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Earthquake Loss Estimation in Seoul Metropolitan Regions in Korea under Moderate Earthquake Scenarios

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ABSTRACT:

The purpose of this study is to evaluate the sensitivity of earthquake loss to the variation of earthquake magnitude and epicentral distance in low-to-moderate seismicity regions such as Seoul in Korea. Loss estimation is performed using the methodology of HAZUS, developed by FEMA to analyze and estimate losses from disasters. Structure inventory includes the structural type very popular in Korea but unavailable in HAZUS such as residential RC wall-type building structures. The magnitude of scenario earthquake is varied from 5.5 to 6.5. The epicentral distance is also varied from 15 to 25km from the center of the study region. In this study, the direct loss by the main shock is estimated, but the loss due to liquefaction, landslide, fire, and so on following the earthquake are not considered.

1 INTRODUCTION

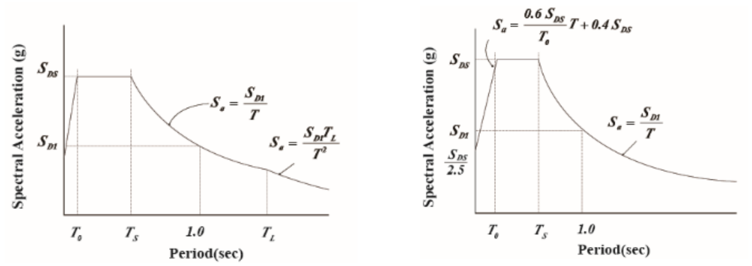
Currently, 40% of the total population in Korea lives in Seoul, and Gangnam-gu is one of the congested districts of Seoul including many housing, commercial facilities, and social facilities. In addition, a number of building were built with non-seismic design. For this reason, significant damages by earthquake will occur and it lead to economic losses and casualties. Recently, large earthquakes threatened the safety of nearby people and structures. On February 27, 2010 at 03:34 am local time, a powerful earthquake of magnitude 8.8 struck central Chile. The earthquake caused the death of 521 persons, and more than a third of a million buildings were damaged to varying degrees, including several cases of total collapse of major structures(2010, Elnashai). The great Wenchuan Earthquake occurred on May 12, 2008 in the Sichuan Province of China, and had a magnitude of 8.0. According to official reports, there were 69,225 deaths, 379,640 injuries and 17,939 missing as of Aug. 11, 2008 (2008, Yifan). A moment magnitude (Mw) 6.2 earthquake struck beneath the outer suburbs of Christchurch, New Zealand’s second largest city, on 22 February 2011 local time. The effects of the earthquake on the region’s population and infrastructure were severe including 181 fatalities, widespread building damage, liquefaction and landslides (2012, Kaiser). In 2010, a magnitude 7.0 earthquake struck the Republic of Haiti, with an epicentre located approximately 25km south and west of the capital city of Port-au-Prince. Near the epicentre of the earthquake, in the city of Leogane, it is estimated that 80~90% of buildings were critically damaged or destroyed (2012, DesRoches).

In this study, earthquake scenario analysis was conducted to evaluate the sensitivity of earthquake loss to the variation of combination of magnitude (M) and epicentral distance (R) in Gangnam-gu, Seoul, Korea. Loss estimation was conducted by using the methodology of HAZUS, developed by FEMA to analyze and estimate losses from disasters.

2 SELECTING THE EARTHQUAKE SCENARIOS FOR DESIGN EARTHQUAKE IN KOREA

2.1 Response spectrum of design earthquake in Korea

Recently, seismic design in KBC2009 is legislated following the design philosophy of American Society of Civil Engineers (ASCE) in U.S. For this reason design earthquake spectrum of KBC and ASCE are similar. Figure 1 compares the design spectrums. These are almost same, but the region of constant spectral displacement is not existed on KBC spectrum. Figure 2 shows design earthquake spectrum of KBC2009 for Seoul. The study region, Gangnam-gu almost has S_D soil condition. Herein assumed whole the study regions soil types are S_D.



(a) ASCE 7-10 (b) KBC 2009

Figure 1. Compare the design spectrums

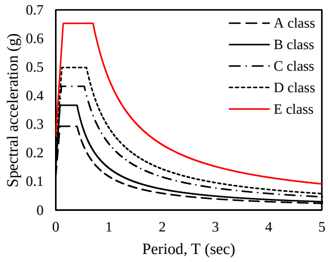


Figure 2. Design spectrums for Seoul

2.2 Scenario earthquake and DE response spectrum

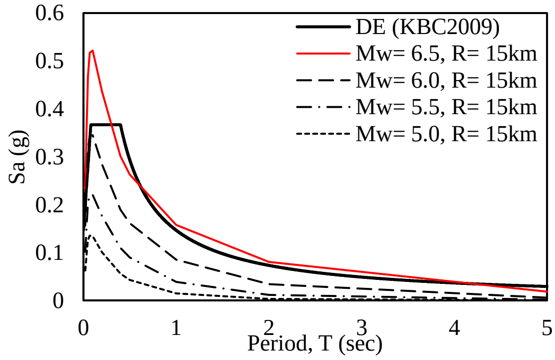
Earthquake with magnitude larger than 6 and epicentral distance less than 10 km are associated with scenarios of vary low probability of occurrences in low-moderate seismicity (2012, Lumantarna). Earthquake scenarios are determined for combinations of the magnitude ($5.0 \le M \le 6.5$) and epicentral distance (15 km $\le R \le$ 45 km) based on the design earthquake (DE) in Korea in Korean Building Code 2009 (KBC 2009). To select the scenario earthquakes corresponding DE, response spectrums of scenario earthquakes are developed using attenuation relationship. Equation 1 is attenuation relationship developed by Jo and Baag (2003) in Korea.

$$\ln A = C_0 + C_1 R + C_2 \ln R - \ln[\min(R, 100)] - \frac{1}{2}\ln[\max(R, 100)] \quad (1)$$

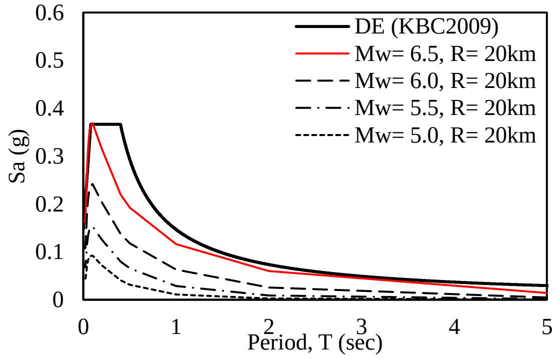
where, A, R, M_w and C are acceleration (cm/sec^2), epicentral distance (km), magnitude and coefficient. For scenario cases that M_w is changed 5.0 to 6.5 and epicentral distance changed 15 to 45km, scenario spectrums are developed by attenuation relations and compared with design earthquake in KBC 2009. Figure 3a, b, c and d show the comparing scenario earthquake spectrums with design spectrum of KBC2009. Figure 3a shows scenario spectrums with epicentral distance 15km. Mw 6.5 scenario of these is similar with the constant spectral velocity region of design earthquake spectrum. And M_w 6.0 scenario of these is similar with spectral acceleration values at short period. Figure 3b shows scenario spectrums with epicentral distance 20km. M_w 6.5 scenario of these is similar with design earthquake overall. In the scenario which epicentre is farther from study region than 20km, scenario earthquake spectrums are no corresponded with design earthquake in Korea depicted in Figure 3c and d. Table 1 shows a result of scenario earthquakes corresponding design earthquake in Korea.

Table 1. Selected earthquake scenarios corresponding design earthquake in Korea

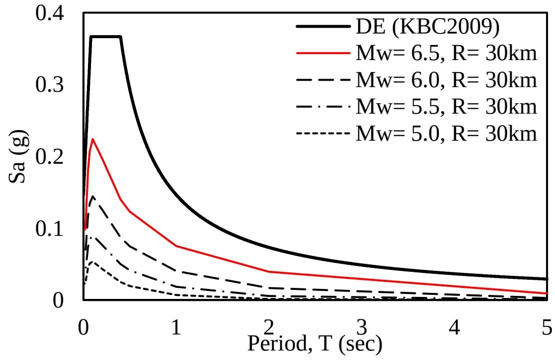
	Magnitude, M_w	Epicentral distance (km)
Case 1	6.0	15
Case 2	6.5	15
Case 3	6.5	20



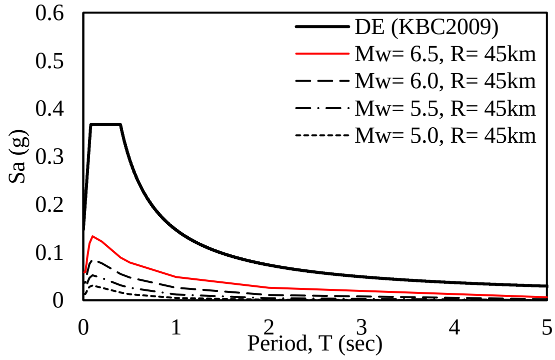
(a) Epicentral distance= 15km



(b) Epicentral distance= 20km



(c) Epicentral distance= 30km



(d) Epicentral distance= 45km

Figure 3. Comparing scenario earthquake spectrums with design spectrum of KBC2009

3 DAMAGE OF BULIDING STRUCTURES FOR SCENARIO EARTHQUAKES

Hazus is developed by FEMA in U.S to estimate the losses by disaster with earthquake, flood and wind. Herein paper follows the loss estimation methodology of Hazus to estimate earthquake losses in Gangnam-gu, Seoul in Korea. Figure 4 shows flowchart of the earthquake loss estimation methodology of Hazus. According to this methodology, inundation, fire, debris, casualties, shelter and direct/indirect economic loss can be estimated. However, in this study, just direct loss of Gangnam-gu is estimated. Gangnam-gu is congested areas for social economy activity and housing. This area consists of 14 division areas, called 'Dong' units. Table 2 shows the name of division districts, and Table 3 and 4 show building inventories classified by building type and occupancy. In the building type classification, S1 is steel MRF, C1 is concrete MRF, C2 is concrete shear wall and C3 is concrete MRF with infilled wall. L, M and H are low, mid and high rise building. Thus, S1M means midrise steel MRF building. Occupancy is divided into residential, commercial, industrial, agriculture, religion/non-profit, government and education building. However, buildings for industrial and agriculture are not in Gangnam-gu. Very few steel buildings is in study regions and low rise concrete buildings are constructed in Gangnam-gu, depicted in Table 3. Table 4 shows that most structure is building for residence or commercial.

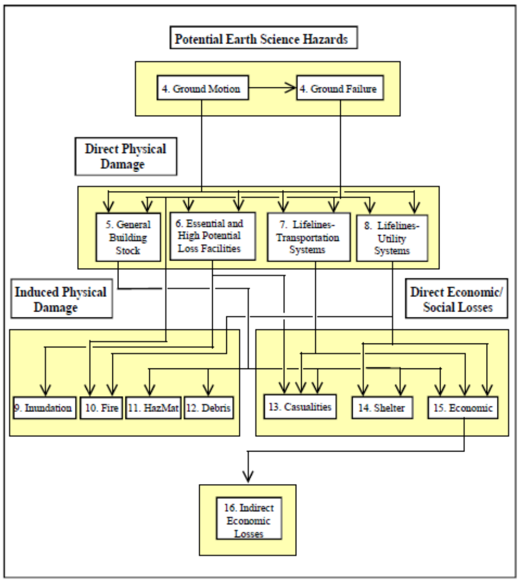


Figure 4. Flowchart of the earthquake loss estimation methodology.

Table 2. Division of study region, Gangnam-gu

District No.	1	2	3	4	5	6	7
Name	Apgujeong	Cheongdam	Sinsa	Nonhyeon	Samseong	Daechi	Yeoksam
District No.	8	9	10	11	12	13	14
Name	Dogok	Gaepo	Irwon	Suseo	Jagok	Segok	Yulhyeon

Table 3. Building inventory by building type

	S1L	S1M	S1H	C1L	C1M	C1H	C2L	C2M	C2H	C3L	Total
district 1	0	0	0	9	0	1	23	2	131	3	169
district 2	12	4	0	293	34	10	427	70	78	370	1298
district 3	6	3	1	762	41	2	591	2	7	310	1725
district 4	1	0	0	682	152	9	1813	8	30	1061	3756
district 5	0	0	3	426	188	3	932	4	112	235	1903
district 6	2	0	0	501	103	47	893	5	184	335	2070
district 7	0	0	1	808	303	168	1936	0	103	1007	4326
district 8	0	1	1	344	12	17	266	0	147	0	788
district 9	1	0	0	236	2	2	872	0	521	214	1848
district 10	0	0	0	143	0	0	448	0	195	237	1023
district 11	0	0	0	50	0	4	45	0	82	0	181
district 12	0	0	0	0	0	0	206	0	76	0	282
district 13	0	0	0	3	0	0	224	0	82	0	309
district 14	2	0	0	5	0	0	175	0	32	0	214
Total	24	8	6	4262	835	263	8851	91	1780	3772	19892

Table 4. Building inventory by general occupancy

	Residential	Commercial	Religion	Government	Education	Total
district 1	153	5	1	2	8	169
district 2	749	532	7	2	8	1298
district 3	603	1110	8	1	3	1725
district 4	2745	1001	6	2	2	3756
district 5	1084	801	5	10	3	1903
district 6	1404	650	5	3	8	2070
district 7	2903	1391	10	9	13	4326
district 8	402	372	3	2	9	788
district 9	1591	233	4	8	12	1848
district 10	873	141	4	0	5	1023
district 11	120	47	2	7	5	181
district 12	280	0	0	0	2	282
district 13	302	3	1	0	3	309
district 14	206	5	0	3	0	214
Total	13415	6291	56	49	81	19892

Figure 5 shows building occupancy distribution of division districts. Twice of buildings are in Nonhyeon and Yeoksam than other districts.

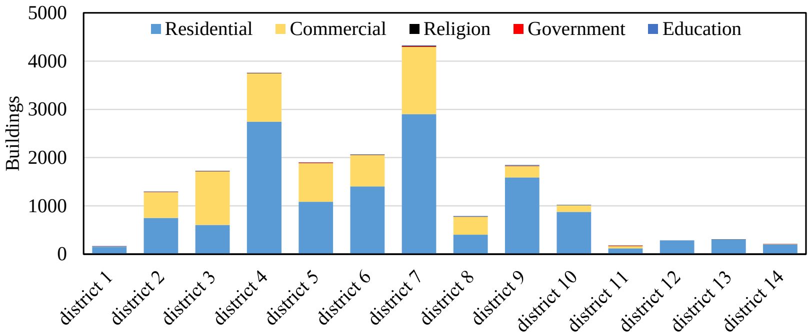


Figure 5. Building occupancy distribution of each districts

3.1 Definition of damage states

Damage states are defined following definition of Hazus. Damage states consisted of 4 states, slight, moderate, extensive and complete damage. Generally, slight damage means that small cracks at corners of elements and minor deformations in connections occur, moderate damage means that large cracks at corners of elements occur and some steel members have yielded, Extensive damage means that most elements have exceeded their yield capacities and complete damage means that Structure has collapsed or is in imminent danger of collapse. In Hazus, collapse is defined some percentages of buildings reaching or exceeding complete damage state.

3.2 Probability and building count of reaching damage states

To calculate probability of reaching damage states, seismic performance assessment method of ATC 40 and fragility analysis are carried out. After scenario spectrums developed in previous chapter are changed into Acceleration-Displacement Response Spectrum (ADRS) format, performance point can be calculated using capacity curves of structures. Target spectral displacement and acceleration can be obtain by performance point, and probabilities corresponding target values are obtained. In this study, capacity curves and fragility curves given in Hazus is used, because structures in Korea and U.S are not much different. Figure 6 shows scenario spectrum ADRS format. The constant spectral acceleration region is defined by the short period spectral acceleration, obtained through attenuation relationships. The region of constant spectral velocity has the spectral acceleration proportional to 1/T and is attached to the spectral acceleration at a period of 1 second, obtained through attenuation relationships. T_{AV} is obtained as the intersection of the regions of constant spectral acceleration and constant spectral velocity. The constant spectral displacement region has spectral acceleration proportional to $1/T^2$ and it is attached to T_{VD}. T_{VD} can be calculated by equation 3.

$$T_{VD} = 10^{\frac{M-5}{2}} \quad (3)$$

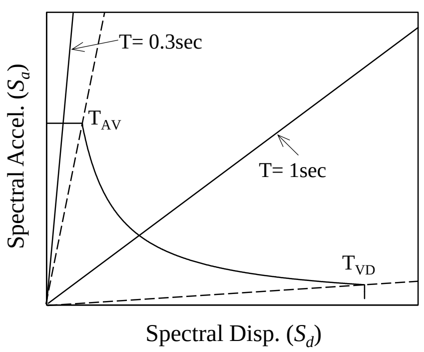


Figure 6. Standardized response spectrum shape

Figure 7 shows Calculation the performance point. Standardized scenario spectrum is reduced by acceleration domain reduction factors, R_A and velocity domain reduction factor, R_V. Capacity curve intersects reduced response spectrum. The intersecting point is performance point. The reduction factors are based on effective damping, β_{eff}, as given in equations 4 and 5 below.

$$R_A = 2.12/(3.21 - 0.68\ln(100B_{eff})) \quad (4)$$

$$R_V = 1.65/(2.31 - 0.41\ln(100B_{eff})) \quad (5)$$

Effective damping, β_{eff} is also a function of the amplitude of response, as expressed in equation 6.

$$B_H = \kappa \left(\frac{Area}{2\pi\ D\ A} \right) \quad (6)$$

Figure 8 shows probabilities of reaching damage state obtained by performance point. Figure 9 shows damaged building counts of reaching damage state. Table 5 shows one example of probabilities of reaching damage states located in district 1. Figure 9a, b and c show damage count of low rise concrete buildings which have larger building count then the others. Figure 9d and e show the damage count of residential and commercial building. The second case scenario cause larger damage to building structures than the other scenarios. The third case scenario cause similar damage counts with the first case scenario.

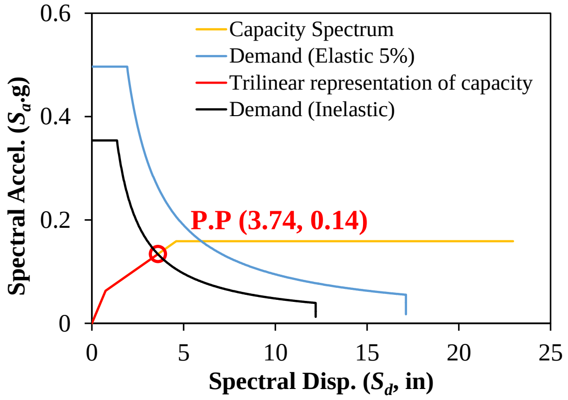


Figure 7. Calculation the performance point

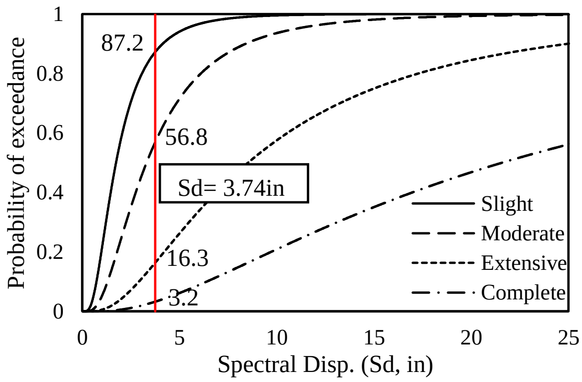
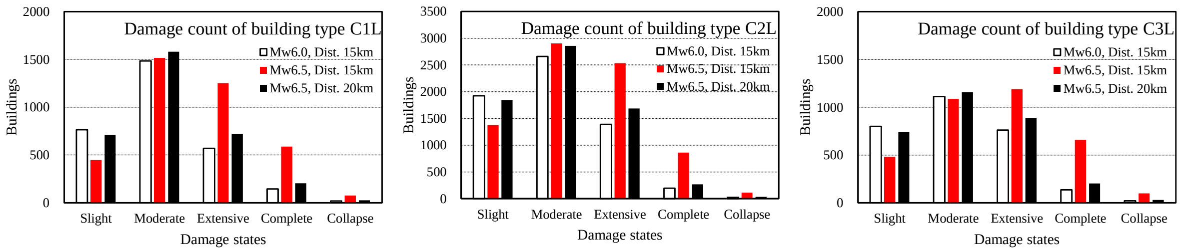


Figure 8. Calculation the probability of reaching damage states (district 1.C2H M_w= 6.5. R=15km)

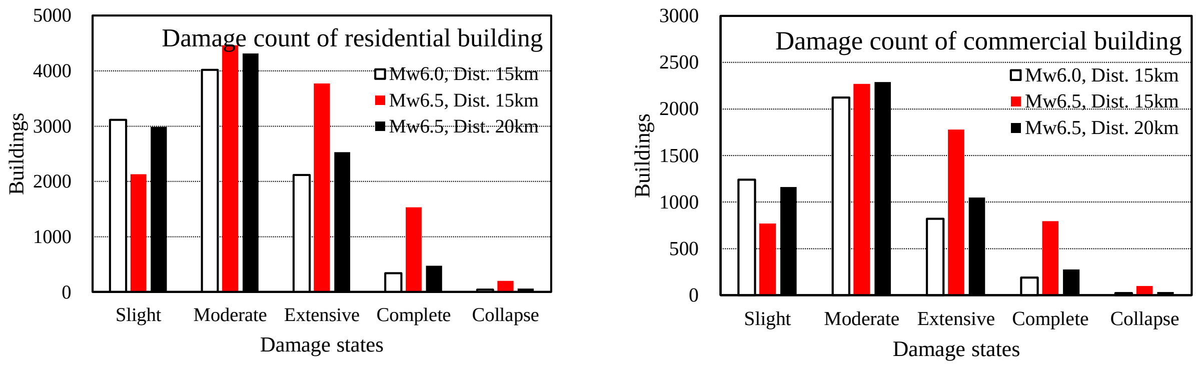
Table 5. Probabilities of reaching damage states located in district 1

Building type	M_w 6.0, Dist. 15km				M_w 6.5, Dist. 15km				M_w 6.5, Dist. 20km			
	Slight	Moderate	Extensive	Complete	Slight	Moderate	Extensive	Complete	Slight	Moderate	Extensive	Complete
C1L	0.190	0.321	0.099	0.021	0.129	0.379	0.249	0.093	0.175	0.364	0.150	0.039
C1H	0.247	0.289	0.081	0.018	0.158	0.406	0.267	0.113	0.249	0.352	0.124	0.032
C2L	0.228	0.277	0.119	0.011	0.179	0.339	0.254	0.060	0.223	0.301	0.148	0.017
C2M	0.295	0.247	0.029	0.008	0.241	0.422	0.132	0.044	0.295	0.320	0.054	0.016
C2H	0.327	0.183	0.030	0.005	0.303	0.405	0.131	0.032	0.354	0.266	0.055	0.010
C3L	0.223	0.282	0.173	0.023	0.147	0.303	0.305	0.130	0.209	0.301	0.212	0.039



(a) Concrete MRF (b) Concrete shear wall (c) Concrete MRF with infilled wall

Figure 9. Damaged building counts of reaching damage state



(d) Residential building (e) Commercial building

Figure 9. Damaged building counts of reaching damage state (continued)

4 ESTIMATION DIRECT ECONOMIC LOSSES BY DAMAGES OF STRUCRES

The results of damage estimates in the previous chapter are used in the estimation of the direct economic losses. Direct economic loss is represented by building replacement cost, repair cost ratios and probability of reaching damage states of model structures. The distribution of the structural building types will vary for each occupancy type building and district. Figure 10 shows a schematic representation. The green box represents on single district. The large circle represent the different occupancy type building, such as residential, commercial, and so on. And the small circles represent the different structural type buildings within an occupancy type building. Replacement costs are used the average of spot price of buildings in Gangnam-gu. Repair cost is expressed as equation 7 and 8 below.

$$CS_{ds,i} = \sum_i BRC_i \times PMBTSTR_{ds,i} \times RCS_{ds,i} \quad (7)$$

$$CS_i = \sum_{ds} CS_{ds,i} \quad (8)$$

Where, $CS_{ds,i}$ is cost of structural damage (repair and replacement costs) for damage state *ds* and occupancy I, BRC_i is building replacement cost of occupancy *i*, $PMBTSTR_{ds,i}$ is probability of occupancy *i* being in structural damage state *ds* and $RCS_{ds,i}$ is structural repair and replacement ratio for occupancy *i* in damage state *ds*. Table 6 shows fractions of the total replacement cost of buildings located in district 1 in the first case scenario. In Table 6, RES3 (B~F) means multi family dwelling with 3~50 units, COM1 means store for retail trade, COM2 means warehouse, COM4 office for professional or technical service, REL1 means church or building for non-profit, GOV1 is office for general service, GOV2 is emergency response service such as police, fire station and EOC, and EDU1 is grade schools.

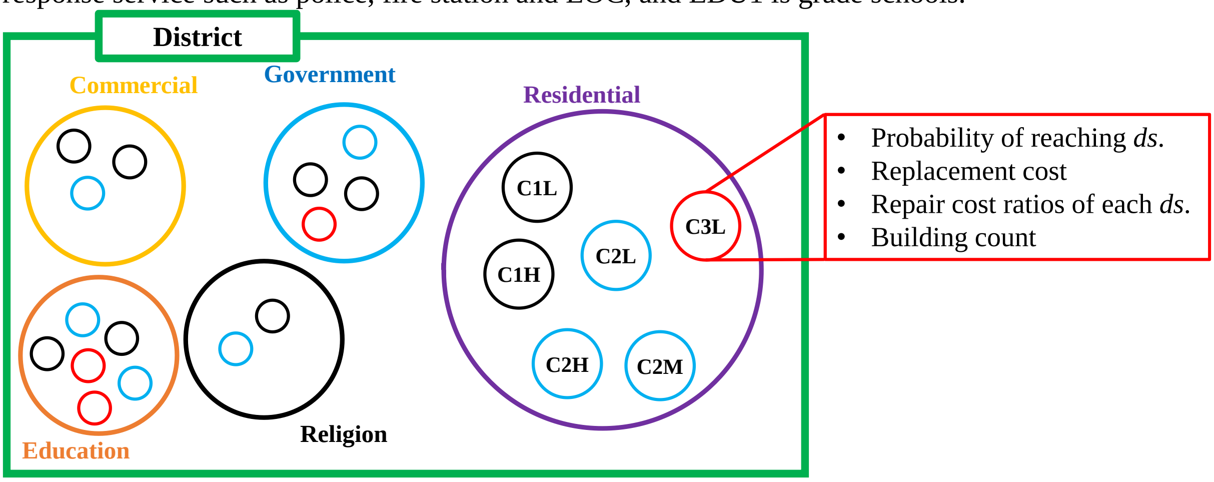
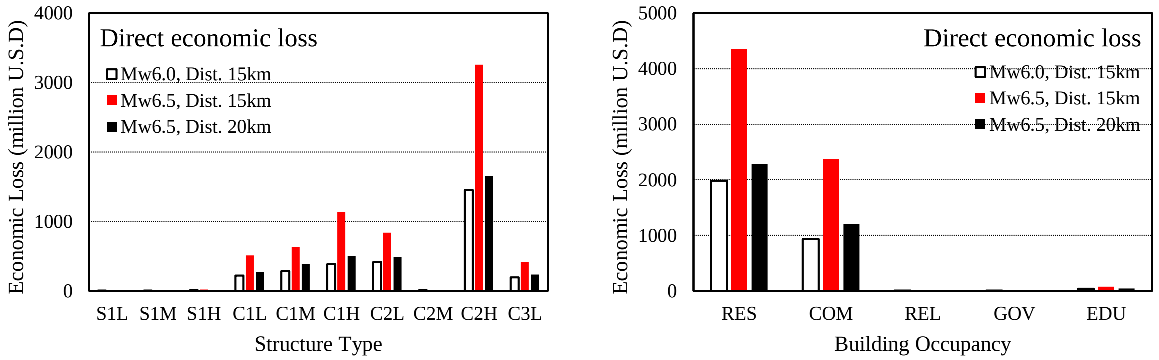


Figure 10. Schematic representation of the distribution of structural and occupancy type buildings in a district

Figure 11 shows the direct economic loss occurred in the whole study region. Damages of high rise concrete shear wall buildings caused the largest loss occurred, depicted in Figure 13a. Most of the C2H type buildings are high rise RC residential building. This type of building has almost 10 percentages of the whole buildings in study region and has the highest denomination in Gangnam-gu. In this reason, occurring large economic loss from damage of C2L is reasonable. Figure 13b shows economic loss as a building occupancy. Two third parts of entire economic loss occurred from damage of residential buildings and one third parts of economic loss occurred from damage of commercial buildings. In the first case scenario, direct economic loss in Gangnam-gu is 2.97 billion U.S. $. In the second case scenario, direct economic loss in Gangnam-gu is 6.83 billion U.S. $. In the third case scenario, direct economic loss in Gangnam-gu is estimated about 3.55 billion U.S. $.

Table 6. fractions of the total replacement cost of buildings located in district 1

Building type	Occupancies										
	RES3B	RES3C	RES3D	RES3F	COM1	COM2	COM4	REL1	GOV1	GOV2	EDU1
C1L	0	0	0	0	0.0312	0.0685	0.0204	0.0209	0.0190	0.0162	0.0404
C1M	0	0	0	0	0	0	0	0	0	0	0
C1H	0	0	0	0	0	0.0297	0	0	0	0	0
C2L	0	0.242	0	0	0	0	0	0	0	0	0.1171
C2M	0	0	0.0150	0	0	0	0	0	0	0	0
C2H	0	0	0	0.829	0	0	0	0	0	0	0
C3L	0.0595	0	0	0	0	0	0	0	0	0	0
Total	0.0595	0.2424	0.0150	0.829	0.0312	0.0981	0.0204	0.0209	0.0190	0.0162	0.1575



(a) (b)

Figure 11. Direct economic losses for (a) building type and (b) occupancy classification

5 CONCLUSIONS

The results of earthquake loss estimation in Seoul metropolitan regions are as follow.

Scenario earthquakes corresponding design earthquake in Korea have 3 cases. First, scenario is M_w 6.5 and epicentral distance 15km earthquake Second scenario is M_w 6.0 and epicentral distance 15km earthquake. Last scenario is M_w 6.5 and epicentral distance 20km earthquake. Last scenario is most similar with design earthquake in Korea than the other scenarios.

Large damage count is occurred from damage of the building types which are low rise concrete building with MRF, shear wall or MRF with infilled wall.

In the results of economic loss estimation, the largest loss is occurred from damages of high rise concrete shear wall buildings. About 1650 million U.S.D. loss are occurred from damages of C2H buildings by the third case scenario. This loss is 47% of total economic loss, 3550 million U.S.D.

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