Earthquake Engineering, Tenth World Conference © *1992 Balkema, Rotterdam. ISBN 90 5410 060 5*

Tall building design in the low seismicity area: The case of Korea

Ch.-K.Choi & H.-K.Chung
Department of Civil Engineering, Korea Advanced Institute of Science and Technology, Daejeon, Korea

ABSTRACT: Korea has long been known as a country of low seismicity. Consequently, little attention has been given to the earthquake resistant design except some nuclear power plants built recently in Korea. By analyzing historical earthquake records in Korea, exceptional seismic activities able to cause damages to buildings were recorded during the period from 15th century to 18th century. Seismic activities have been weakened after that period and this weak seismicity period would be resumed as a seismic gap in which period the seismic energy might be accumulated. Therefore it is worried in Korea that severe seismic damages to buildings may come before long and that now is the time to prepare for protection from earthquakes. Therefore, new earthquake resistant design code has been developed and enacted. This paper describes the background, and some provisions of the code in the form of Building Law, Building Law Enforcement Ordinance and Detailed Structural Design Regulations.

1 HISTORICAL EARTHQUAKE RECORDS IN KOREA

In a country where large scale earthquake damages do not occur frequently, the practicing engineers have had little need for earthquake resistant design except some important structures such as nuclear power plant. The historical earthquake records of Korea, the first of which is dated as early as 27 AD, indicate that Korea can never be a earthquake-free zone. Therefore, in order to provide some measures for the earthquake disaster mitigation as the potential earthquake disaster increases as the concentration of urban population and the construction of large and tall buildings are being expedited recently, the earthquake resistant design code has been introduced in 1988 first time in the Korea's history.

The two major problems related to the introduction of new earthquake resistant design code are the difficulties for finding experienced engineers in the earthquake engineering and for justifying the additional construction cost due to the earthquake resistant design. With these reasons, the code provisions needed to be written carefully to minimize the impact on the national economy and to be easily understood by the practicing engineers.

As shown in Fig.1 (a), about 2400 historical earthquakes have been recorded during the period of last two thousand years and among those earthquakes, about two hundred are estimated to be greater than $MM\ VII$ intensity(Fig.1 (b)).

Most of the historical earthquakes of Korea had

Table 1 Major earthquakes occurred in Korea

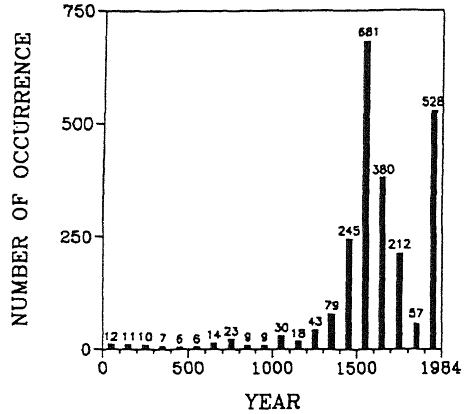
Region	Date	Magnitude	Remarks
Ssanggesa	July 4, 1934	5.3	
East Sea	September 6 1968	5.4	
Mt. Sokli	September 15, 1978	5.2	
Honsubg	October 7, 1978	5.0	

been recorded in densely populated areas such as capital cities and their vicinities. Therefore, many of earthquakes in the remote areas may have not been recorded because of the lack of proper transportation and communication systems at that time.

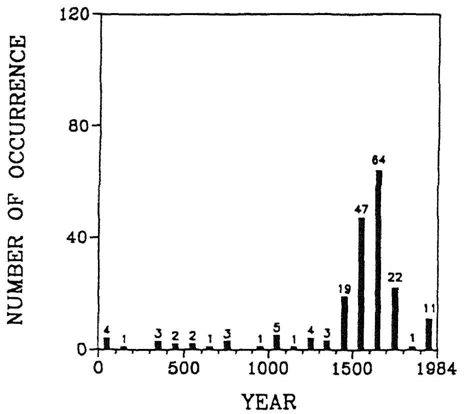
Among the severe historical earthquakes of Korea, the one occurred in Gyongju, the capital city of Shilla Dynasty, in 779 AD was accompanied the highest losses ever recorded ; killing about one hundred people.

As seen in Fig.1, earthquake activity records in Korea during the period from 15th to 18th century were exceptionally vigorous. After two centuries of rather strong activities, the seismic activities in Korea have been calmed down for another two centuries. The later two centuries are presumed as seismic gap by seismologists and there are worries that the gap may be nearing to the end and the accumulated energy during the period may be released to cause some strong earthquake activities in Korea again.

Since the opening of the 20th century, when the first seismograph was installed in 1905, there are four major earthquakes recorded in Korea of which



(a) Total number of occurrence



(b) Number of occurrence for MM ≥ VII

Figure 1 The Historical earthquakes in Korea

magnitudes were equal or greater than 5.0 as given in Table 1.

After all said, Korea is still an area of the low seismicity where some exceptionally vigorous earthquake activities had been recorded in the past and, as some worry, there may exist a certain probability of potential earthquake in the future. Thus, to protect from the potential earthquake disaster, the introduction of the earthquake resistant design code is needed.

2 THE NECESSITY OF EARTHQUAKE RESISTANT DESIGN CODE IN KOREA

In the low seismic area, the level of damage in the case of earthquake should be carefully compared with the extra construction cost for the protection from earthquake. It should be the society concerned who decide if they need a seismic resistant design codes despite the extra construction cost, or not.

As discussed earlier, there exists the probability of earthquake occurrence in Korea. If the earthquake of the similar magnitude with the major ones recorded in Korea should occur, excessive damage will result from the concentration of urban population and the construction of large and tall buildings due to rapid industrialization. Some structural systems currently used in Korea, such as one-way RC shear wall building generally used in multi-story apartment buildings, have poor seismic resistant mechanisms. Although this system can save the construction time and cost, the use of this type of structure is prohibited in the area of high seismicity because of its disadvantages in the case of seismic excitations. By supplementing with appropriate earthquake resistant design code, general improvement in the quality of building may be expected in Korea.

Therefore, some of the engineers in Korea who emphasize the necessity of earthquake resistant design code have already used the provisions in the globally recognized codes such as UBC in their structural design. The majority of the engineers, however, are reluctant to use the foreign provisions because earthquake resistant design procedures are different from a country to another and it is difficult to transfer the code of a country to another. In order to stipulate the earthquake resistant design procedures in Korea, in stead of writing an entirely new design code, the current Building Law, Building Law Enforcement Ordinance and Detailed Structural Design Regulations have been revised effective as of January 1988 ·ith the Government initiative.

Thus, the earthquake resistant design code in Korea has been used for several years now and has shown some positive effects. The quality of structural design and construction in Korea has been substantially improved since.

3 BASIC STRATEGIES OF THE NEW CODE

Based on the recommendations provided by the Architectural Institute of Korea which conducted basic research for the Ministry of Construction before their revising the existing Laws and Regulations, the following basic concepts of earthquake resistant design has been developed and stipulated in new codes.

1) Considering the current state of earthquake resistant design technology in Korea and the fact that the code is constituted for the first time in Korea, the design procedures should be simplified to a great extent. Thus, the application of more sophisticated and complex technologies such as the dynamic analysis and consideration of $P - \delta$ effect, etc., that make less-experienced structural engineers troublesome, are not included but substituted with more simplified methods such as the static equivalent analysis. The code can be improved as the practicing engineers become more experienced in earthquake resistant design in the fu-

Table 2 Seismic zone factor

Zone	0	1	2
A	-	0.08	0.12

Table 3 Importance factor

Importance	3	2	1
urban area	1.0	1.2	1.5
rural area	0.8	1.0	1.2

ture.

2) In order to avoid any serious impact on national economy, the scope of application of the first code is narrowed down to the important buildings such as buildings which have 6 floors or more, assembly hall, hospitals, communication centers, etc.

4 SOME PROVISION IN THE KOREAN CODE

As do many other earthquake resistant design codes around the world, the Korean seismic design code utilizes the static equivalent analysis technique, which is advantageous in computational efforts and economy. The static equivalent analysis may be applied appropriately to regular buildings which have similar stiffnesses and masses between adjacent members and floors. The Korean seismic design code urges to use the dynamic analysis in irregular buildings.

In static equivalent analysis techniques, dynamic characteristics of building are decided first and then, the base shear proportional to total weight of building and story shears are calculated afterward.

4.1 Base shear

Base shear is the fundamental part of the earthquake resistant design and obtained by the following equation.

$$V = \frac{AISC}{R}W \tag{1}$$

where, V = base shear, A = seismic zone factor, I = importance factor, C = dynamic coefficient, S = site coefficient for soil characteristics, R = response modification coefficient and W = effective weight of structure. Each factor is decided by the following concepts.

Seismic zone factor - The seismic map in Korean code is divided into three zones as shown in Fig.2. The zone factors, which are directly related to the maximum effective ground acceleration, were decided based on the historical and instrumental seismic records(Table 2).

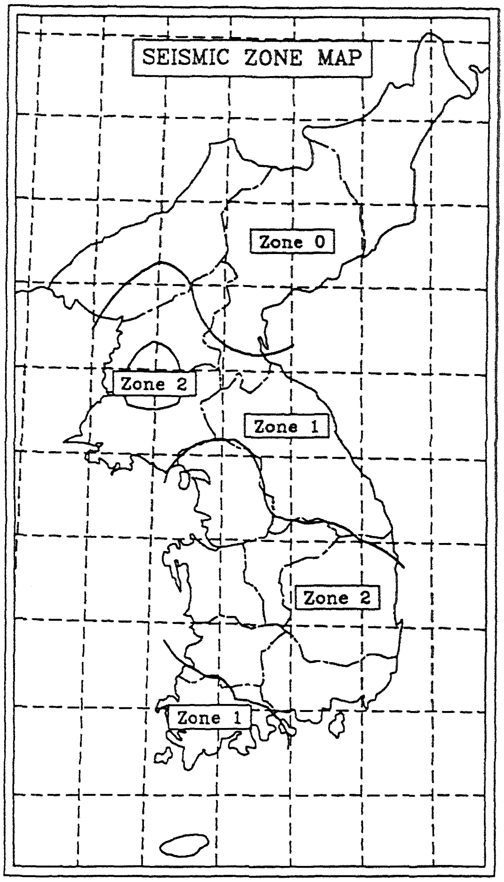


Figure 2 The Seismic zone map in Korea

Importance factor - It is not desirable in the economic point of view that all buildings are completely safe in the case of seismic excitation. Therefore, the earthquake resistant design code should give balanced satisfaction between the social and economic requirements. The importance factor has to do with the degree of hazard to human life that the failure of building might cause. In Korean code, importance of a building is decided by social and economic value of the building and different factors for the same importance are applied to the city planning area and rural area defined by the Law, reflecting the fact that the same ground shaking may cause more severe damage in the population concentrated urban area.

Natural period and dynamic coefficient - To carry out the earthquake resistant design the dynamic characteristics of buildings must be understood, and it is the most important to decide the natural period and mode shapes. Natural period and mode shapes have effects on the magnitudes and distributions of earthquake loads, respectively. The natural period may be approximately calculated based on formulations in ATC3-06(Table 4). Dynamic coefficient transforms the dynamic effects into static equivalent effects in the case of seismic excitation and is obtained in a similar manner to one in UBC as follows.

$$C = \frac{1}{1.2\sqrt{T}}(CS \leq 1.75) \qquad (2)$$

where, T is natural period.
Soil factor - To consider the earthquake effects of soil characteristics, the site coefficients are classified into three categories as shown in Table 5. Soft soil has larger value of soil factor than hard soil. To prevent the overestimation of design spectrum, an upper limit of 1.75 for the product $C \times S$ is adopted.
Response modification coefficient - This factor takes the non-linear behaviors and damping effects of the structure into account. The factors in ATC3-06 has adopted in the code with some modifications.

4.2 Vertical distribution of base shear

The lateral force at the x-th floor can be expressed by the vertical distribution of the base shear as Eq. (3) in the Korean code. The k values in this equation is determined by Fig. 3.

$$F_x = \frac{W_x h_x^k}{\sum_{i=1}^{n} W_i h_i^k} V \qquad (3)$$

4.3 Story shear

The story shear at the x-th floor is decided by the following equation in the Korean code.

$$V_x = \sum_{i=x}^{n} F_i \qquad (4)$$

4.4 Other provisions

Eccentric torsional moment and additional torsional moment - The torsional responses in buildings arise from two sources : (1) eccentric torsional moment, and (2) additional accidental torsional moment.

The eccentric torsional moment arising from eccentric distributions of mass and stiffness can be taken into account by determining the distance between the center of mass and the center of shear stiffness. The additional accidental torsional moment is also determined by assuming that the mass is displaced from the calculated center of mass in each direction a distance equal to five percent of the building dimension at that level perpendicular to the direction of the force under consideration.

Overturning moment - At any level, the overturning moments to be resisted are determined using those lateral seismic forces(F_x) which act on levels above the level under consideration as following

Table 4 Natural periods

	Steel moment resisting frame	RC moment resisting frame	All other building
Korea	$0.085h^{3/4}$	$0.060h^{3/4}$	$0.09h/\sqrt{B}$
UBC 85	N/10	$0.05h/\sqrt{D}$	$0.05h/\sqrt{D}$
UBC 88	$0.035h^{3/4}$	$0.030h^{3/4}$	$0.020h^{3/4}$
ATC3-06	$0.035h^{3/4}$	$0.025h^{3/4}$	$0.05h/\sqrt{L}$
UNITs:meter in Korean code and ft in other codes.			

Table 5 Soil factors

Soil Type	Hard ⟷		Soft
	S1	S2	S3
S	1.0	1.2	1.5

Table 6 Comparison of design spectrum

	Steel Moment Resisting Frame	RC Bearing Wall System
Korea	$\frac{V}{W}=\frac{0.02}{\sqrt{T}} \leq 0.035$	$\frac{V}{W}=\frac{0.0343}{\sqrt{T}} \leq 0.06$
UBC 88	$\frac{V}{W}=\frac{0.015}{(T)^{2/3}} \leq 0.0275$	$\frac{V}{W}=\frac{0.03}{(T)^{2/3}} \leq 0.055$
ATC3-06	$\frac{V}{W}=\frac{0.0216}{(T)^{2/3}} \leq 0.0375$	$\frac{V}{W}=\frac{0.0384}{(T)^{2/3}} \leq 0.0667$

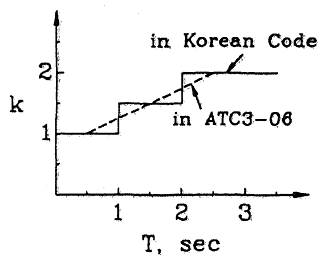


Figure 3 The comparison of k value

equation. The reduction factor is applied in order to take into account the fact that the lateral seismic forces under consideration may not be imposed at once.

$$M_x = \rho \sum_{i=x}^{n} F_i(h_i - h_x) \qquad (5)$$

where, ρ is equal to 1.0 for top 10 stories, 0.8 below the top 20 stories and is interpolated for top 11-19 stories.

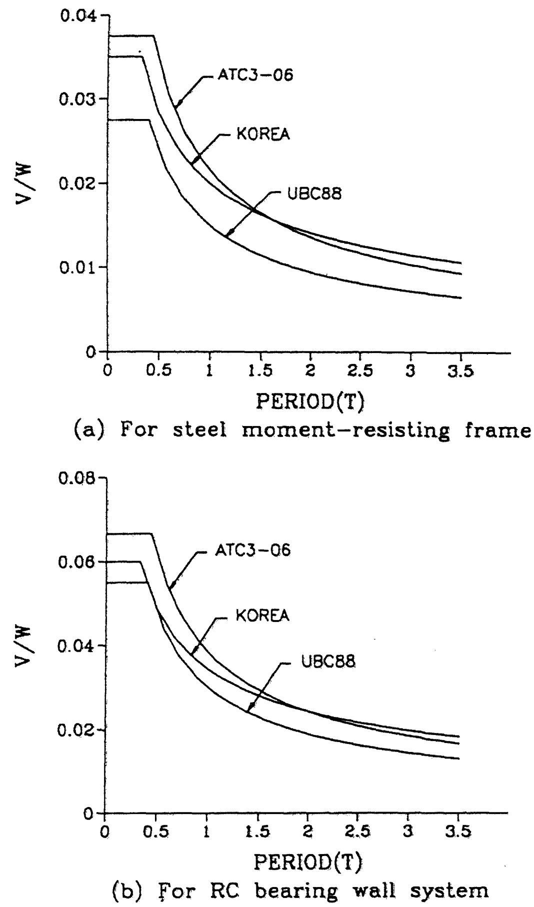


Figure 4 Comparison of design spectrum

Table 7 List of the buildings used in the example

Name	Material	Structural system	Total No. of floors	Use	Location
E-Soo	R C	Dual	9	Office	Seoul,Korea
Yang-Jae	Composite	Dual	20	Office	Seoul,Korea
Euljee	Steel	Dual	30	Office	Seoul,Korea
DLI Bldg	Steel	Dual	60	Office	Seoul,Korea
*	Steel	Dual	40	*	Seoul,Korea
*	Steel	Dual	50	*	Seoul,Korea
Note : Assumed weight per unit area=6.86KN/m^2 * denotes assumed building in Choi(1992) UNIT : KN, m					

$P-\Delta$ effects and story drift limitation - It is the story drift to be directly related to the non-structural damages of buildings. Excessive story drift causes the severe $P-\Delta$ effect in which case the geometric nonlinearity must be considered. Story drift is constrained to less than 1.5% of story height.

Architectural consideration - Adjacent structures should be located away from each other by two times the sum of deformation of adjacent structures. Some provisions for the non-structural elements and furniture are included in Korean code. More sophisticated analysis - For the important structures such as tall buildings(with more than 20 floors), and structures with irregular configuration, a more sophisticated analysis methods such as modal analysis, mode superposition method and direct integration method, are implicitly recommended to use in the code.

5 COMPARISON OF EARTHQUAKE LOADS WITH OTHER CODES

In this paper, earthquake loads of Korean code is compared with those of other codes by analyzing the design spectrum of them. In this comparison, it is assumed that seismic zone factor, importance factor and soil factor are 0.12, 1.0 and 1.2, respectively and two structural systems, i.e., steel moment-resisting frame system and RC bearing wall system, are analyzed. The results are shown in Fig. 4 and Table 6.

The general trends of design spectrum in Fig.4 show that V/W values of Korean code are generally larger than those of UBC 88 and are smaller than those of ATC3-06 at the period between 1.5 and 2.0, and vice versa as the period increases. It is the reason for the differences in design spectrum that each code uses the different response modification coefficients and the dynamic coefficient of Korean code is inversely proportional to $\sqrt{T}$, while that of other codes is inversely proportional to $T^{2/3}$.

Considering the low seismicity in Korea, the above mentioned differences in each code can be explained as the following. : (1) In the low seismicity area, buildings do not need to have large flexibility. In this reason, response modification coefficient of Korean code is smaller than that of the other codes(ATC, UBC, etc.), and (2) The dynamic coefficient is inversely proportional to period, theoretically. Korean code, however, has a need to use a larger design values of earthquake loads in order to consider $P-\Delta$ effects, indirectly.

6 COMPARISON WITH WIND RESISTANCE DESIGN CODE IN KOREA

In order to compare the story shears by earthquake resistant design code with those by wind resistant design code in Korea, six different buildings used in Choi and Chung(1992) are used(Table 7). The dimensions of the buildings and load cases are shown in Fig. 5.

The earthquake and wind resistant design loads at each floor level and the accumulated loads at various building heights are given in Fig. 6. The increments of story forces with the building heights are fairly uniform in earthquakes while those in winds

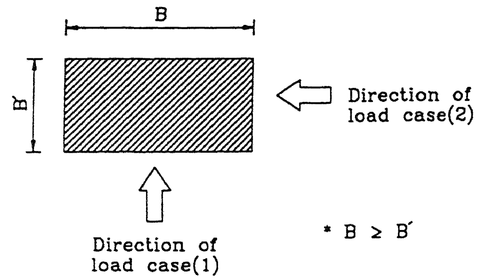


Figure 5 Dimensions of the buildings and load cases

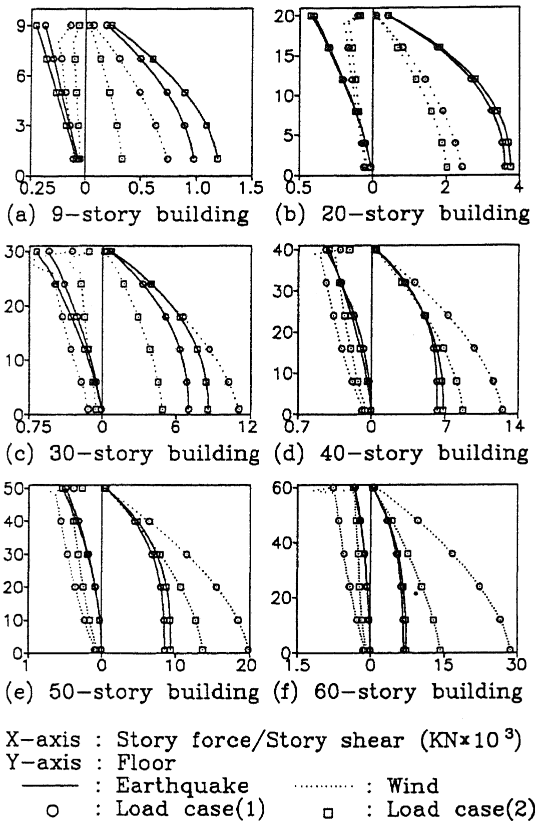


Figure 6 Story shears and story forces for various building height

are increased steadily as the number of floors are increased except top floor where the effective loading area is half one of the other floors. It has been observed(Fig. 6) that for any buildings of more than 40 stories the wind load becomes dominant.

7 CONCLUSION

Even in the low seismicity area, there exists the probability of excessive damage in the case of earthquake by the concentration of urban population and the construction of large and tall buildings due to rapid industrialization.

Korea now has its first version of earthquake resistant design code parts of which are benefited from the research done elsewhere. By the introduction of the code, Korea is no longer earthquake free zone for the design and construction of building structures as stated by the established law and enforcement.

The code, which is designed for low seismicity zone, is expected to have significant effect on the general improvement of building construction and stimulate researches in the earthquake engineering. The code itself is also expected to be improved as the general earthquake resistant design technology in Korea progresses.

Comparing with the wind load, for high rise buildings(say, 40 stories or more), wind load effect is more severe than the earthquake load.

REFERENCES

Applied Technology Council, 1978, Tentative provisions for the development of seismic regulations for buildings, ATC3-06, National Bureau of Standards, Washington D.C.

Choi, C.K. and et al., 1987, The study on making the earthquake resistant design code, the Ministry of Construction, Korea.

Choi, C.K. and et al., 1988, Earthquake resistant design in the low seismicity area - the case of Korea - , Proceedings of 9th WCEE, Vol.5, Tokyo-Kyoto, Japan: 929-934.

Choi, C.K. and et al., 1988, Theory and techniques for earthquake resistant design of buildings, Department of Civil Engineering, Korea Advance Institute of Science and Technology.

Choi, C.K. and et al., 1989, Integrated building design system(part 1) - linear three dimensional analysis, SEMR 89-01, Department of Civil Engineering, Korea Advance Institute of Science and Technology.

Choi, C.K. and Chung, H.K., 1992 (To be published), Simplified building analysis with sequential dead loads-CFM, Journal of structural engineering, ASCE.

Eum, S.H. and et al., 1983, Seismic risk map of Korea, Korea Institute of power and resources.

Housner, G.W. and et al., 1983, Engineering monograph on earthquake criteria, structural design and strong motion records, EERI, Berkely, California.

International Conference of Building Officials, UBC , 1985, Whittier, California.

International Conference of Building Officials, UBC , 1988, Whittier, California.