidelines for designing structures to withstand earthquake load. In conjunction with structural codes such as concrete design code (SNI 2847:2013) [2] and steel design code (SNI 1729:2015), the Indonesian Seismic Code (SNI 1726:2012) should be used to ensure buildings capability to withstand earthquakes.

One of the most common criteria that are not accurately assumed is floor rigidity. In SNI 1726:2012, there is a clause which states "Diaphragms of concrete slabs or concrete filled metal deck with span-to-depth ratios of 3 or less in structures that have no horizontal irregularities are permitted to be idealized as rigid" [1,3]. However, in buildings with concrete slabs, rigid floor diaphragm is usually assumed regardless of the large diaphragm span-to-depth ratio. This may cause inaccurate story drifts in the building model [4].

In the effort of improving the seismic performance of existing structures, many techniques can be used, and one of them is by installing dampers. Damper is an energy dissipation system that can be installed in a structure. The use of energy dissipation systems for an earthquake-resistant structure is useful for improving the seismic performance of a structure [5,6]. In this study, a type of damper produced by Vorspann System Losinger (VSL), namely VSL Gensui Damper, is used to improve the seismic performance of an elongated structure. VSL Gensui Damper is a wall type viscoelastic damper that consists of multilayers of rubber and steel that has 400x400x15mm in dimension (Figure 1~~Figure 1~~). To maximize the benefit of using dampers while still paying good attention to the cost induced, strategic placement of dampers is a must.

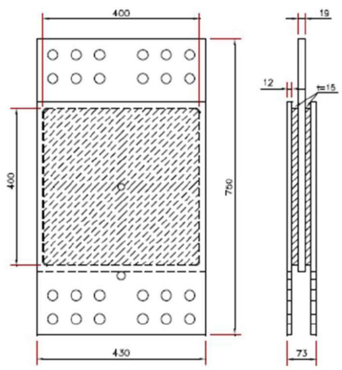

Figure 1. VSL-Gensui Damper

Strategic Placement of dampers

Two damper placement strategies are used in this study. As the first strategy, Simplified Sequential Search Algorithm (SSSA) [7] is adopted. In this case, t~~T~~he proposed modification of SSSA by Angkasaputra and Sebastiano [8] is used, in which the original damper placement indicator of SSSA is modified by only considering~~using~~ story drift and neglecting story velocity. Hereafter the modification is called as the Modified Simplified Sequential Search Algorithm (MSSSA). The second strategy used is Optimum Damper Allocation Method (ODAM) [9]. The uniform damper placement which is the initial step of the ODAM method is used for comparison against the previous two methods. In a previous research Andini and Goenawan [10], studied the two methods on a simple structure and concluded that both ODAM and MSSSA are effective in reducing interstory drift.

In ODAM, the total number of dampers used is decided ~~at~~ from the beginning, and typically the dampers are placed at every story of selected frames. Then the dampers in the story with minimum drift will be moved to the floor with maximum drift. This process is repeated until certain acceptance criteria are met, or the last two damper relocations indicate swaps between the same two stories. In the MSSSA method, each damper addition is placed at the story with the largest drift in the selected frames. The damper addition is stopped when certain acceptance criteria are met. In this study, the maximum story drift ratio of the structure is targeted to be less than 0.4%. Meanwhile, the average damage index of the structure is targeted to be reduced as much as 25% and 35% for earthquakes with scheme Y and scheme X, respectively. Scheme Y and X represent the dominant earthquake in the Y and X direction corresponding to the building. For a comparable comparison between the methods, the number of the dampers on all method is determined to be 44 dampers and 16 dampers, for schemes Y and X, respectively. However, in some cases it is found that by using the MSSSA method, the number of dampers which is required to meet the targets are less.

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Considered Structure

An existing hotel located in Mataram, West Timor, Indonesia, is chosen to be studied. This five-story building has 14 meters height and 62.3 meters by 15.5 meters floor plan dimension resulting in span-to-depth ratio larger than 3.0 which requires semi-rigid floor assumption to obtain accurate building deformation [1]. The floor plan of the typical 1st to 3rd floor, 4th floor, and roof floor can be seen in Figures 2, 3, and 4, respectively.

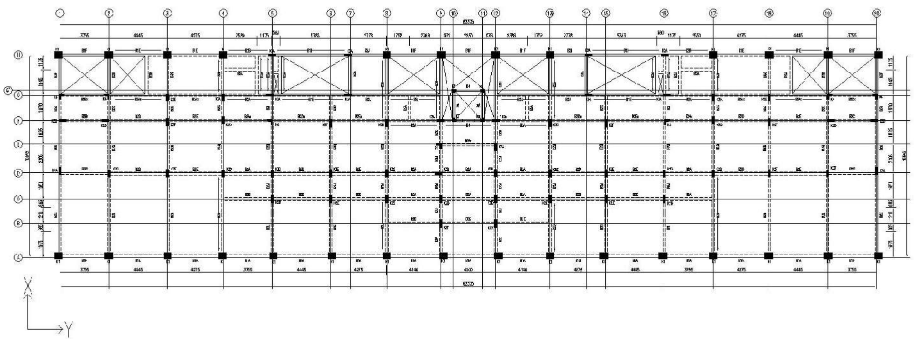

Figure 2. Typical Floor Plan (1st floor – 3rd floor)

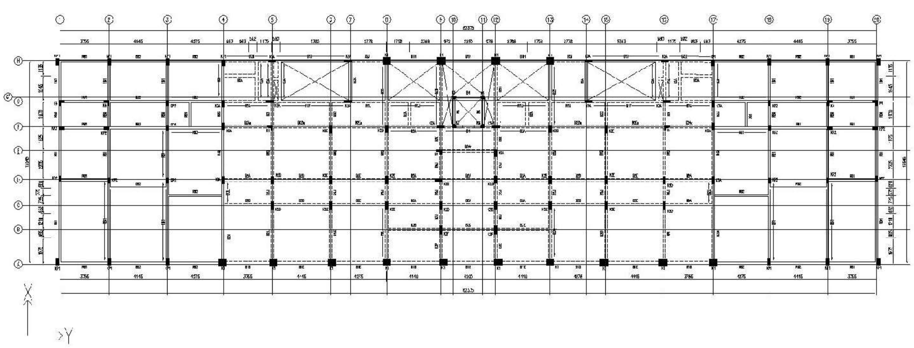

Figure 3.Floor Plan of the 4th floor

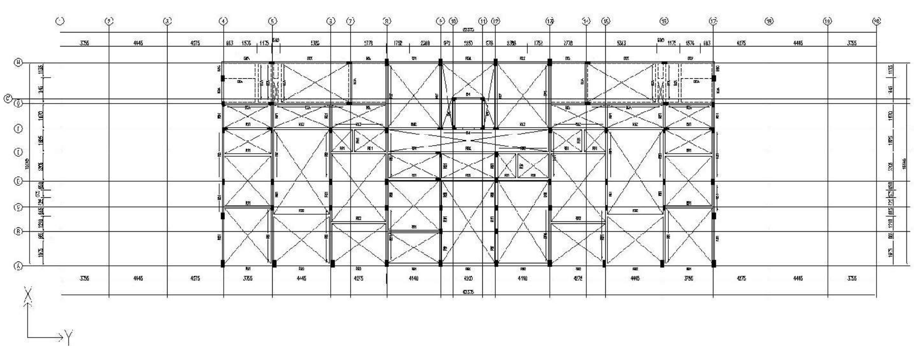

Figure 4 Floor Plan of the roof floor

~~Modelling~~Modeling of the Structure and Analysis

Computer software SAP2000 [11] is used to model the existing structure, as shown in Figure 5~~Figure 5~~. The auto-hinge feature of SAP2000 is used to determine the non-linear hinges properties of all beams and columns.

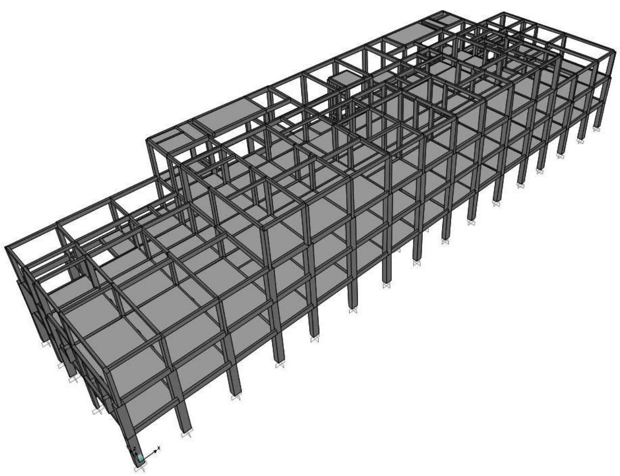

Figure 5. Modeling of Existing Building in SAP2000

The ground-motions records used for the analysis are The Imperial Valley earthquake, recorded at El Centro station, May 19th, 1940, obtained from the Pacific Earthquake Engineering Research (PEER). These Ground-motions are matched to Mataram's Maximum Considered Earthquake (MCE) response spectrum. MCE is a 2500-year return period earthquake and is 1.5 times greater than the Elastic Design Earthquake (EDE), which is required by SNI 1726:2012 for designing an earthquake-resistant structure. Imperial Valley's PGA in East-West (EW) and North-South (NS) direction is 0.21 g and 0.281 g, respectively, which can be seen in Figure 6~~Figure 6~~. To maintain the PGA ratio of the Imperial Valley earthquake in both directions, the original NS and EW ground accelerations are matched to 100% and 70% of

Mataram's MCE, respectively. The modified ground acceleration is presented ~~can be seen~~ in Figure 7~~Figure 7~~. In this study, spectrum consistent EW and NS ground motions are subjected to the building twice. First, the NS and EW component is applied in the Y and X-axis of the building, respectively. Then the directions of the two components are switched to ensure the most severe case is analyzed in both orthogonal directions.

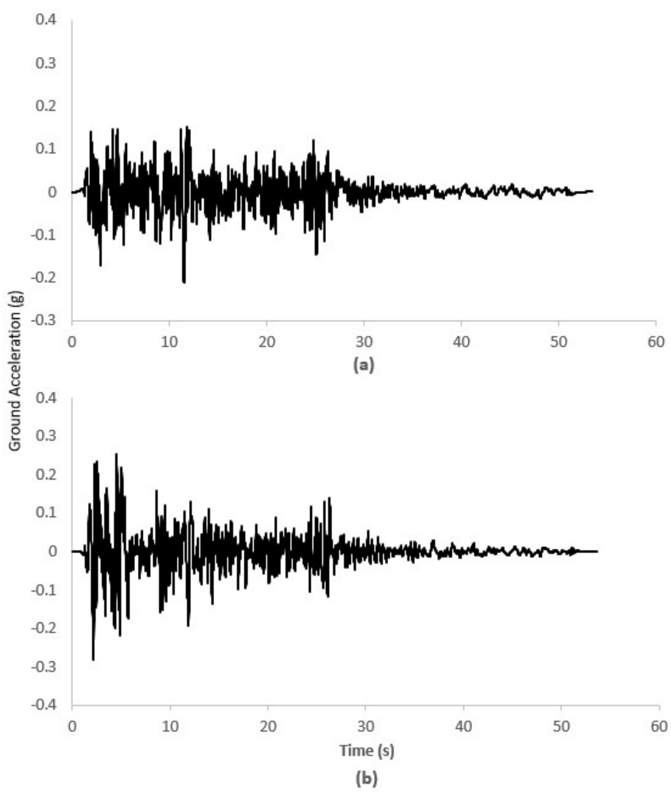

Figure 6. Imperial Valley Earthquake ground accelerations: (a) EW Component; (b) NS Component

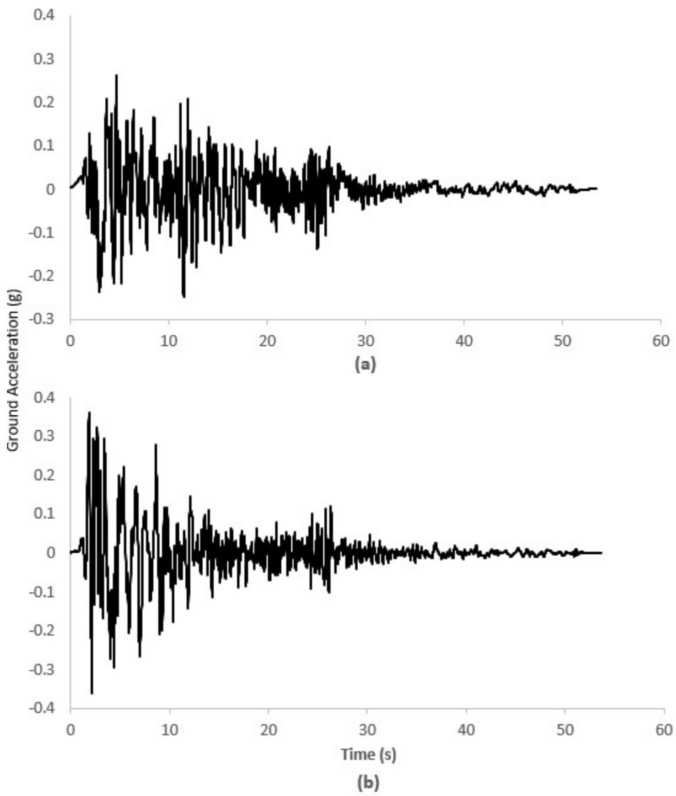

Figure 7.Modified Imperial Valley Earthquake ground accelerations: (a) EW Component; (b) NS Component

VSL Gensui Damper is modeled as non-linear link property with plastic wen type. There are several parameters that need to be calculated, which are effective stiffness, effective damping stiffness, yield strength, and post-yield stiffness ratio. The parameters can be obtained by using several charts and equations [12].

Analysis Result

Structural performance can be determined from the story drift and damage index of the plastic hinges in the structure. Asian Concrete Model Code (ACMC) 2001 is used to determine the damage index classification of the plastic hinges [13]. The states of plastic hinge damages are Immediate Occupancy (IO), Life Safety (LS), Collapse Prevention (CP), and beyond CP, which correspond to damage index values of 0-10%, 10%-25%, 25%-40%, and 40%-100%, respectively. In this study, to give a brief idea of overall damage of the structural elements, the damage indices are averaged. Mid-range values of each damage states are used, which correspond to 5%, 17.5%, 32.5%, and 70% for damages below IO, between IO and LS, between LS and CP, and beyond CP, respectively. Figures 8 to 11 present the drifts of the structure with a certain number of dampers with MSSSA and ODAM placement strategies as well the 0.4% story drift ratio target of each floor used in this study (DR 0.4%). In these figures, drifts of original structure (bare) and structure with a certain number of dampers which are distributed in all stories of selected frames (uniform) are also shown as comparison. Labels "X" and "Y" indicate the direction of the dominant NS earthquake component. Although a two-dimensional earthquake is used, dampers placement in schemes “X” and “Y” are analyzed separately. Figure 8~~Figures 8~~ and 9 show drifts of structure with rigid (R) floor assumption due to dominant ground motion in the X and Y directions, respectively. Figures 10 and 11 show drifts of structure with semi-rigid (SR) floor assumption due to dominant ground motion in the X and Y directions, respectively. MSSSA and ODAM indicate the damper placement method used, while the numbers behind them show the number of dampers used. Uniform and Bare indicate the initial step of the ODAM method and original structure without any dampers installed, respectively. In Figures 8 to 11, "DR 0.4%" represents the 0.4% story drift ratio target of each floor used in this study. It can be seen in Figures 8 and 11, that the number of dampers required to meet the drift target by using MSSSA method is less than that of ODAM method. MSSSA12 and MSSSA42 indicate that 12 and 42 dampers are sufficient to reach the target instead of 16 and 44 dampers which are required by ODAM method.

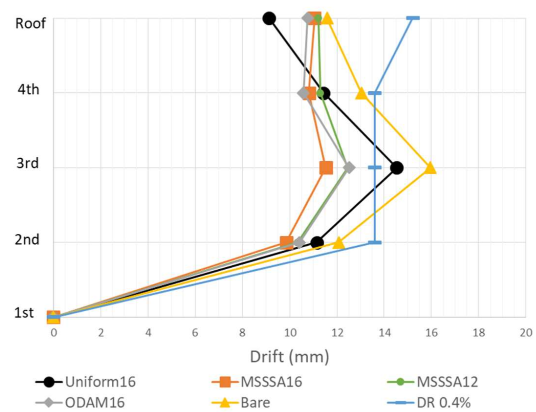

Figure 8.Drift in the X direction of the structure for R-X case

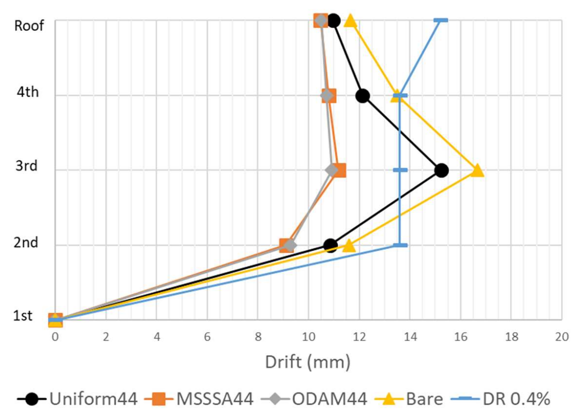

Figure 9. Drift in the Y direction of the structure for R-Y case

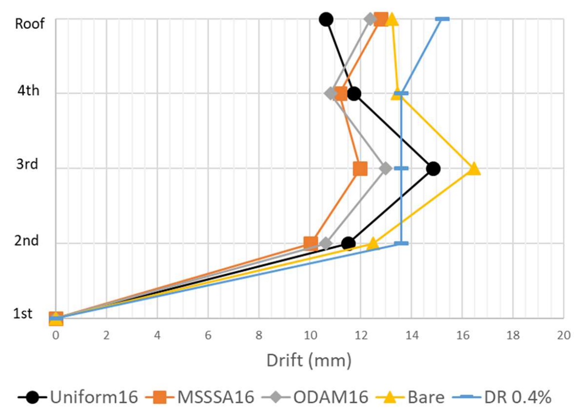

Figure 10. Drift in the X direction of the structure for SR-X case

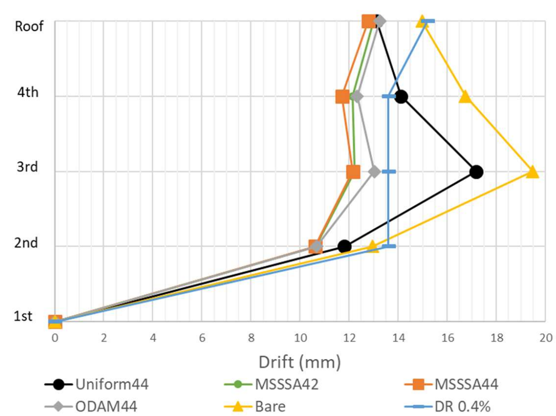

Figure 11. Drift in the Y direction of the structure for SR-Y case

For cases using semi-rigid floor assumption (Figures 10 and 11), the plotted drifts are the maximum drift values among all frames of the structure. It can be seen from the figures that both ODAM and MSSSA succeeded in reducing the drift below the target. Despite using the same number of dampers installed (44 dampers and 16 dampers for scheme Y and scheme X, respectively), building with uniformly distributed dampers in all stories fails to reach the target.

The final placement of dampers in each placement method is presented in Figures 12 to 16, where the marks **O** and **X** indicate damper positions using MSSSA and ODAM placement, respectively. In Figures 12 to 16, the dampers are always installed parallel to the marked frames. While the number of dampers installed on each floor can be seen on the caption of the figures shown.

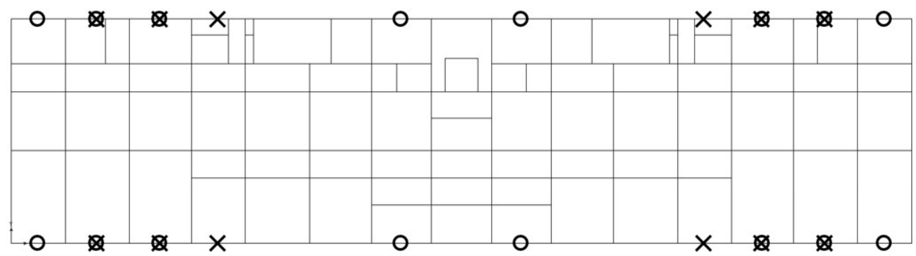

Figure 12. Damper Placement at 3rd floor (R-X and SR-X); MSSSA: 16 dampers; ODAM: 12 dampers

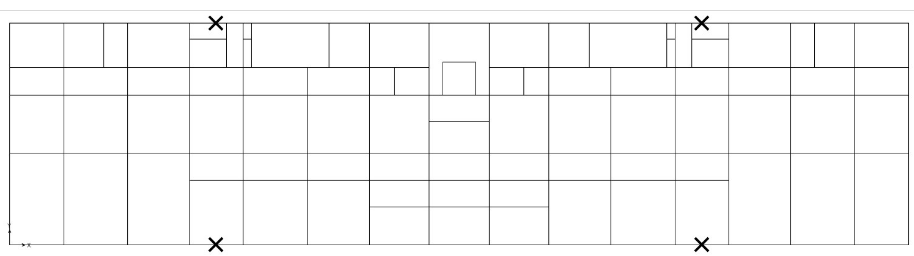

Figure 13. Damper Placement at 4th floor (R-X and SR-X); MSSSA: 0 damper; ODAM: 4 dampers

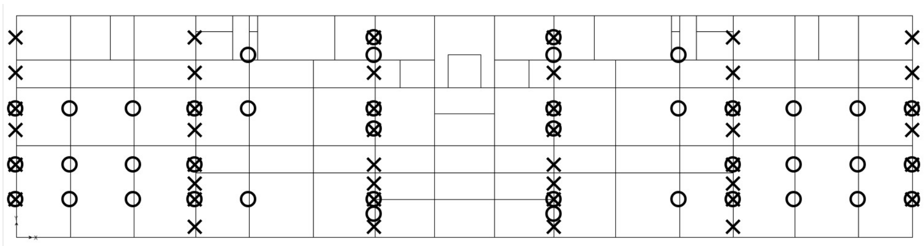

Figure 14. Damper Placement at 3rd floor (R-Y); MSSSA: 44 dampers;

ODAM: 44 dampers

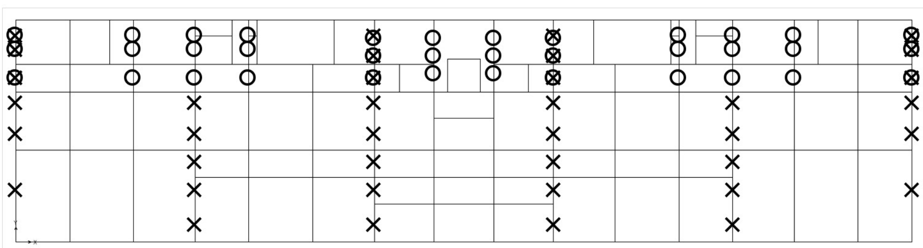

Figure 15.Damper Placement at 3rd floor (SR-Y); MSSSA: 36 dampers;

ODAM: 38 dampers

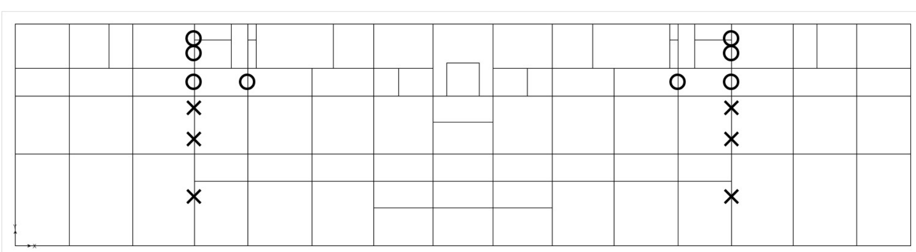

Figure 16.Damper Placement at 4th floor (SR-Y); MSSSA: 8 dampers;

ODAM: 6 dampers

It can be seen in Figure 13 that there are no dampers placed for MSSSA strategic placement because there is always larger drift on floor other than 4th floors in every step of damper addition. However, some dampers may still exist on 4th floor for the ODAM method since dampers are installed on each floor in its initial placement.

Table 1. Plastic Hinges (R-X)

Plastic Hinges (B-IO)																
	Bare				Uniform				MSSSA				ODAM			
Step	Beam	Column	Total	DI	Beam	Column	Structure	DI	Beam	Column	Structure	DI	Beam	Column	Structure	DI
Bare	155	46	201	0.480%												
1					116	44	160	0.382%	72	41	113	0.270%	[redacted]			
2									67	39	106	0.253%	84	41	125	0.298%
3													76	40	116	0.277%
					Improvement % :			20.40%	Improvement % :			47.26%	Improvement % :			42.29%

Table 2. Plastic Hinges (R-Y)

Plastic Hinges (B-IO)																
	Bare				Uniform				MSSSA				ODAM			
Step	Beam	Column	Total	DI	Beam	Column	Total	DI	Beam	Column	Total	DI	Beam	Column	Total	DI
Bare	155	44	199	0.475%												
1					126	40	166	0.396%	150	44	194	0.463%	[redacted]			
2									142	40	182	0.435%	116	39	155	0.370%
3									137	40	177	0.423%	110	38	148	0.353%
4									127	40	167	0.399%	85	39	124	0.296%
5									122	39	161	0.384%	87	40	127	0.303%
6									113	39	152	0.363%	84	39	123	0.294%
7									88	38	126	0.301%	76	39	115	0.275%
						Improvement % :		16.58%		Improvement % :		36.68%		Improvement % :		42.21%

Table 3. Plastic Hinges (SR-X)

Plastic Hinges (B-IO)																
	Bare				Uniform				MSSSA				ODAM			
Step	Beam	Column	Total	DI	Beam	Column	Structure	DI	Beam	Column	Structure	DI	Beam	Column	Structure	DI
Bare	266	47	313	0.747%												
1					215	46	261	0.623%	171	41	212	0.506%	[redacted]			
2									160	40	200	0.478%	179	43	222	0.530%
3													164	42	206	0.492%
					Improvement % :			16.61%	Improvement % :			36.10%	Improvement % :			34.19%

Table 4. Plastic Hinges (SR-Y)

Plastic Hinges (B-IO)																
	Bare				Uniform				MSSSA				ODAM			
Step	Beam	Column	Total	DI	Beam	Column	Total	DI	Beam	Column	Total	DI	Beam	Column	Total	DI
Bare	244	44	288	0.688%												
1					201	40	241	0.575%	235	45	280	0.669%	[redacted]			
2									228	49	277	0.661%	192	39	231	0.552%
3									220	46	266	0.635%	185	39	224	0.535%
4									217	60	277	0.661%	131	52	183	0.437%
5									216	41	257	0.614%	157	40	197	0.470%
6									188	40	228	0.544%	156	39	195	0.466%
7									172	40	212	0.506%	154	38	192	0.458%
8									173	42	215	0.513%				
					Improvement % :			16.32%	Improvement % :			25.35%	Improvement % :			33.33%

The damage severity of the plastic hinges is presented in Tables 1 to 4. In the tables, only B-IO hinges are displayed because there is no more severe hinge state than B-IO. In total, there are 2094 points of potential non-linear hinges assigned in the structure. More severe damages of structures using semi-rigid floor assumption are observed if compared to structures using rigid floor assumption indicated by increase of plastic damages. Due to dominant earthquake in the Y direction, the total number of plastic damages increases from 199 to 288, 166 to 241, 126 to 215, and 115 to 192 in the case of bare, uniformly distributed dampers, MSSSA, and ODAM models, respectively (see Tables 2 and 4). This fact is also true in the case with dominant earthquake in the X direction (see Tables 1 and 3). Tables 1 to 4 also show that the application of dampers clearly reduces damages of the structure. For example, in the case of SR-Y (Table 4~~Table 4~~), the number of plastic hinges decreases from 288 in bare model to 215 and 192, in MSSSA and ODAM, respectively. However, at certain steps, the number of plastic hinges may increase, especially in ODAM, because the dampers are not added but moved among stories of the building. Uniformly distributed dampers do not reduce the damage as effective as both placement methods, as there are still 241 total plastic damages. It can be seen is earthquake scheme Y, where the deformations are still relatively large, ODAM and MSSA methods show much better performance compared to the structure with uniformly distributed dampers.

In this structure, there are significant differences from the results with semi-rigid and rigid floor assumption analysis. It is obvious that in a relatively large horizontal span dimension compared to its perpendicular, the concrete slab may not be rigid enough to simulate rigid body movement of the whole floor diaphragm. The results of the analysis with the semi-rigid model produce more severe drifts compared to that of the rigid floor model. The drift of frames in the same story may differ significantly in semi-rigid floor assumption, which is not the case in rigid floor assumption. The drift of frames information is very useful to determine damper placement throughout the study.

Conclusion

In this study, the effort to improve the seismic performance of a structure is conducted by installing VSL Gensui Dampers. The floor plan of the building has a large span to depth ratio that it should be analysed as semi-rigid floor. From non-linear time history analysis results, some conclusion can be made as follows:

1. More extreme story drifts are observed in structure analyzed by using semi-rigid floor assumption in the direction perpendicular to a longer floor plan dimension. This assumption is imperative since different drift of frames in the same story can be obtained. This is important for strategic damper placement in the floor plan since drifts are used as placement indicator. Story drifts in the direction of larger floor plan dimension obtained from either rigid or semi-rigid floor assumptions show in-significant differences.

2. In this study, the MSSSA damper placement method shows the most consistent performance in reducing the story drifts as well as element damages. Even though the final result of damper placement is similar, the ODAM placement method has its limitation compared to MSSSA method that number of dampers used must be determined in the beginning, and dampers can only be swapped among stories of initially chosen frames. In R-Y and SR-X cases, the required numbers of dampers are 44 and 16 for both methods. However, MSSSA method indicates that 4~~1~~2 and 4~~2~~

12 dampers are sufficient in SR-Y~~X~~ and ~~S~~R-~~Y~~X, respectively.~~ compared to ODAM which requires 16 and 44 dampers.~~

3. Both MSSSA and ODAM damper placement methods can improve the structure damage index and drift to meet the targeted performance.

4. Despite using the same number of dampers as in MSSSA and ODAM methods, uniform damper placement is less effective in improving the seismic performance of the structure.

5. It should be noted that the damper requirements in each direction are analyzed separately, despite that 2D earthquake is used. The final behavior of the structure should be represented with dampers in both directions installed.

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