철근콘크리트구조의 경제적인 내진 신뢰성

Cost-effective Reliability of RC structure in Korea under earthquake

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요 약

지진이 발생하는 환경에서 철근콘크리트구조의 신뢰성을 수명주기비용에 근거하여 체계적으로 평가하는 방법을 제시하였다. 구조물의 기능성과 경제적인 효용성을 나타내기 위하여 각각 손상확률과 평균수명주기비용의 개념을 사용하였다. 생애주기 동안 발생할 수 있는 지진에 의하여 구조물이 입게 될 손상을 보상하기 위하여 소요되는 평균손상비용을 평균수명주기비용의 주요 항목으로 고려하여 분석하였다. 구조물의 다양한 손상상태에서 손상비용을 나타내기 위해 요구되는 비용함수는 Park-Ang 손상지수의 중앙값을 독립변수로 하는 함수로 가정하였다. 지진에 의한 구조물의 손상해석은 UCI에서 개발된 SMART-DRAIN의 시뮬레이션기법을 사용하여 그 불확실성을 고려하였다.

제시된 방법을 현행 규준에 의하여 설계된 7층 사무실 건물에 적용하여 그 가능성을 살펴보았다.

1. Introduction

In structural design, the acceptable safety level of structure is ensured by satisfying the

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• 본 논문에 대한 토의를 1997년 12월 30일까지 학회로 보내주시면 1998년 2월호에 토의회답을 게재하겠습니다.

requirements of design code, which is necessary but not sufficient condition in economic point of view. Cost-effective criteria of structural design can be developed by considering reliability and its effect on the life cycle cost (LCC). In order to develop more cost-effective criteria of the seismic design code, the level of reliability and LCC of the structures designed by the current code need to be evaluated at the same time. These concepts can be implemented by proper integration of seismic hazard analysis, damage assessment and LCC evaluation process. Thus, the procedure to develop the optimal design criteria needs to include: (1) estimation of structural damage under earthquake (2) estimation of total life time cost (3) reliability assessment and determination of target reliability. In this study, a systematic approach for evaluation of cost-effective reliability based on these concepts is presented.

2. Expected life cycle cost

2.1 Expectation life cycle cost

LCC for the building is the sum of all the expenditures associated with all items during its entire service life. Cost items of the building at the seismic zone can be classified into initial cost and damage cost due to earthquake. Damage cost of the building at the seismic zone needs to be expressed by expected value because of the uncertain characteristics of the earthquake. For a given intensity of the earthquake, combining the initial cost with expected damage cost (EDC) yields expected life cycle cost (ELCC) as follows.

$$E[C_t] = C_i + E[E_d] \tag{1}$$

where C_t is life cycle cost, C_i is initial cost, and C_d is damage cost due to earthquake.

The EDC at the arbitrary time of a seismic occurrence could be obtained by integrating all possible damage costs for the damage level under a given level of earthquake intensity, as well as by integrating for all possible earthquake intensities. As the damage cost is due to future events, it needs to be expressed as present value to be on a common basis with initial cost. Thus, the present value of EDC can be expressed as

$$E[C_d] = \int_{a_{min}}^{a_{max}} [\int_o^{\infty} C_d(x) f_{X|A}(x|a)dx] \\ (P|F,q,t_a) f_A(a)da \tag{2}$$

where X is damage level, A is earthquake intensity, $C_d x$ is damage cost function of damage level, $f_{X|A}(x|a)$ is conditional PDF of damage level at a given earthquake intensity, $f_A(a)$ is PDF of earthquake intensity at a given location, and $(P|F, q, t_a)$ is present worth factor of future costs at occurrence time of a earthquake intensity t_a. As it is impossible to get PDF of damage level in real problems, the first term in Eq.(2) can be approximated as a function of global median damage index X_{median} (Kim 1992).

$$\int_o^{\infty} C_d(x) f_{X|A}(x|a)dx \cong C_d(x_{median}|a) \tag{3}$$

Seismic hazard at a site is usually defined as the probability of exceeding an expected peak ground acceleration during a specific time interval. PDF of earthquake intensity of Eq.(2) can be obtained from the probability of exceeding as

$$f_A(a)da = dF_A(a) \tag{4}$$

where $F_A(a)$ is probability of exceeding of earthquake intensity at a given location during life time.

Present worth factor at occurrence time of earthquake intensity is also modified to cover the specific time interval. Present worth factor of Poisson's process during a specific time interval L can be obtained from the formula proposed by Ang and et al. (1995) and written as

$$(P|F,q,L_a) = \frac{1}{\nu L}\sum_{n=1}^{\infty}\sum_{k=1}^{n}\frac{\Gamma(k,\alpha L)}{\Gamma(k,\nu L)}\left(\frac{\nu}{\alpha}\right)^{k}\frac{(\nu L)^{n}}{n!}e^{-\nu L} \qquad (5)$$

where $\alpha=\nu\ln(1+q)$, and q is annual discount rate, which is used to measure the effect of a compound interest rate. The present worth factors of Eq.(5) is shown in Fig.1

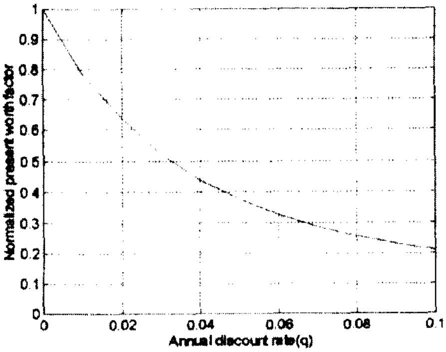

Fig1. Present worth factor(L=50yrs)

Thus, from the fact that the present worth factor is invariant for the different annual arrival rate ν Eq.(2) can be approximated as

$$E[C_d] = \int_{a_{min}}^{a_{max}} C_d(X_{median}|a)(P|F,q,L_a)dF_A(a)$$
$$\cong (P|F,q,L)\sum_{i=1}^{m} C_d(X_{median}|a_i)P(a_i) \qquad (6)$$

where $P(a_i)$ is the probability of exceeding of earthquake intensity over life time.

2.2 Initial cost

The initial building cost consists of the total amount for the planning and construction of a building project up to the point of completion or occupancy. Site cost, development cost, site work cost, construction cost, professional fee, overhead and profit can be included in the initial cost. As most of the initial costs except the construction cost are unaffected by the level of reliability, the effect due to those items is excluded in this study. Construction cost can be classified into the cost of the structure, cost of the non-structure (architecture, mechanical and electrical system) and indirect cost. Among them, structural cost is the most dominantly affected by the level of reliability underlying its design. On the contrary, the non-structural costs are scarcely affected by the level of the reliability and considered as non-variable cost in this study. Therefore, the initial cost function can be developed as following sequences. (1) The same structure may be designed repeatedly by providing this can be accomplished by designing the same structure for different earthquake resistance capacity under the requirement of an existing seismic code. (2) For each of the designs, the corresponding cost of structure can be estimated. (3) Structural cost change rates for the other structures are estimated. (4) Non-structural costs are assumed to be constant for all design scheme. And (5) Indirect cost is obtained by using the same cost change rate of the other construction costs. In the above sequences, the cost change rate is defined as the rate between the cost considered to the basic cost. Basic cost is defined as the cost of the building designed according to the earthquake load requirement of current building code. From these considerations, initial cost of the building for the different design schemes can be expressed as

$$C_i = C_s^o(1+\omega_s) + C_{ns}^o + C_{ini}^o / 1 + \frac{C_s^o(1+\omega_s) + C_{ns}^o}{C_s^o + C_{ns}^o} / \quad (7)$$

where C_i is the initial cost of the building, C_s^o is the basic cost of structure, C_{ns}^o is the basic cost of non-structure, C_{ini}^o is the basic cost of indirect initial cost, and ω_s is the structural cost change rate.

2.3 Damage cost

Damage cost consists of the cost of repair or replacement of the building, the cost of contents, the cost of injury, the cost associated with fatality, and indirect economic cost. Each damage cost item under the certain earthquake intensity can be described by using damage cost interpolation function and maximum damage cost. Thus, damage cost term in Eq.(6) can be expressed as

$$\begin{aligned} C_d(x_{median} \mid a_i) &= C_r + C_c + C_{inj} + C_f + C_{in} \\ &= \sum_{j=1}^{5} C_{d\,max}^j h_j(x_{median} \mid a_i) \end{aligned} \quad (8)$$

where C_d is damage cost, C_r is the cost of repair or replacement, C_c is the cost of contents loss, C_{inj} is the cost of injury, C_f is the cost of fatality, C_{in} is the cost of indirect economic loss, $C_{d\,max}^j$ is maximum damage costs and h_j is the damage cost interpolation functions of each item. The maximum damage cost is defined as the damage cost at the completely collapsed state of a building under earthquake. The prototype of interpolation function in this study is assumed as the two parameters exponential function of the median global damage of the structure;

$$h(x_{medan}) = 1 - exp^{\gamma(x_{median})^{\alpha}} \quad (9)$$

where γ and α are constants. The interpolation function covers the values from 0.0 to 1.0. The exponential function is taken as interpolation function because the characteristics of damage cost of different items can be simply modeled by adjusting two parameters. The values of the parameters can be obtained from previous available data which can describe the relation between damage cost and corresponding damage states.

3. Damage evaluation

3.1Local damage index

Damage of reinforced concrete members is expressed as a linear combination of the damage caused by the excessive deformation and that contributed by hysteretic energy dissipation due to repeated cyclic loading. This is defined by a damage index as follows (Park and Ang 1985) ;

$$D = \frac{\delta_m}{\delta_u} + \beta \frac{E}{Q_y \delta_u} \quad (10)$$

where D is member damage index, δ_u is ultimate displacement capacity, Q_y is yield strength, β is the rate of strength degradation, δ_m is maximum response displacement, and E is dissipated hysteretic energy.

3.2 Global damage index

Performance and safety can be quantitatively defined in terms of structural damage. For a class of structures considered in this study, its global damage is a function of the local damages of its members such as columns and girders. The global damage index may be defined as

$$(D_g > d) = \underset{i}{U}(D_i > d) \qquad (11)$$

where D_g is global damage index, d is damage threshold, D_i is damage of critical component i. In the above equation, D_i may be computed as a combination of the damage to several components, such as a story damage that is computed as a weighted average of the damage to columns in the story.

The probability of failure or the probability that some seismic performance limit state is reached is thus defined as the probability that the global damage exceeds the specified damage threshold. , i.e.,

$$P_d = P[D_g > d] \qquad (12)$$

where P_d is the probability of damage. When the value of damage threshold d is 1.0, it implies the probability of failure. Only a few studies have been performed to find the relationship between Park-Ang damage index and damage level of real building structure. However, the relation between damage state and story drift of the building has been studied experimentally by Bertero and et al., (1992). Therefore, in this study, the story drift effect is referred to provide the relation between damage index and real damage states indirectly. When an ultimate displacement of a column is larger than maximum story drift for the completely collapsed situation at the story where the columns are located, the former is reduced to the latter and damage index in this case implies the damage states due to correspondent drift at the story. When an ultimate displacement of the column is less than maximum story drift, damage index can imply local damage states of the columns due to the capacity of each column.

3.3 Damage parameters and ground motion for damage analysis

In assessing the global damage of a structure, the structure should be modeled and analyzed for its response to a given earthquake. The process must involve nonlinear and hysteretic response analysis So as to model the nonlinear hysteretic behavior of R.C. beams and columns, the element type E02 in DRAIN-2DX (Prakash, Powell and Campbell 1993) is used in this study. The structural capacity terms in damage model of R.C. beams and columns are obtained by applying the approaches presented by Park-Ang(1985) and Baker(1965). And the ground acceleration is modeled as a non-stationary stochastic process with both frequency and amplitude

Table 1 Member Properties of Design Schemes

Base Shear	Member	B (cm)	h (cm)	p (%)	A_s (cm^2)	A_{sc} (cm^2)	Av (cm^2)	Sv (cm)	Ls (cm)	δ_c (cm)	δ_y (cm)	δ_u (cm)	Mu (tm)
0.0En	Column	40	40	0.48	3.20	3.20	1.42	20	350	0.35	1.06	5.48	11.72
	Beam	15	60	1.20	7.80	3.6	1.42	20	600	0.35	5.59	21.63	12.34
0.5En	Column	40	40	0.48	12.0	12.0	1.42	20	350	0.57	1.33	5.83	19.44
	Beam	15	60	1.20	11.7	3.6	1.42	20	600	0.35	5.47	18.23	18.29
1.0En	Column	40	40	0.48	20.8	20.8	1.42	20	350	0.60	1.35	5.89	27.71
	Beam	20	60	0.98	15.6	4.8	1.42	15	600	0.35	5.49	17.51	23.39
2.0En	Column	45	45	0.48	30.37	30.37	1.42	15	350	0.46	1.65	5.94	49.04
	Beam	30	60	0.61	22.62	7.2	1.42	15	600	0.35	5.49	16.67	35.47
3.0En	Column	50	50	0.48	31.25	31.25	2.54	15	350	0.36	1.78	5.83	63.97
	Beam	40	60	0.48	32.24	32.24	1.42	15	600	0.35	5.42	15.51	50.23

modulation (Yeh and Wen 1990). The filtering equations for the ground motion are:

$$\ddot{x}_g + \left[\frac{\phi''(t)}{\phi'(t)} + 2\zeta_g\omega_g\dot{x}_g\right] + [\omega_g\phi'(t)]^2 x_g = -I(t)[\phi'(t)]^2\zeta(\phi(t)) \quad (13\text{-}1)$$

$$\ddot{x}_f + \left[\frac{\phi''(t)}{\phi'(t)} + 2\zeta_f\omega_f\dot{x}_f\right] + [\omega_f\phi'(t)]^2 x_f = 2\zeta_g\omega_g\phi'(t)\dot{x}_g + [\omega_g\phi'(t)]^2 x_g \quad (13\text{-}2)$$

where $\omega_g, \varsigma_g, \omega_f$ are ς_f are the parameters of the Clough and Penzien filter. $\zeta(\phi(t))$ is a Gaussian white noise in the time scale with the spectral intensity S_o . $\phi(t)$ is the frequency modulation function, and $I(t)$ is an intensity envelope function. The ground acceleration is then obtained as

$$a(t) = 2\varsigma_g\omega_g\frac{1}{\phi'(t)}\dot{x}_g + \omega_g^2 x_g - 2\varsigma_f\omega_f\frac{1}{\phi'(t)}\dot{x}_f - \omega_f^2 x_f \quad (14)$$

3.4 Implementation of computer code for simulation and nonlinear dynamic analysis

The structural properties and earthquake loading parameters usually involve uncertainties. Thus these parameters should be treated as random variables. Structural parameters treated as random variables are story mass, damping ratio, elastic modulus and strength of concrete, yield strength of steel bars. Ultimate displacement and the parameters in the damage model are treated as random variable. The parameters of the Clough-Penzien filter and the strong motion duration should be also considered as random variables. In order to perform the Monte Carlo simulation of structural response from which the damage statistics and reliability are obtained, a computer program SMART-DRAIN have been developed in UCI(A. H-S Ang and et al. 1995) by utilizing DRAIN-2DX. Subsidiary codes for evaluation of ELCC and failure probability are developed by using Matlab.

4. Illustration

The general approach descried above is illustrated for the example building of 7-story reinforced concrete framed structure located in Seoul and designed by current Korea Building code (Fig.2).

Structures with different capacities are designed for different levels of seismic safety by varying the code specified base shear coefficients. The beams and columns are designed as uniform capacity structure. The member properties and the damage capacities of members for each design scheme which are obtained by the methods previously mentioned are shown in Table1. The statistics of parameters for simulation and nonlinear dynamic analysis of the example structure are shown as Table2.

The parameters for damage are assumed as normal. The parameters for structure and earthquake are assumed as log-normal and their coefficients of variation are taken from available data (Sues et al. 1983, Park and Ang 1985). The seismic hazard analysis is performed on the based of the historical earthquake record at Seoul during 583 years (Lee 1992). The earthquake intensities of historic data are recorded by MMI scale, these values are converted to PGA by Bolt (1978). The seismic hazard curve of the site for 50 years is shown in Fig.3.

4.1 Initial cost

In this study, 6 different office buildings

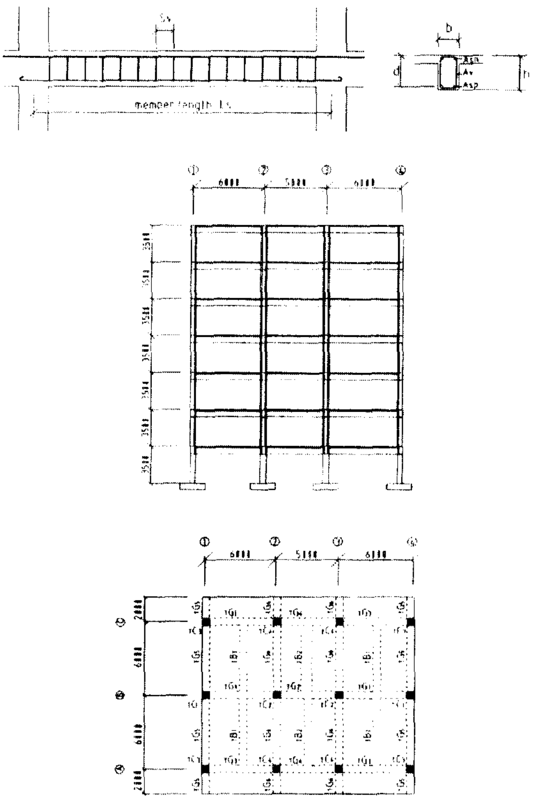

Fig.2 Section and Plan of Illustrated Building

Table 2 Statistics of Parameters

	Parameter	Mean	C.O.V	Distribution
Damage	δ_u	$1.0\bar{\delta}_u$	0.30	Normal
	β	$1.0\bar{\beta}$	0.30	Normal
	Mu	$1.0\bar{M}u$	0.20	Normal
Structure	m	$1.0\bar{m}$	0.10	Log-Normal
	ζ	0.05	0.60	Log-Normal
	fy	$1.0\bar{f}y$	0.10	Log-Normal
Structure	f'c	$1.0\bar{f}'c$	0.30	Log-Normal
	Ec	$1.0\bar{E}c$	0.30	Log-Normal
	ω_g	16.90	0.40	Log-Normal
Earthquake	ζ_g	0.94	0.40	Log-Normal
	ω_f	0.70	0.00	-
	ζ_f	0.60	0.00	-
	T(sec)	5.50	0.70	Log-Normal

built in Seoul in 1995 were surveyed in order to analyze the unit area cost of initial cost and the component cost ratio (Table3).

The average of the unit area cost is found to be 696.245 won/m2. The averages of component cost ratio of structural, nonstructural and indirect cost to total initial cost are 22.49%, 61.97% and 15.54% respectively. The basic initial cost of the example building is obtained by multiplying the mean unit area cost by gross area of the building and assumed to be 1,325,667,616won. The nonstructural and indirect initial costs of all items can be obtained by multiplying corresponding component cost ratio to basic initial cost. The structural costs for each design scheme are calculated based on average unit price as surveyed buildings. Thus, initial costs for each design scheme are estimated by using Eq.(7). Normalized initial costs of each item are obtained by dividing the initial costs by basic initial cost. For the design schemes designed for the base shear from zero to three times bigger than

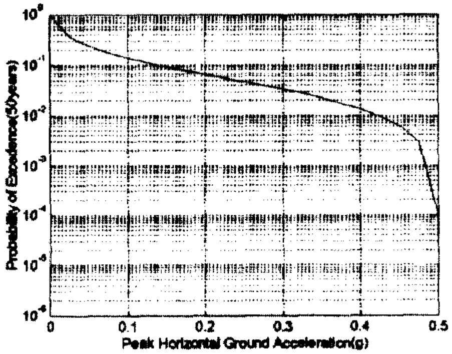

Fig.3 Seismic Hazard Curve (L=50yrs)

Table 3 Cost Ratio of Office Building

BLDG No.	Area(m²)	Unit Area Cost (won/m²)	Cost Ratio (%)		
			C_s	C_n	C_{in}
1	625.31	625,301	18.57	63.02	18.14
2	1161.57	740,817	18.11	68.22	13.67
3	2079.69	587,250	25.45	53.47	21.08
4	2308.22	883,677	28.00	57.10	14.90
5	1276.31	658,607	21.92	64.57	13.51
6	1387.50	681,785	22.91	65.53	11.56
Mean		696,254	22.49	61.97	15.54

nominal base shear of current design code, the initial costs range from 95.9% to 109.1% of basic initial cost(Table 6).

4.2 Damage cost for each item

Maximum damage costs and parameters of each cost item are evaluated as followings.

Repair and replacement cost - Replacement cost is sum of the initial costs and cost for demolition. In Korea costs for the demolition of the building usually range from 3% to 5% of the initial cost. In this study the ratio of the replacement cost to the initial cost is assumed to be 1.04.

Contents cost - Ratio of contents cost to initial cost in the office building was surveyed by Rojahn and et al.(1985) and known to be about 0.34. When the building is collapsed, all of the contents are assumed to be destroyed. Thus, the ratio of contents cost to initial cost is assumed to be 0.34.

Fatality cost - Number of occupants per 22.5 in day time is one and when building is collapsed, 20% of them are recorded as fatality by Rojahn and et al.. Records for the previous collapse accidents of bridge and building show that the loss of fatality per capita ranges from 192 to 333million won per capita. In this study, the loss of fatality per capita is assumed to be 200 million won. The ratio of loss of fatality to basic initial cost is found to be about 2.55.

Injury cost - When building is collapsed, 10% of all injuries are disabling injuries and the others are non-disabling injuries. Records for the previous accidents of bridge and building collapse show that the number of injuries per unit floor area is from 1.88 to 1.96 times of fatalities. Number of injuries per unit floor area is assumed as about 1.76 times of fatalities in this study. The loss of a disabling injury is equal to the loss of fatality and average cost of non-disabling injuries is about 13% of fatality loss. The ratio of loss of injuries to basic initial cost is found to be about 0.97.

Indirect cost - Ripple effect of indirect cost is neglected in this study because the sum of ripple effect would equal zero, and no economic evaluation is necessary (Wiggins 1979). Only the loss of rental during the period of repairing work or reconstruction. Total rental cost of the office building is assumed 60% of basic initial cost and annual interest rate of the rental cost is assumed 8%. The reconstruction period of the example building is assumed about one year and two months. Movement fee of 20% of cost of contents and indirect cost of 10% of initial cost additionally considered. The ratio of indirect loss to basic initial cost is found to be about 0.23

Parameters for damage cost interpolation functions - For intermediate damage state, the relation between damage cost and the maximum damage cost can be established by referring the data from the past hazard records. But such kinds of data can not be available in Korea so far. So as to find the parameters for interpolation function for injury or fatality, the estimates proposed by Rojahn and et al. is used (Table 4). For the repairing or replacement cost the marginal damage index for whole replacement is assumed as about 0.8. And for contents and indirect cost, the interpolation function is assumed to be increased almost linearly. The

Table 4 Matrix of Damage State

Cost Item	Damage Index					
	0.0	0.05	0.20	0.45	0.8	1.0
Repair	0.00	0.05	0.20	0.60	0.99	1.00
Contents	0.00	0.05	0.20	0.45	0.80	1.00
Injury	0.00	0.00	0.002	0.024	0.242	1.00
Fatality	0.00	0.00	0.00	0.005	0.05	1.00
Indirect	0.00	0.05	0.16	0.46	0.78	1.00

	α	γ
Repair	1.80	5.00
Contents	2.70	5.00
Injury	1.80	5.00
Fatality	24.0	5.00
Indirect	2.70	5.00

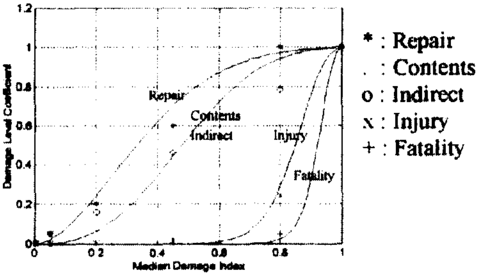

Fig.4 Damage Cost Interpolation function

parameters for each interpolation function are determined by curve fitting method to those values. The shapes of interpolation function of each cost item are shown in Fig.4.

4.3 Damage probability and median damage index

The maximum response displacement, dissipated hysteretic energy and corresponding statistics of damage index can be obtained by using simulation technique. The results for corresponding median damage index and damage probabilities are shown in Table5 and Fig.5.

Median damage index increases as the PGA increases and nominal base shear decreases. Under the moderate seismic intensity of PGA less than 0.2g, the failure probabilities of most of design schemes are known to be negligible.

On the contrary, for much higher seismic intensity than specified in current code, *i.e.*, PGA bigger than 0.3g, the failure probability is quite high.

Table 5 Damage Probability

Base Shear	Damage Probability	
	$P(D_u > 0.5)$	$P(D_c > 1.0)$
0.00 En	0.0365	0.0221
0.50 En	0.0318	0.0191
0.75 En	0.0266	0.0134
1.00 En	0.0213	0.0111
1.25 En	0.0161	0.0076
1.50 En	0.0122	0.0036
2.00 En	0.0082	0.0012
3.00 En	0.0057	0.0009

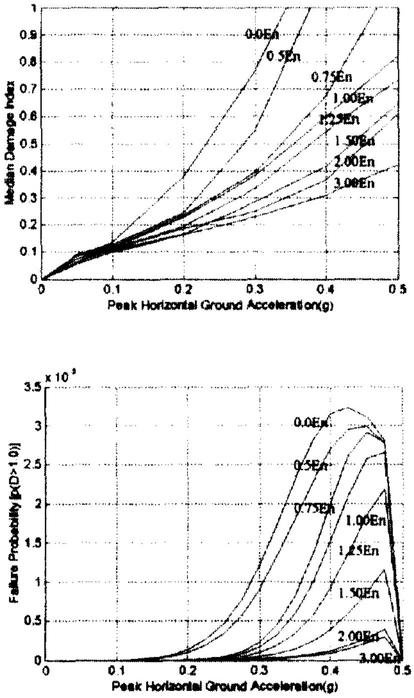

Fig.5 Median Damage Index and Damage Probability

4.4 ELCC and reliability

The relations between ELCC and failure

probability of the building for different discount rate are shown in Fig.6. Damage costs of the scheme cover from 12.82% to 2.42% and from 5.13% to 0.97% of basic initial cost when annual discount rate is 2% and 8% respectively. ELCC's of the schemes cover from 104.79% to 111.52% and from 101.03% to 110.07% of basic initial cost when annual discount rate is 2% and 8% respectively. On each of the ELCC curves, the points at which the cost curves reach the minimum indicate the target optimal reliability for the given earthquake intensity, i.e., a conditional optimum risk or reliability. As discount rate is changed from 2% to 8% the optimal failure probabilities are varied from 0.0134 to 0.0221. These results show that as discount rate increases, the optimal failure probability increased slightly. This fact implies that when discount rate is high, the initial cost is much more important than damage cost in the future. When annual

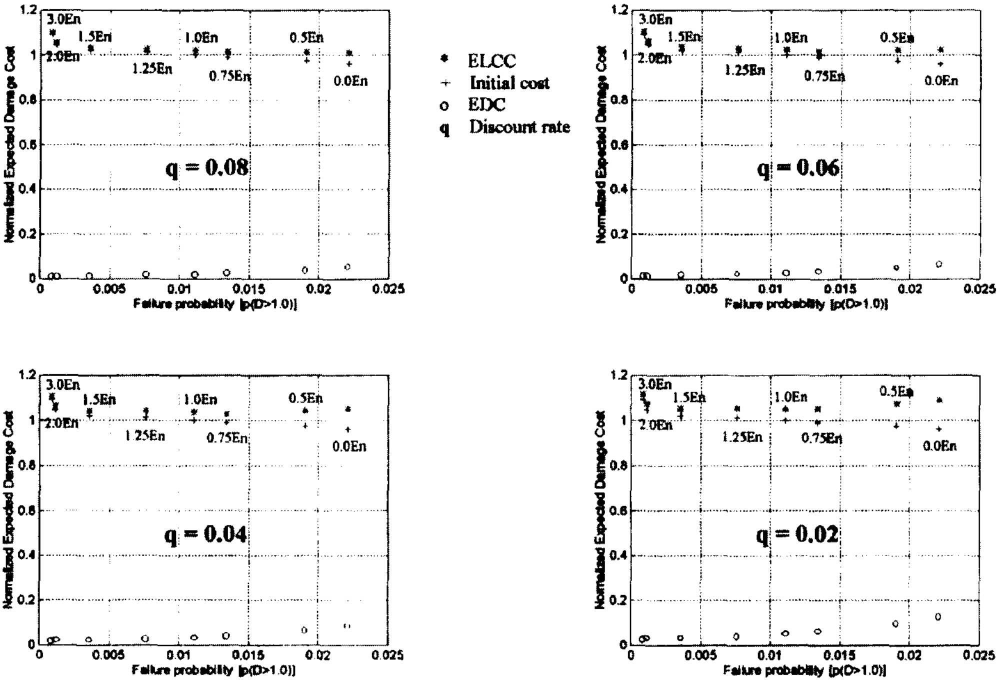

Fig.6 Normalized EDC and ELCC for Design Schemes

Table 6 Normalized Cost

Base Shear	Initial Cost	Annual discount rates (q)							
		0.02		0.04		0.06		0.08	
		EDC	ELCC	EDC	ELCC	EDC	ELCC	EDC	ELCC
0.00En	0.9590	0.1282	1.0872	0.0883	1.0473	0.0656	1.0246	0.0513	1.0103
0.50En	0.9750	0.0986	1.0736	0.0679	1.0429	0.0505	1.0255	0.0394	1.0144
0.75En	0.9880	0.0599	1.0479	0.0413	1.0293	0.0307	1.0187	0.0240	1.0120
1.00En	1.0000	0.0481	1.0481	0.0331	1.0331	0.0246	1.0246	0.0192	1.0192
1.25En	1.0120	0.0407	1.0529	0.0280	1.0400	0.0208	1.0328	0.0163	1.0283
1.50En	1.0210	0.0319	1.0529	0.0220	1.0430	0.0163	1.0373	0.0128	1.0338
2.00En	1.0440	0.0304	1.0744	0.0210	1.0650	0.0156	1.0596	0.0122	1.0562
3.00En	1.0910	0.0242	1.1152	0.0167	1.1077	0.0124	1.1034	0.0097	1.1007

discount rate is smaller than 2%, the target reliability of current design code is supposed between 75% and 100% of nominal base shear. But when annual discount rate is larger than 8%, damage cost saving by increasing the level of reliability can not be considered as economical

5. Conclusion

From this study so far, followings would be concluded.

1. Under the moderate seismic intensity of PGA less than 0.2g, the failure probabilities of most of design schemes are known to be negligible. On the contrary, for much higher seismic intensity than specified in current code, *i.e.*, PGA \bigger than 0.3g, the failure probability is quite high.

2. When annual discount rate is between 2% and 8%, the optimal reliability of current design code is supposed to be between 0.9866 and 0.9779. For the same kinds of office buildings as illustrated, cost-effective nominal base shear is found to be between 75% and 100% when annual discount rate is 2%. Moreover, cost-effective nominal base shear is found to be less than 75% of nominal base shear of current design code when annual discount rate is 8%..

3. Optimal reliability level is found to be dependent on the discount rate. For the higher discount rate, the lower reliability level is found to be more cost-effective. This fact implies that economic effect needs be considered for the determination of the safety level of the design code and the proposed approach could be applied effectively for the same purposes.

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ABSTRACT

A systematic approach for the evaluation of cost-effective reliability based on LCC of reinforced concrete framed structure under earthquake load is presented. Damage probability and ELCC are used as indicators for the structural performance and economic efficiency of the building. EDC, which covers all the damage cost due to the earthquake during life time, is taken as one of the most important component of the ELCC. EDC is assumed as a function of median of Park-Ang damage index for the different damage states of the structure. Damage analyses for the structures under the situations of uncertainty are performed by the simulation technique implemented in SMART-DRAIN which has been developed at UCI. The proposed method is illustrated by the example of 7-story reinforced concrete framed structure designed in accordance with current Korean Building Code.

Keywords: reliability, damage, failure, probability, damage index, LCC, cost, earthquake.

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