A STUDY ON THE INFLUENCE OF SEISMIC ZONING FACTORS ON THE STRUCTURE COST AND THE REPAIR COST OF THE RC SCHOOL BUILDING

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ABSTRACT

In Japan, the seismic zoning factors (Z) is defined for each region as a numerical value of 1.0 to 0.7. Z represents the relative ratio of the expectation of the earthquake ground motion obtained by past earthquake records etc. In the region which Z is from 0.7 to 0.9, the member cross section is smaller and the structure cost is smaller than the region which Z equal to 1.0 in general. On the other hand, when a large earthquake occur in the region which Z is from 0.7 to 0.9, the structural damage may increase and the repair costs may increase. In this study, RC school building model was prepared under Z=1.0, 0.9, 0.8 respectively and the structure cost was calculated. In addition, time history response analysis was carried out and determined the level of disaster according to the obtained maximum story drift angle. After that, the repair cost was calculated. As a result, the lowest structure cost showed in the case of Z=0.8. The highest structure cost showed in the case of Z = 1.0. However, the repair cost tend to be higher in the case of Z=0.8 than in the case of Z=1.0.

Keywords: RC school building, pushover analysis, time history response analysis

INTRODUCTION

In Japan, the seismic zoning factors (Z) is defined for each region as a numerical value of 1.0 to 0.7. Z represents the relative ratio of the expectation of the earthquake ground motion obtained by past earthquake records etc. In the region which Z is from 0.7 to 0.9, the member cross section is smaller and the structure cost is smaller than the region which Z = 1.0 in general. On the other hand, when a large earthquake occur in the region which Z is from 0.7 to 0.9, the structural damage may increase and the repair costs may increase. In this study, the analysis model was prepared under Z=1.0, 0.9, 0.8 respectively and the structure cost and repair cost was calculated.

RESEARCH OUTLINE

Original Design Model

The original design model was created based on the existing RC school building. The existing RC school building was built in Yamaguchi Prefecture, which was designed with Z=0.8. The 2nd floor framing plan of the original design model is shown in Figure 1 and the framing elevation of the original design model is shown in Figure 2. Table 1 and 2 show the beam and column cross section of the original design model. The existing RC school building needs much time to calculate structure cost and repair cost because the building has many kinds of cross section. Thus the original design model which has a few kinds of cross sections was made in order to examine more patterns.

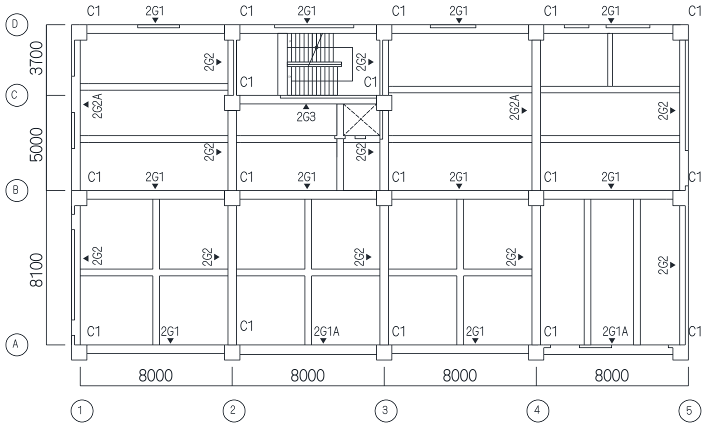

Figure 1. 2nd floor framing plan

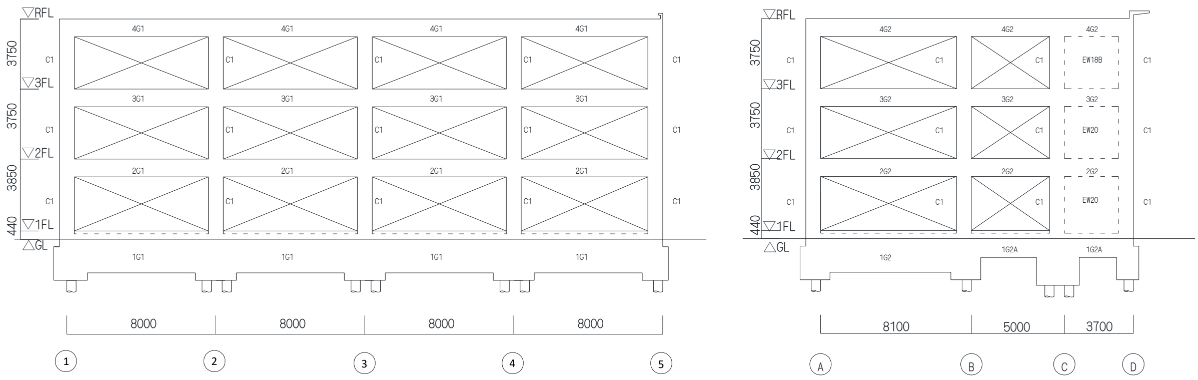

Figure 2. Framing elevation

Table 1. Girder cross section

			G1	G2	G3	G1A	G2A
R Floor	B×D		45×95	45×95	45×95	-	-
	Longitudinal bar	Upper	4-D25	5-D25	3-D25	-	-
		Lower	4-D25	4-D25	3-D25	-	-
	Stirrup		3-D10@150	3-D10@150	3-D10@150	-	-
Third Floor	B×D		45×95	45×95	45×95	-	45×100
	Longitudinal bar	Upper	6-D25	5-D25	7-D25	-	7-D25
		Lower	4-D25	4-D25	4-D25	-	5-D25
	Stirrup		4-D13@200	4-D13@200	4-D13@200	-	4-D13@200
Second Floor	B×D		45×95	45×95	45×95	50×100	45×100
	Longitudinal bar	Upper	6-D25	5-D25	7-D25	8-D25	7-D25
		Lower	4-D25	4-D25	4-D25	6-D25	5-D25
	Stirrup		4-D13@200	4-D13@200	4-D13@200	4-D13@200	4-D13@200
First Floor	B×D		45×180	45×180	45×180	-	45×100
	Longitudinal bar	Upper	7-D25	7-D25	7-D25	-	7-D25
		Lower	6-D25	6-D25	6-D25	-	6-D25
	Stirrup		8-D13@200	8-D13@200	8-D13@200	-	8-D13@200

Table 2. Column cross section

			C1
Third Floor	B×D		80×80
	Longitudinal bar		16-D25
	Hoop	X	4-D13@100
		Y	2-D13@100
Second Floor	B×D		80×80
	Longitudinal bar		16-D25
	Hoop	X	4-D13@100
		Y	2-D13@100
First Floor	B×D		80×80
	Longitudinal bar		16-D25
	Hoop	X	4-D13@100
		Y	2-D13@100

Analysis Model

A flowchart of this study is shown in Figure 3. Z=0.8 was multiplied by 1.125 and 1.25 to be equivalent to Z=0.9 and 1.0. Modification of member cross sections of the original design model are needed under Z=0.9 and 1.0 because seismic force is multiplied by 1.125 and 1.25 compared to Z=0.8. Table 3 shows a list of analysis model created by the modification of the member cross section. In this study, member cross section was modified by increasing of reinforcement bar diameter, the number of reinforcement bar, girder depth, girder width and column depth.

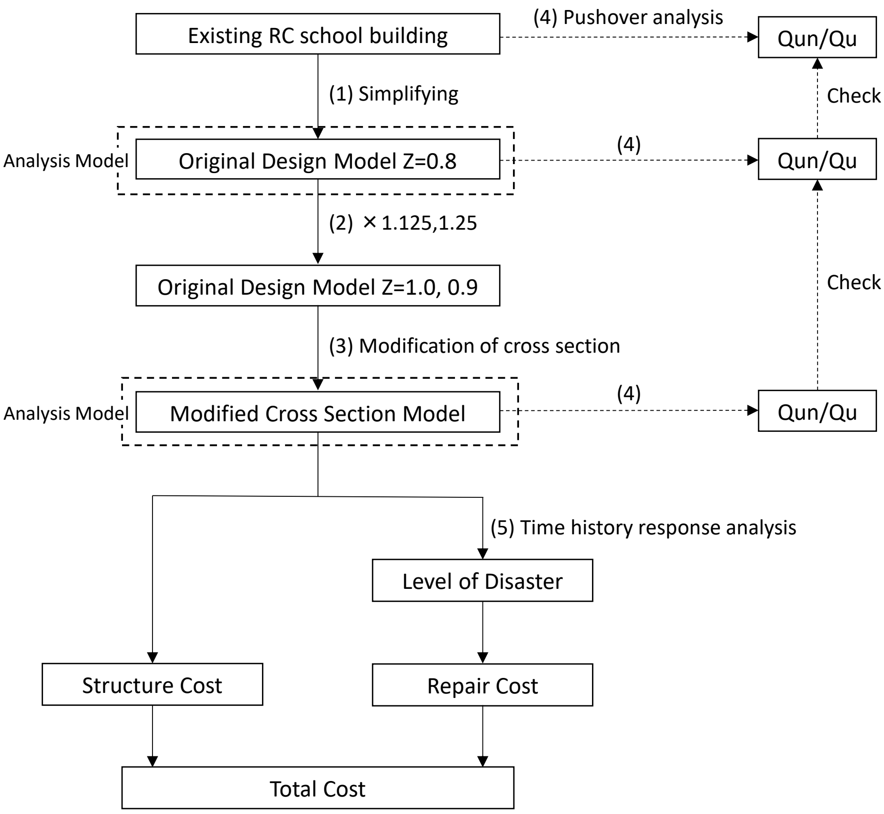

Figure 3. Flowchart of this study

Table 3. List of the analysis model

	Original Design Model	Modified Cross Section Model		
	Z = 0.8	Z = 0.9		Z = 1.0
		N*1	D*2	DN*3
No Modification in Cross Section	Original Design	N1	D1	-
Girder Depth +5cm	-	N2	D2	-
Girder Width +5cm	-	N3	D3	-
Girder Depth and Gither Width +5cm	-	N4	D4	-
Girder Width and Column Depth +5cm	-	N5	D5	DN5
Girder Depth and Column Depth +5cm	-	N6	D6	DN6

*1: Increase the number of longitudinal bar

*2: Increase longitudinal bar diameter

*3: Increase the number of longitudinal bar and longitudinal bar diameter

Pushover analysis

Pushover analysis is carried out to confirm that Qu/Qun of the modified cross section model is equivalent to Qu/Qun of the original design model. Qu/Qun means the horizontal load-carrying capacity margin that divides horizontal load-carrying capacity Qu by required horizontal load-carrying capacity Qun. The pushover analysis finishes when the maximum story drift angle reaches 1/50 rad. External force distribution used for pushover analysis is set based on Ai distribution (The Building Center of Japan, 2016).

Structure Cost

The calculation of structure cost include columns, girder, beams, slab, and shear wall. The structure cost was calculated by multiplying quantity of concrete, form and reinforcement bar by the unit price mentioned in the book (Reseach Institute on Price of Construction Materials and Wages, 2018; Reseach Institute on Building Cost and the Building Surveyor's Institute of Japan, 2017). Table 4 shows the unit price of the members.

Table 4 Unit price of the members

Reinforcement Bar (yen/kg)				Concrete (yen/m^3)		Form (yen/m^2)
D10	D13	D25	D29	Fc21	Fc24	
76,000	74,000	75,000	76,000	15,850	16,300	1,560

Time History Response Analysis

The time history response analysis was carried out about the original model(Z=0.8), D2(Z=0.9) and DN6(Z=1.0). The seismic waves used in this analysis are three seismic waves of EL Centro NS (1940), Hachinohe EW (1968) and Taft EW (1952). Table 5 shows the maximum acceleration, the maximum velocity and the duration of the three seismic waves used in this analysis. The velocity of these seismic waves were set to 25 cm/s and 50 cm/s, and the analysis was carried out with six seismic waves in total.

Table 5. Maximum acceleration, maximum velocity and duration of the three seismic waves

Seismic Wave	Maximum Acceleration (cm/s²)	Maximum Velocity (cm/s)	Duration (s)
ELCentro NS	341.70	33.59	53.74
Hachinohe EW	229.65	34.56	50.98
Taft EW	175.9	17.49	54.38

Repair Cost

The correspondence among story drift angle, level of disaster and repair cost is shown in Table 6. The level of disaster was determined based on the story drift angle obtained by the time history response analysis as in the guideline (Architectural Institute of Japan, 2004). The repair cost based on the level of disaster described in the existing research (Suwa, H., 2001) was used. When the story drift angle is less than 1/200, level of disaster is no damage or minor and the repair cost is 0 to 10,000 yen/m^2. When the story drift angle is 1/200 rad to 1/100 rad, level of disaster is minor damage and the repair cost is 10,000 to 29,000 yen/m^2. When the story drift angle is 1/100 rad to 1/75 rad, level of disaster is intermediate damage and the repair cost is 29,000 to 50,000 yen/m^2. The repair cost is calculated by multiplying the repair cost per unit floor area by the floor area.

Table 6. Correspondence among story drift angle, level of disaster and repair cost

Story Drift Angle (rad)	Level of Disaster	Repair Cost (yen/m²)
~1/200	No Damage or Minor	0～10,000
1/200 ~ 1/100	Minor Damage	10,000～29,000
1/100 ~ 1/75	Intermediate Damage	29,000～60,000
1/75 ~ 1/50	Major Damage	Rebuilding

Modeling Method

3D frame model is used in the pushover analysis and the time history response analysis. Girders are modeled by the uniaxial spring model. Columns and shear walls are modeled by the MN model. In the time history response analysis, Takeda-model is used for hysteresis loops of girders and columns. The damping constant was set to be instantaneous stiffness proportional type, and was 3% with respect to the first eigen period.

THE RESULT OF THE PUSHOVER ANALYSIS

The relationship between story shear force and story drift angle obtained by the pushover analysis is shown in Figure 4. The analysis results of Qu/Qun at the story drift angle of 1/200 rad, 1/100 rad and 1/50 rad are shown in Table 7. The story shear force of the original design model was smallest of the story shear force of all models. Qu/Qun of most modified cross section models were greater than equal to Qu/Qun of the original design model. Qu/Qun of N1, N3 and D1 were slightly lower at the story drift angle of 1/200 rad but they were greater than equal to Qu/Qun of the original design model at the story drift angles of 1/100 rad and 1/50 rad.

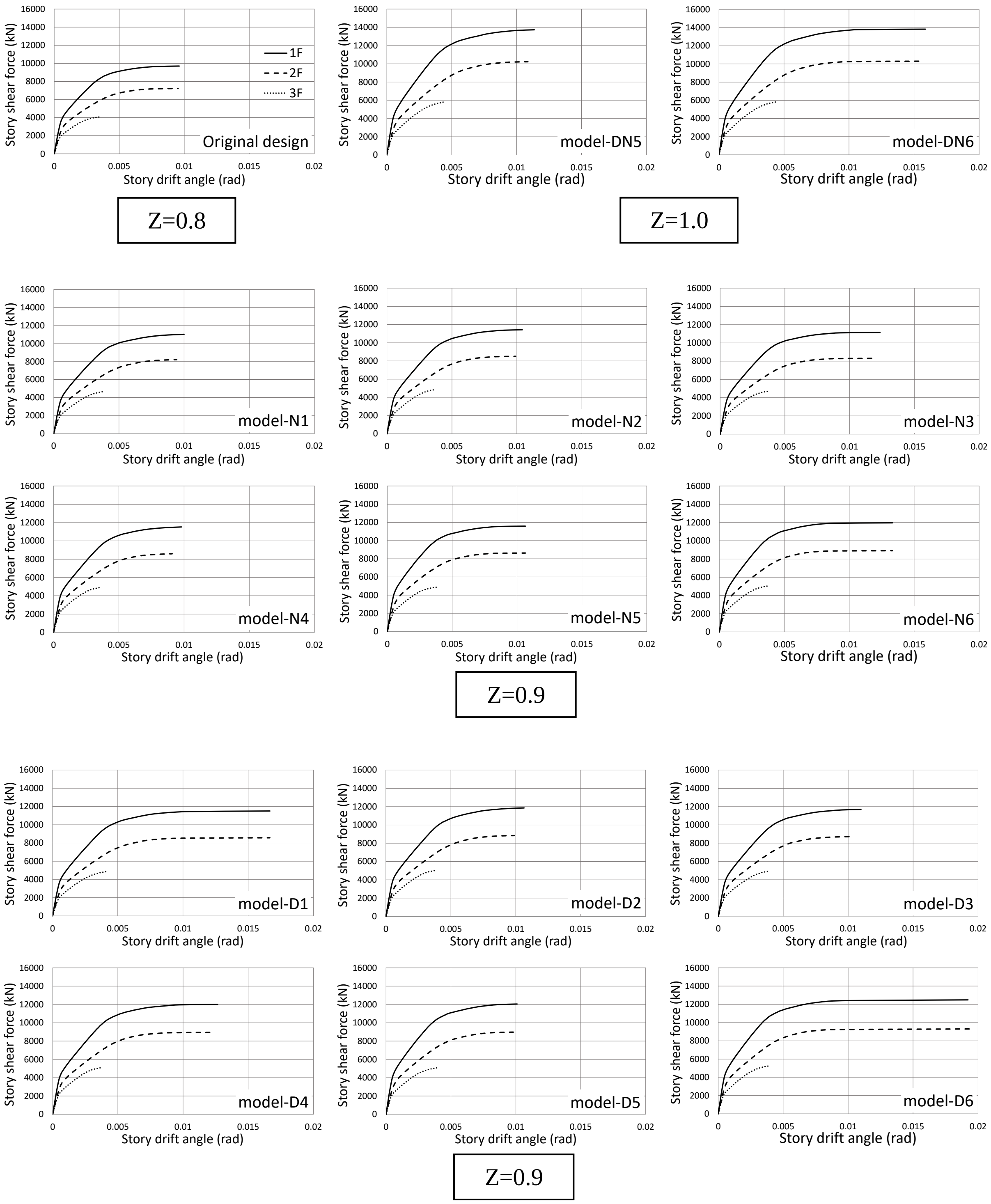

Figure 4. Relationship between story shear force and story drift angle

Table 7. Calculation result of horizontal load-carrying capacity margin (Qu/Qun)

Story Drift Angle		1/200 (rad)	1/100 (rad)	1/50 (rad)
Z	Model	Qu/Qun		
0.8	Original Design	1.30	1.40	1.40
0.9	N1	1.26	1.41	1.42
	N2	1.30	1.45	1.45
	N3	1.24	1.39	1.40
	N4	1.30	1.43	1.43
	N5	1.31	1.43	1.44
	N6	1.36	1.50	1.50
	D1	1.28	1.46	1.48
	D2	1.32	1.50	1.51
	D3	1.32	1.50	1.51
	D4	1.32	1.48	1.49
	D5	1.34	1.49	1.49
	D6	1.40	1.55	1.57
1.0	DN5	1.31	1.51	1.53
	DN6	1.35	1.58	1.60

THE CALCULATION RESULT OF STRUCTURE COST

The calculation result of the structure cost is shown in Table 8. The averages of increase rate for the structure cost were 8% for N1 to N6, 9.3% for D1 to D6, and 12% for DN5 to DN6. The averages of increase amount for the structure cost were 2.15 million yen for N1 to N6, 2.35 million yen for D1 to D6, and 3.30 million yen for DN5 to DN6.

Table 8. Calculation result of the structure cost (million yen)

Z	Model	Form	Concrete	Rebar	Total	Amount of Increase
0.8	Original Design	4.98	14.35	7.81	27.15	—
0.9	N1	4.98 (+0%)	14.35 (+0%)	9.27 (+19%)	28.62 (+5%)	1.46
	D1			9.51 (+22%)	28.86 (+7%)	1.70
	N2	5.04 (+1%)	14.59 (+2%)	9.35 (+20%)	28.99 (+7%)	1.84
	D2			9.61 (+23%)	29.25 (+8%)	2.10
	N3	5.01 (+1%)	14.97 (+4%)	9.39 (+20%)	29.37 (+8%)	2.22
	D3			9.58 (+23%)	29.56 (+10%)	2.41
	N4	5.07 (+2%)	15.24 (+6%)	9.46（+21%）	29.78 (+10%)	2.62
	D4			9.66 (+24%)	29.98 (+11%)	2.83
	N5	5.03 (+1%)	15.18 (+6%)	9.43（+21%）	29.65 (+10%)	2.49
	D5			9.63 (+23%)	29.85 (+11%)	2.69
	N6	5.07 (+2%)	14.80 (+3%)	9.56 (+23%)	29.44 (+8%)	2.29
	D6			9.61 (+23%)	29.49 (+9%)	2.34
1.0	DN5	5.03 (+1%)	15.18 (+6%)	10.41 (+36%)	30.63 (+13%)	3.48
	DN6	5.07 (+2%)	14.80 (+3%)	10.39 (+35%)	30.27 (+11%)	3.11

THE RESULT OF TIME HISTORY RESPONSE ANALYSIS

The maximum story shear force obtained by the time history response analysis is shown in Figure 5. The maximum story drift angle obtained by the time history response analysis is shown in Figure 6. The maximum story shear force of the third floor of each case were almost the same, but the maximum story shear force of the first floor of each case were considerably different. The maximum story drift angle of Z=1.0 was smallest in most cases. The maximum story drift angle of Z=0.8 was largest in most cases. The maximum story shear force was smallest in the three seismic waves when Hachinohe wave was inputted. The maximum story shear force was slightly larger than that of EL Centro wave when Taft wave was inputted.

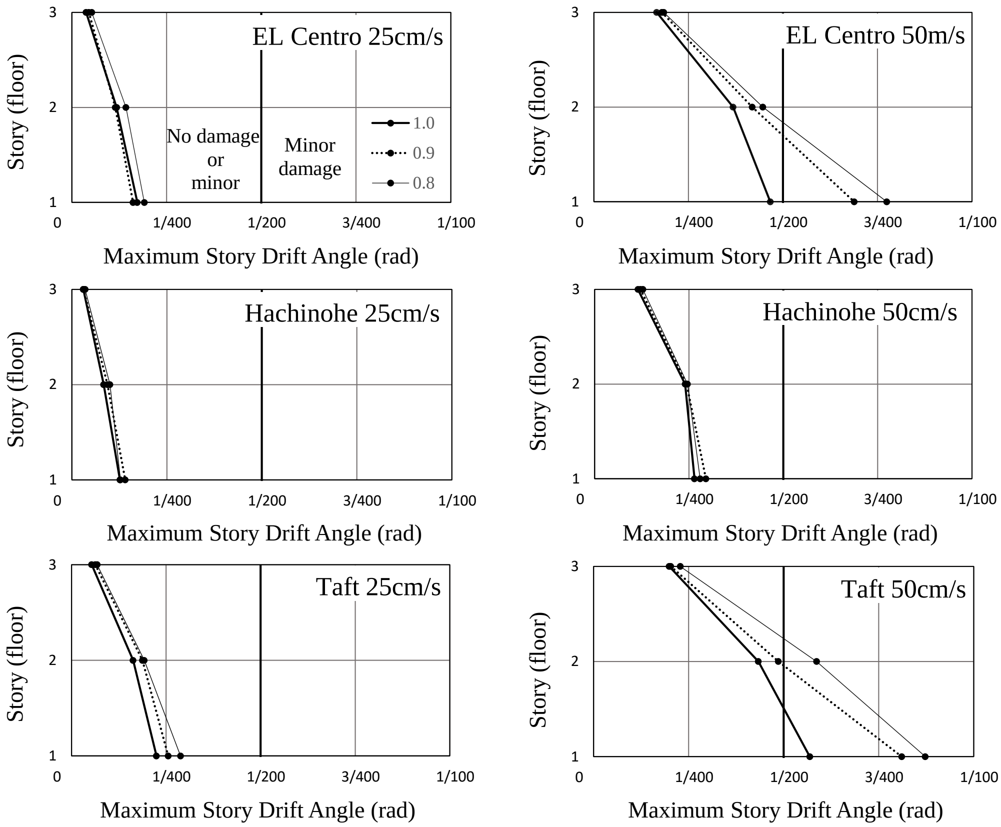

Figure 5. Maximum story shear force

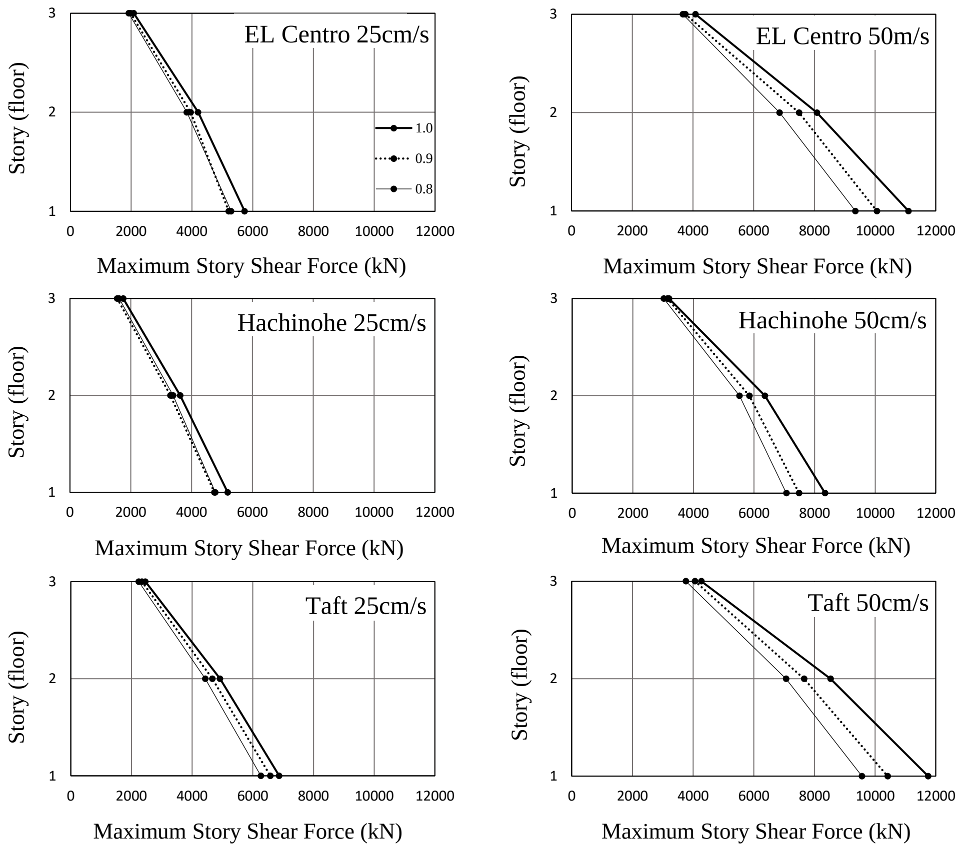

Figure 6. Maximum story drift angle

THE CALCULATION RESULT OF REPAIR COST

The calculation result of repair cost of each case is shown in Table 9. Table 9 indicates the minimum and maximum repair cost of each case. The repair cost was the same for 3 waves of 25 cm/s, regardless of the seismic zoning factors. The repair cost was the same for Hachinohe wave of 50 cm/s, regardless of the seismic zoning factors. When the EL Centro wave of 50 cm/s was inputted, the repair cost of Z=1.0 was lowest and the repair cost of Z=0.8 was almost the same as the repair cost of Z=0.9. When the Taft wave of 50 cm/s was inputted, the repair cost of Z=0.8 was highest and the repair cost of Z=1.0 was almost the same as the repair cost of Z=0.9.

Table 9. Calculation results of repair cost (million yen)

		25(cm/s)			50(cm/s)		
Z	Floor Number	EL Centro	Hachinohe	Taft	EL Centro	Hachinohe	Taft
0.8 (Original)	1	0 ~ 5.38 (No Damage or Minor)			5.38 ~ 15.59 (Minor Damage)	0 ~ 5.38 (No Damage or Minor)	538 ~ 15.59 (Minor Damage)
	2				0 ~ 5.38 (No Damage or Minor)		
	3						0 ~ 5.38 (No Damage or Minor)
	Floor Total	0 ~ 16.14			5.38 ~ 26.35	0 ~ 16.14	10.76 ~ 36.56
0.9 (D2)	1	0 ~ 5.38 (No Damage or Minor)			5.38 ~ 15.59 (Minor Damage)	0 ~ 5.38 (No Damage or Minor)	5.38 ~ 15.59 (Minor Damage)
	2				0 ~ 5.38 (No Damage or Minor)		0 ~ 5.38 (No Damage or Minor)
	3						
	Floor Total	0 ~ 16.14			5.38 ~26.35	0 ~ 16.14	5.38 ~ 26.35
1.0 (DN6)	1	0 ~ 5.38 (No Damage or Minor)			0 ~ 5.38 (No Damage or Minor)	0 ~ 5.38 (No Damage or Minor)	5.38 ~ 15.59 (Minor Damage)
	2						0 ~ 5.38 (No Damage or Minor)
	3						
	Floor Total	0 ~ 16.14			0 ~16.14	0 ~ 16.14	5.38 ~ 26.35

TOTAL COST COMPARISON

The total cost including the structure cost and the repair costs of the analysis model is shown in Figure 7. Figure 7 indicates the maximum total cost when the three waves of 50cm/s were inputted. When the El Centro wave of 50 cm/s was inputted, the structure cost of Z=0.8 was lowest. However the total cost of Z=1.0 was lowest because the repair cost of Z=1.0 was lowest. When the Hachinohe wave of 50 cm/s was inputted, the repair cost of all seismic zoning factors were the same. Thus the total cost of Z=0.8 was lowest. When the Taft wave of 50 cm/s was inputted, the structure cost of Z=0.8 was lowest. However the total cost of Z=0.8 was highest because the repair cost of Z=0.8 was much higher.

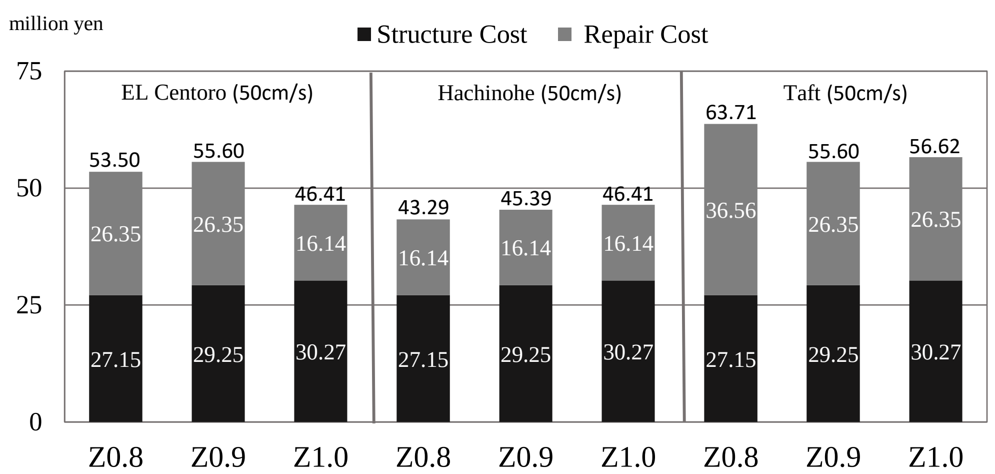

Figure 7. Calculation results of total cost (50cm/s waves)

CONCLUSION

The structure cost, the repair cost and the total cost were calculated under the modifying the cross sections due to the increase of the seismic zoning factors. The findings are summarized as follows.

- Depending on the modification of the cross sections due to the increase of the seismic zoning factors, the averages of increase rate for the structure cost were 8% for N1 to N6 (Z=0.9), 9.3% for D1 to D6 (Z=0.9) and 12% for DN5 to DN6 (Z=1.0).
- The repair costs were the same for the three waves of 25 cm/s, regardless of the seismic zoning factors. The repair costs were the same for Hachinohe wave of 50 cm/s, regardless of the seismic zoning factors. When EL Centro wave of 50 cm/s was inputted, the repair cost of Z=1.0 was lowest and the repair cost of Z=0.8 and that of Z=0.9 were almost the same. When the Taft wave of 50 cm/s was inputted, the repair cost of Z=0.8 was highest and the repair cost of Z=1.0 and that of Z=0.9 were almost the same.
- When the EL Centro wave of 50 cm/s was inputted, the total cost of Z=1.0 was lowest. When the Hachinohe wave of 50 cm/s was inputted, the total cost of Z=0.8 was lowest. When the Taft wave of 50 cm/s was inputted, the total cost of Z=0.8 was highest.

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