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HEIGHT EFFECT ON SHEAR MODEL RESPONSE OF STEEL STRUCTURE WITH HYSTERESIS DAMPERS

構造－振動

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Steel Structure　Hysteresis Damper
Shear Model　N-R State Analysis

1. Introduction

To understand the performance of dampers to reduce structural damage, it is important to perform response analysis to obtain necessary data to evaluate structure performance[1]. Structural analysis using 3D model configuration enables us to understand structural behavior very well. On the other hand, shear model that considers effective deformation of dampers allows us to perform analysis quickly and enables us to understand basic relationships in structural behavior[2]. Effective deformation of damper is considered by creating shear model based on No-Damper (N-State) model and Rigid-Damper (R-State) model[2) 3)].

In this paper, shear model of steel structure with various height using hysteresis damper will be constructed and the Time History Analysis will be performed. The response analysis then will be compared to the 3D model (hereinafter referred to as member model) to see the accuracy of the shear model.

2. Building Overview

Buildings that will be considered are steel structure with three different stories, which are 15-story, 36-story, and 45-story based on Miyamoto et al.[1]. Story height is 5.7 m for the first floor and 4 m for 2nd ~ 45th floor. Typical plan view of buildings can be seen in Fig.1 and elevation plan for the respective model can be seen in Fig.3. Hysteresis damper will be used in this paper with its position can be seen as red line in Fig. 1 and Fig. 3. Column and beam will be modeled as elastic with structural damping proportional to the stiffness with its first mode damping is 2%. Details about element dimensions can be seen from Miyamoto et al.[1].

Damper that will be used is the buckling restrained brace, which has plastic section and elastic section. The plastic part will be placed in the middle of elastic part with the ratio of plastic length (L_{dpi}) and damper length (L_{di}) is $L_{di} = 3L_{dpi}$. The ratio between damper plastic area (A_{dpi}) and damper elastic area (A_{dei}) is $A_{dei} = 2A_{dpi}$. LY225 material type will be selected for damper plastic part (yield point of $\sigma_y = 225N/mm^2$). Damper configuration can be seen on Fig. 2.

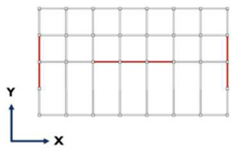


Fig. 1 Typical Plan View

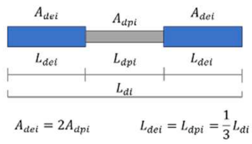
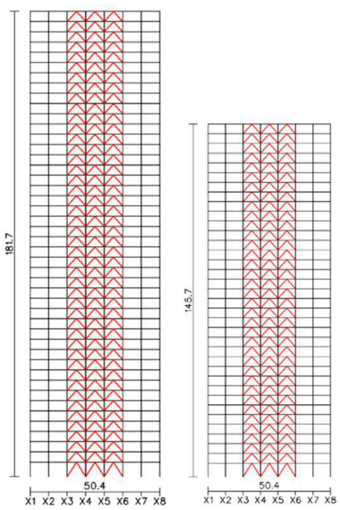
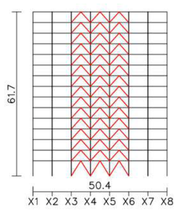


Fig. 2 Damper Diagram





(a) 45 Story　(b) 36 Story　(c) 15 Story

Fig. 3 Elevation Plan

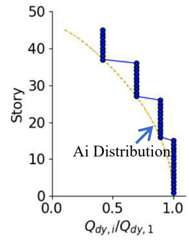


Fig. 4 Damper Yield Ratio

Table 1 No Damper Structural Properties

No. Floor	X-dir. Structural Period (s)		
	1	2	3
15	1.74	0.60	0.34
36	4.77	1.65	0.98
45	6.10	2.14	1.26

Damper dimensions will be divided into 4 different regions following Fig. 4 based on the ratio between current story yield force ($Q_{dy,i}$) and first story yield force ($Q_{dy,1}$) derived from design shear force of Ai distribution. By deciding the damper amount (α_{dy1}), each story yield force can be calculated as follows.

$$Q_{dy1} = \alpha_{dy1} \sum_{i=1}^{N} m_i g \qquad (1)$$

In this paper, damper amount (α_{dy}) of 0.02 will be used and damper dimension will be determined.

Damper parameters that will be used are shown in Table 2.

Table 2 Damper Parameter

Floor	α_{dy1}	$A_{deq,I}$ (mm^2)	$F_{dy,I}$ (kN)	$L_{d,I}$ (mm)	$K_{deq,I}$ (kN/cm)
37 - 45		6629	994	5381	2525
27 - 36		10977	1646	5381	4181
16 - 26	0.02	14074	2111	5381	5361
15-2		15792	2369	5381	6016
1		18741	2811	6386	6016

3. Earthquake Ground Motion

Earthquake ground motion will be used as input motion. In this paper, ART HACHI (Hachinohe 1968 NS, phase characteristic ground motion) seismic wave with highest ground acceleration about 396 cm/s^2 will be applied to the model. Earthquake ground motion can be seen on Fig. 5.

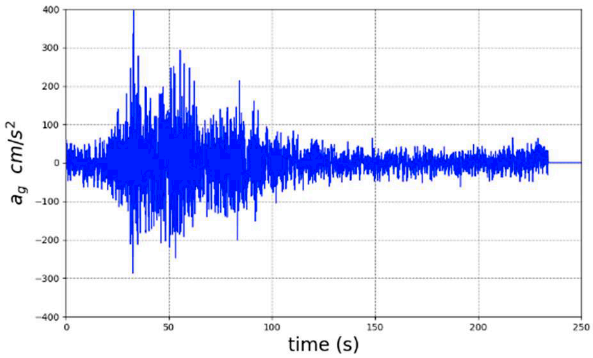


Fig. 5 ART HACHI Ground Motion

4. Member Model Response Analysis

Dynamic Time history analysis will be performed to the member model with various height by using OpenSeesPy software. Analysis performed for damper amount of $\alpha_{dy1} = 0.02$ condition. Structural stiffness for all models considered can be seen in Fig. 6.

Dynamic Analysis for structure with damper is performed by applying ART-HACHI ground motion to obtain structural response: Story acceleration (a_i), story drift ratio (R_i), and story shear force (Q_i). Structural response for 15-story, 36-story, and 45-story can be seen in Fig. 7, Fig, 8, and Fig.9, respectively.

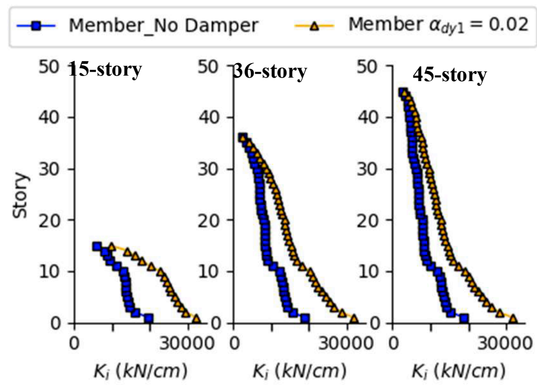


Fig. 6 Member Model Story Stiffness

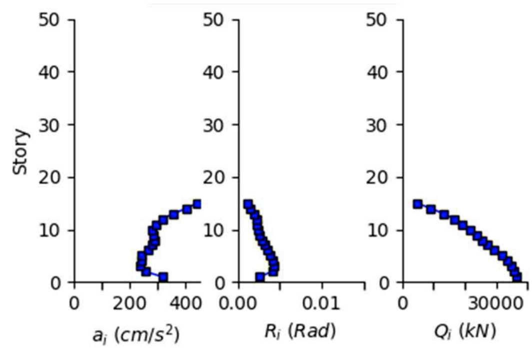


Fig. 7 15-story α_{dy1}=0.02 response

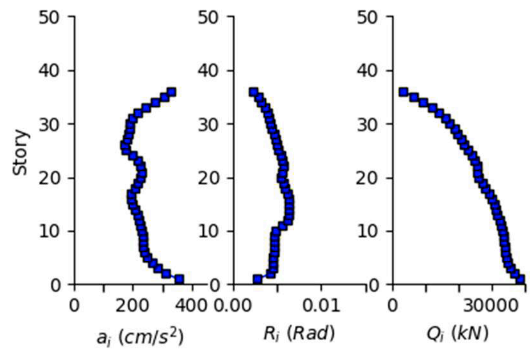


Fig. 8 36-story α_{dy1}=0.02 response

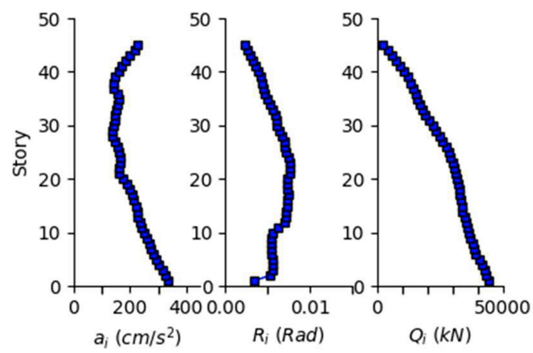


Fig. 9 45-story α_{dy1}=0.02 Response

5. N-R State Analysis

N/R state analysis is a method to create shear models that consider effective deformation ratio. Both models will be analyzed in static condition with Ai distribution force acts as the external force. N-State analysis deals with structure without damper (main frame only), resulting in no damper force acting on the damper position. Effective deformation ratio (α_N) for each damper then can be calculated by knowing damper horizontal deformation in the desired damper position (δ_{dN}) and story drift (u_N)[2) 3)].

R-State analysis is an analysis in which external force Ai distribution is applied to the structure with very stiff damper placed at the desired damper location, resulting to no deformation occurred to the damper. From this condition, stiffness of the damper in R-state condition (K_{dR}) for each damper can be calculated by knowing damper horizontal force (F_{dR}) and R-state story drift (u_R)[2) 3)].

From N/R state analysis, shear models can be created by using analogy from Fig. 10. Shear model consists of 3 main components, which are pseudo-frame (fs), pseudo-brace (bs), and pseudo-damper (ds). Pseudo-frame parameters can be obtained directly from the frame-only structure, while pseudo-brace and pseudo-damper parameters can be calculated by performing the N-R state analysis[2) 3)].

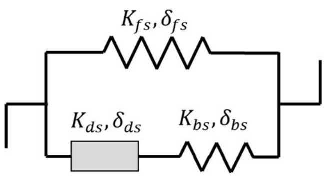


Fig. 10 Shear Model Illustration

For each i-th story, pseudo-brace stiffness (K_{bs}) can be obtained from j-th damper at the story by following equation.

$$K_{bs,i} = \sum_{j=1}^{N_{d,i}} \alpha_{N(i,j)} \times K_{dR(i,j)} \qquad (2)$$

By knowing damper horizontal stiffness from member model (K_d), pseudo-damper stiffness (K_{ds}) for each story can be obtained from following equation.

$$K_{ds,i} = \sum_{j=1}^{N_{d,i}} \left(\alpha_{N(i,j)}\right)^2 \times K_{d(i,j)} \qquad (3)$$

Thus, by using diagram from Fig.10, shear models that consider effective deformation ratio can be created. Value of each parameter for model consideration can be seen from Fig. 11.

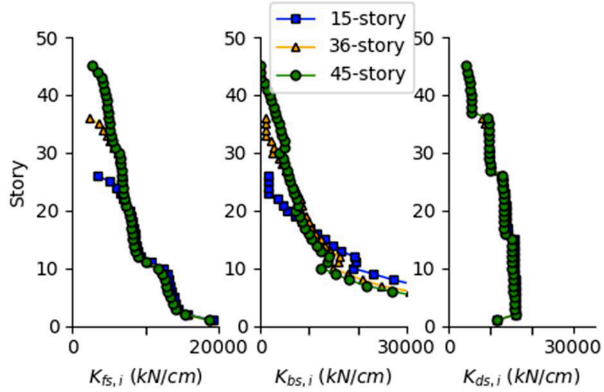


Fig. 11 Shear Model Parameter

Based on the obtained parameters, shear models are created for 15-story, 36-story, and 45-story models. Modal analysis has been performed for all models considered and comparison between modal period of member model and shear model for each model with $\alpha_{dy1} = 0.02$ are shown in Table 3.

Table 3 structure with damper Modal Period

No. Floor	X-dir. Structural Period (s)					
	1		2		3	
	Member	shear	Member	shear	Member	shear
15	1.29	1.29	0.44	0.48	0.25	0.29
36	3.65	3.65	1.21	1.40	0.69	0.87
45	4.75	4.76	1.61	1.84	0.91	1.15

From table 3, it can be seen that for each model, their first mode period is similar. However, as the mode gets higher, errors between member model and shear model are bigger. One of the reasons may be related to the behavior of member model that considers higher mode. This is not considered in shear model and may be the cause of the difference.

6. Shear Model and Member Model Response comparison

In this section, Time history analysis is performed to each model with damper amount ($\alpha_{dy1} = 0.02$) to see the comparison between shear model and member model structural responses.

ART-HACHI ground motion is applied in the x-direction of each model, and story maximum responses: Story acceleration (a_i), story drift ratio (R_i), and story shear force (Q_i). will be obtained and compared to see if shear model is able to produce similar result to the member model.

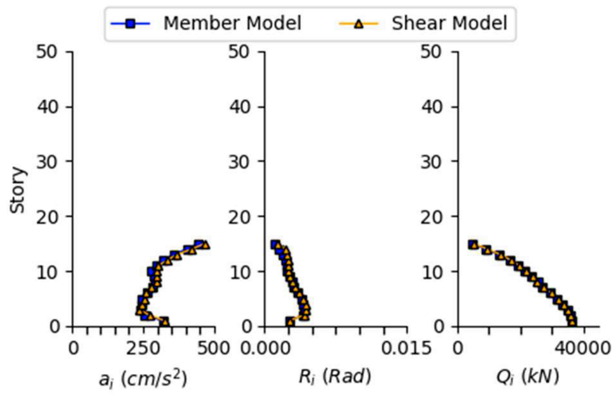


Fig. 12 15-story damped structure response

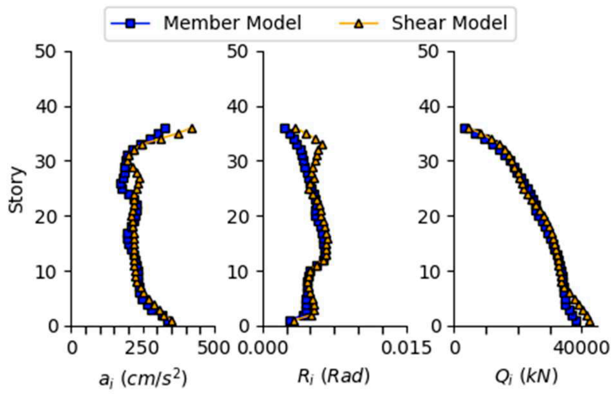


Fig. 13 36-story damped structure response

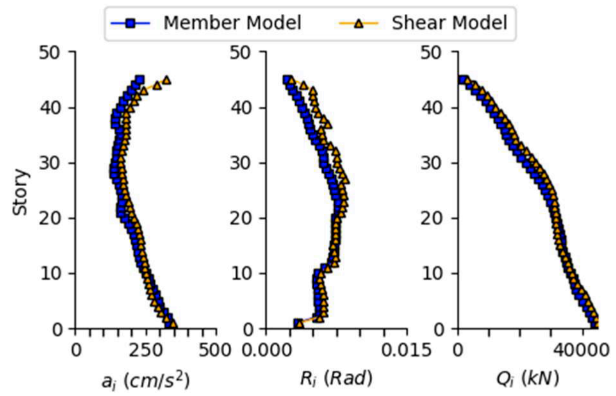


Fig. 14 45-story damped structure response

Structural responses for 15-story model can be seen in Fig. 12. From this figure, it can be seen that shear model response shows pretty good result when compared to member model response.

Structural response for 36-story model can be seen on Fig. 13. From this figure, as the story gets higher, shear model response tends to be different from member model. This difference is highly noticed in story drift ratio and story acceleration.

Structural responses for 45-story model can be seen in Fig. 14. From this figure, as the story gets higher, shear model response tends to be different from member model. This difference is highly noticed in story drift ratio

Structural response comparison shows that as the number of stories is getting higher, shear model response tends to be different compared to the member model for the upper part of building. These differences are highly related due to the existence of bending effects for high-rise building. Because the bending effects are beyond the current scope, this matter is left for future issue.

7. Conclusion

Structural analysis using the shear model method based on N-R state analysis has been performed for steel structure with various heights using hysteresis damper. Damper amount of $\alpha_{dy1} = 0.02$ is used in this analysis and ART HACHI ground motion used as input wave.

Structural analysis and comparison show that for lower story, shear models tend to have similar responses when compared to member models. However, as the structural height increases, shear model result at higher story shows big differences compared to the member model. This difference is highly related to the bending moment effect that occurs in member model.

Future studies of shear models should consider bending effects when modeling high-rise building to improve response accuracy.

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