Seismic Design in Low or Moderate Seismicity Regions: Suggested Approaches

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ABSTRACT

Korea is located in either low or moderate seismicity continental region. It is realized that the design codes and underlying design concept of high seismicity region may not be appropriate to low and moderate seismicity regions. The aim of this paper is to search seismic design concept that is deemed to be appropriate to low and moderate seismicity regions. To this end, the seismicity of Korea will be introduced first and important aspects of seismic design in moderate seismicity region will be discussed. The two-level code system that is going to be adopted in the future seismic regulations of Korea will be introduced.

Key words : *seismic design, moderate seismicity*

1. Introduction

Even though Korea is located rather far away from the active plate boundary, it has never been completely immune from the earthquake hazards. Many historic records and recent seismic activities indicate that at least Korea belongs to a moderate seismicity region. Historic records, i.e., the Royal Chronicles of the Yi Dynasty show that there occurred big earthquakes several times in the past 2000 years and they claimed many human casualties and serious property damages. Earthquake resistant design has been introduced to Korea since 1986 for tall buildings, since 1992 for highway bridges and even earlier than that for nuclear power plants. But the public did not share the necessity of seismic design in general.

The devastating Hyogoken-Nanbu earthquake of January 17, 1995 sent mental shock waves that awakened the public concern about the possible earthquake disaster in Korea. Many seismologists pointed out that a disastrous earthquake could occur at any time soon. The government began to realize that preparatory measures had to be implemented at national level. The consensus among the design engineers and researchers resulted in the foundation of the Earthquake Engineering Society of Korea (EESK) in November 28, 1996. The Yeongweol earthquake of December 13, 1996 was of only magnitude 4.5 but the shaking was felt throughout the country. The structural damage was minimal even at the epicentral region. However, that earthquake gave very strong impact to the public frightened already because of the disaster in Kobe City. Immediately after the earthquake, the Korean government announced research plans for the development of seismic design codes and long term research plans for the accurate evaluation of the seismic hazard in Korea. EESK was entrusted the task to develop seismic performance requirements and code systems for the facilities under the jurisdiction of the Ministry

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The seismic design codes for buildings, bridges, and other facilities have borrowed the basic idea heavily from those developed for the high seismicity region, i.e., California without critical review. However it became evident that that they cannot be applied directly to the seismic design in low or moderate seismicity regions. The seismic design of structures in the region of high intensity ground motion is based on the ductile behavior and large energy absorbing capacity. However, it is highly possible that well designed structures may behavior within elastic limit under the design ground motion in the moderate seismicity region.

Another critical problem of the current code system was found to be lack of coordination. The performance requirements and the design principles are different from one code to another. The seismic zoning, seismic coefficients and design response spectrum are found to be in the same situation. It was felt very strongly that certain kind of coordinated approach must be taken to achieve uniform level of protection from earthquake hazards.

This paper concerns with the seismic design concepts of Korea that is deemed to belong to low or moderate seismicity regions. The seismicity of Korea will be briefly will be introduced first. Important aspects of seismic design in low or moderate seismicity region will be discussed. Examples of structural behavior will be presented. Based on these observations a conceptual framework of the seismic design in low or moderate seismicity region will be discussed.

2. Seismicity of Korea

Recordings on earthquake events in Korea consist of historic earthquake data and instrumental data. The historic records on earthquakes encompass the period from 2 AD to 1904 AD.(1) Since 1905, earthquake events have been recorded using instruments. As mentioned in Introduction, those historic records are considered to be very reliable. The Royal Chronicles of Yi Dynasty (1392 AD-1910 AD) are very famous for its accuracy. It is estimated that there might have occurred 389 events greater than or equal to V on MMI scale.(1) The number of events greater than or equal to VII on MMI scale appears to be over 45.(1) The temporal distribution of the frequency of the historic earthquake events is given in Fig. 1. The maximum intensity seems to reach IX on MMI scale. Because of very heavy reliance on the historic records the seismic hazard assessment in Korea is characterized by its large uncertainty. Interpretation of the historic records tends to be very dependent on the judgement of the individual researcher. The magnitude-frequency relation of the instrumental earthquake data is provided in Fig. 2

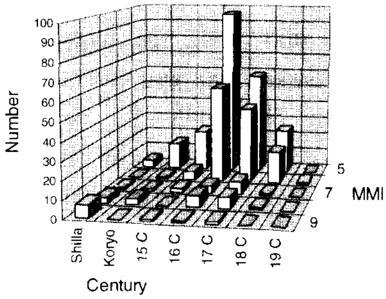


Fig. 1 Frequency of historic earthquake as a function of time and MMI(5)

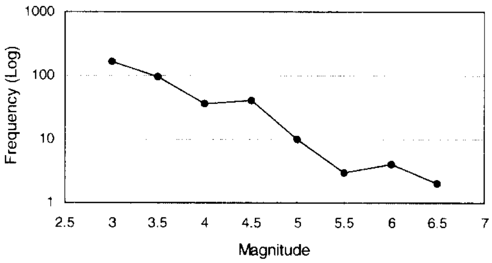


Fig. 2 Magnitude-frequency relation of instrumental earthquake[5]

In 1997, eight leading seismologists of Korea got together for the first time and produced seismic hazard maps for the development of new seismic design codes.[1] Fig. 3, 4 and 5 are seismic hazard maps of 10% probability of exceedance in 10 years, 50 years, and 250 years, respectively. The contours in the maps are based on the mean estimation. Fig. 6 shows hazard curves at Yeongcheon near Taegu. The seismic risk factors defined as the ratio of the peak ground acceleration of a given return period

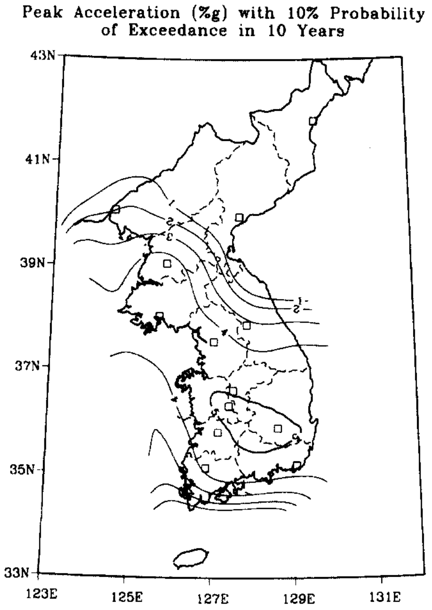


Fig. 3 Seismic hazard map of 10% probability of exceedance in 10 years[1]

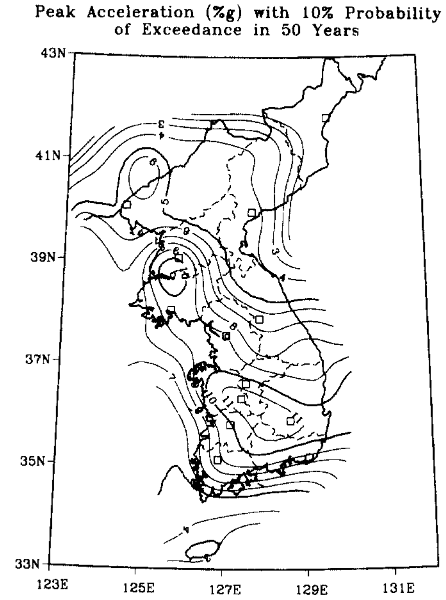


Fig. 4 Seismic hazard map of 10% probability of exceedance in 50 years[1]

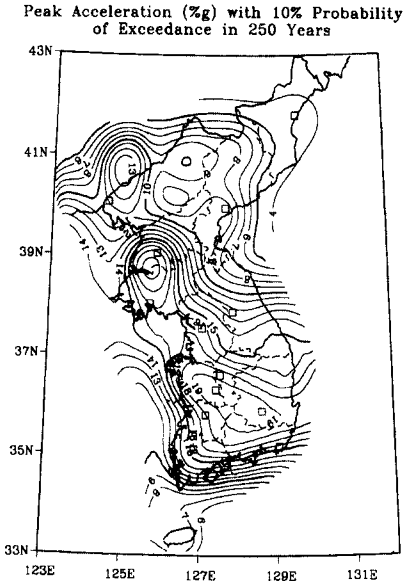


Fig. 5 Seismic hazard map of 10% probability of exceedance in 250 years[1]

to that of a reference return period are calculated. The average values with respect to the acceleration of 475-year return period are listed in Table 1. The risk factor for 2375-year return period found to be 2. In the United States this value is known to range between 2 to 5 in the area other than California.(2,3,4) As for the evaluation of uncertainty, further study is in order.

The attenuation of the intensity of earthquake ground motion in Korea is found to be very close to what observed in the Eastern United States.(5) Attenuation rate is estimated to be faster than in Western United States but a little bit slower than in the Eastern United States.(5)

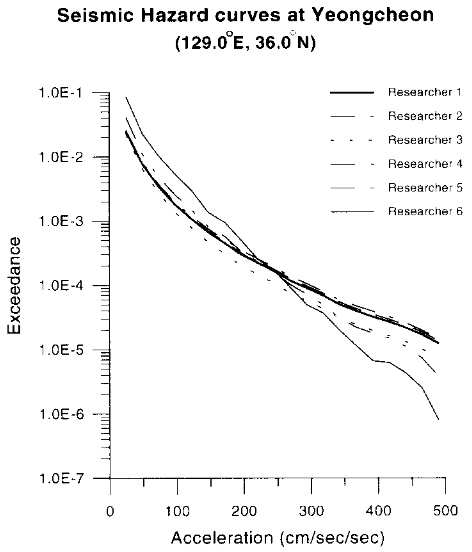


Fig. 6 Seismic hazard curves at Yeongcheon(5)

Table 1 Risk factor

Return period (yrs)	43	95	190	475	900	2373
Risk factor, I	0.40	0.57	0.73	1.0	1.4	2.0

3. Characteristics of seismic hazard in low to moderate seismicity region and implication to the design ground motion

Korea is believed to belong to a low or moderate seismicity region. It shares many common characteristics in seismic hazard with low seismicity continental region. The following discussion is based on the work by M. Power.(4)

Characteristics

In the stable continental region the seismic source show following characteristics(4):

- Seismic sources are not well understood and defined
- Maximum earthquake cannot be readily estimated on the basis of fault dimensions
- Recurrence rates are estimated based on the seismicity data
- Rates of attenuation may be slower than in active tectonic regions
- The presence of hard rocks may increase high frequency contents of ground motion

Implications to design(2,3,4)

- Probabilistic approach may be more appropriate for the estimation of maximum earthquake
- Large uncertainty and high risk factor may justify the use of design earthquake of longer return period
- The standard spectral shape in current codes may considerably overestimate long-period ground motion
- Local site effects will be more pronounced than in the region of high intensity ground motion because the degree of soil non-linearity is expected

less severe and soil damping lower in low intensity regions

4. Characteristics of structural response and implications to the design concepts

It is natural that the seismic design must be based on the dynamic response characteristics of structures under the earthquake loading. The dynamic response of structures is a function of the ground motion and mechanical properties of structures. The earthquake ground motion is local. Therefore seismic design must take into account characteristics of ground motions expected at the site. The seismic codes currently in use are developed in the region of high seismicity and high intensity region.(2) The basic concept is utilizing inelastic deformation under the design earthquake.(2,6) If high ductility and energy absorbing capacity are provided, the structures may withstand the earthquake ground motion many times more strong than the design earthquake without collapse. In the United States, this concept is implemented by introducing response modification factor.(6) But as pointed out in Power,(4) Beavers and Hunt,(3) and ATC,(6) structural responses under low intensity ground motion will be very different from those expected under high intensity ground motion. It is highly probable that the structures may not experience inelastic deformation at all if they are adequately designed for the conventional loads other than earthquake. In such cases, it is very awkward to design structures under the assumption that they will experience inelastic deformation. To meet detailing requirements for the ductility, the constructions may be unnecessarily complicated. Therefore in many cases, considerable overdesign may result as shown conceptually in Fig. 7. On the other hand a blind use of response modification factor may cause unanticipated damage to the components or subsystems. Such circumstances are described in Fig. 8.

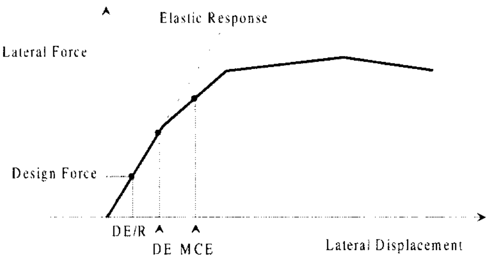


Fig. 7 Seismic response of reinforced frame structures in a low or moderate seismicity region

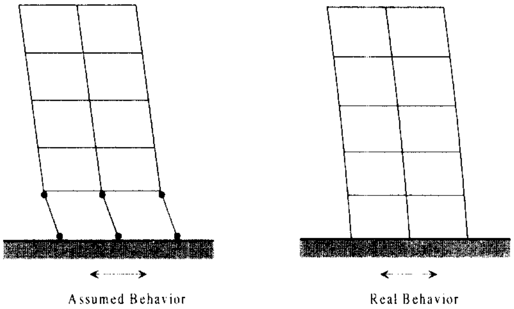
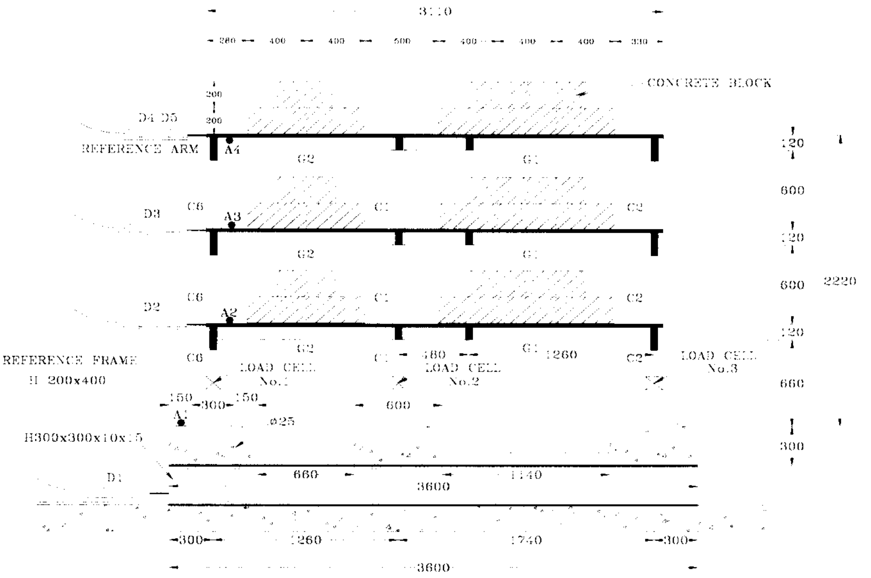
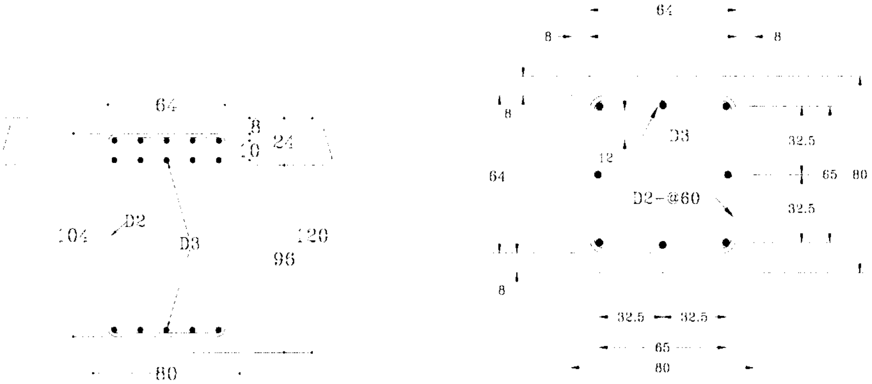


Fig. 8 Peril of the blind use of response modification factor

The plausibility of the above arguments may be supported by test results. One example is a scale model test of a conventionally designed concrete frame structure. Professor H. S. Lee of Korea University performed the test.(7) The test model is reproduced under the permission of Prof. Lee in Fig. 9. The scaled time history of the NS component of



(a) Front view

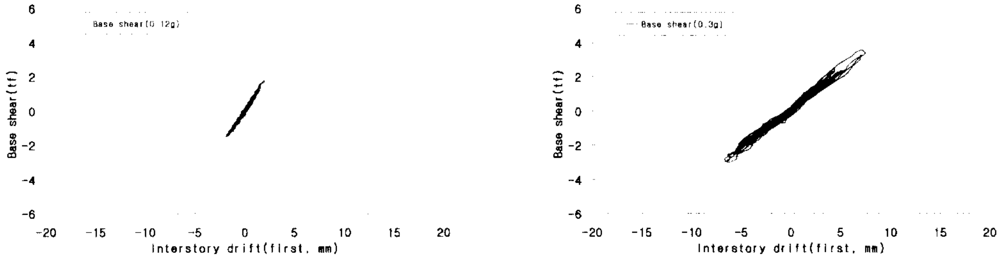


(b) Beam

(c) Column

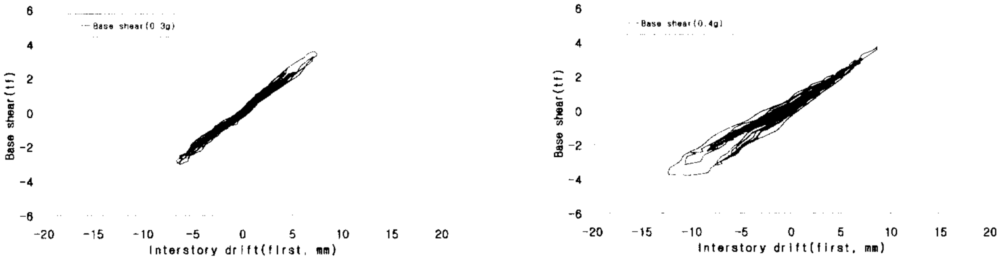
Fig. 9 Scale test model of a conventionally designed concrete frame structure[7]

Taft earthquake is used as the input ground motion for the shaking table test. The PGA values, 0.12g, 0.20g, 0.30g, and 0.4g are prescribed to scale the acceleration time history. The time history of the base shear for each scaled input motion is calculated from the measured data and compared in Fig. 10. With the scaled input of 0.12g and 0.20g, there were not observed any visible damage. At 0.3g, micro-cracks were observed to develop. The visual observation is substantiated by the change of natural period measured before and after of each test. The natural period measured after the test with 0.12g input acceleration was almost identical with the value obtained before the test. But the period measured after the test with 0.2g input level was lengthened by 17% compared



(a) PGA=0.12g

(b) PGA=0.2g



(c) PGA=0.3g

(d) PGA=0.4g

Fig. 10 Time histories of base shear force[7]

with the initial value. Large shear fracture developed in the test with 0.4g input level. The value 0.12g is very close to the PGA expected at rock site for the earthquake of 475-year return period (Fig. 4). The value 0.2g is equal to the Maximum Credible Earthquake as can be seen in Fig. 5.

Very similar observations can be founded in the report.[8,9] A full scale prototype and 1/3 scale model of a conventionally bridge pier were tested.[8,9] Even though it was not detailed for the earthquake load, the prototype bridge pier had demonstrated considerable seismic capacity. It showed elastic behavior up to 0.432g PGA and ductile behavior up to 1.29g with ductility ratio, 4.0.[8] Very similar results were obtained with scale model test. Elastic behavior was observed up to 0.44g PGA and the measured ductility ratio was 1.85. The brittle joint shear failure occurred at the threshold PGA, 0.89g.

The capacity of a conventionally designed bridge pier is analyzed using nonlinear analysis method. The elevation of the pier is given in Fig. 11 and half of the cross section of super structure in Fig. 12. The height of the pier is 13 m and the diameter 2.5 m. The ratio of steel is 1%. The seismic dead weight assumed lumped at the top of the pier is 400 tons. The load-displacement curves shown in Fig. 13 are obtained with nonlinear analysis method with fiber model.[10] The horizontal load is assumed to act at the top of the pier model. The ultimate moment is obtained to be 1,755 ton-m. The ultimate shear strength of the cross section is estimated exceeding 636 ton (Vc=493 ton, Vs=143 ton). The natural period of the pier model, 1.07 sec is obtained using the elastic

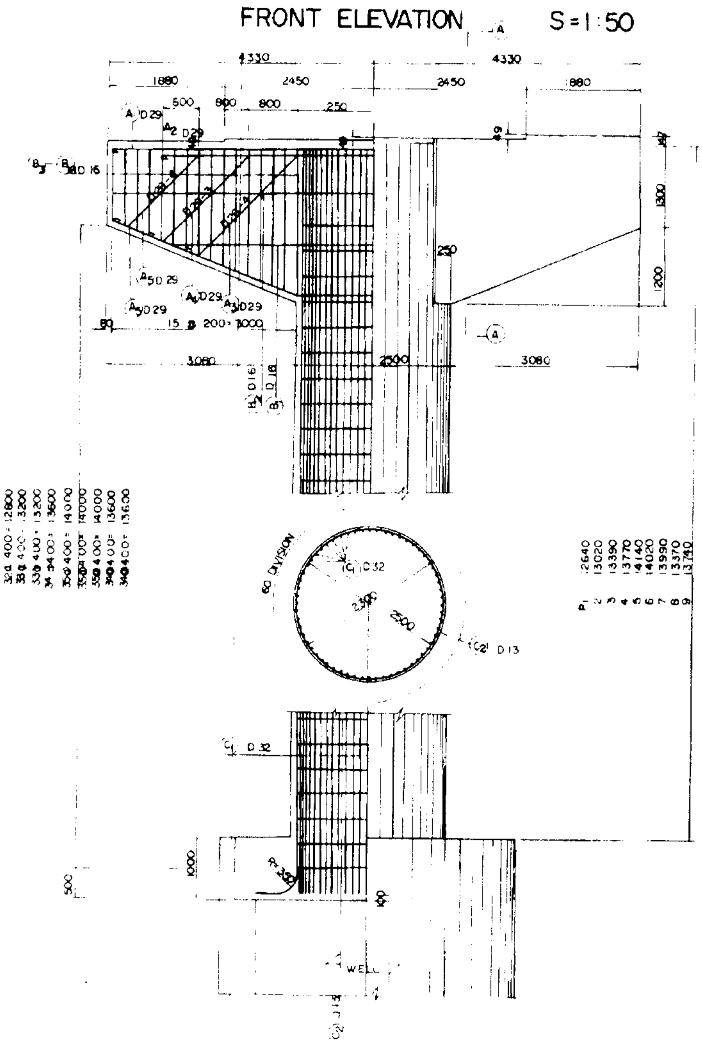


Fig. 11 Front view of pier model

part of the curve with initial yield section properties. The spectral acceleration is assumed to be inversely proportional to the period. The PGA at the elastic limit is found to be 0.18g. Lateral load, natural period, drift ratio and displacement are calculated at various loading steps and are given in Table 2. The periods are calculated based on secant stiffness. Even to reach 1.0 % drift ratio the PGA need exceed 0.33g.

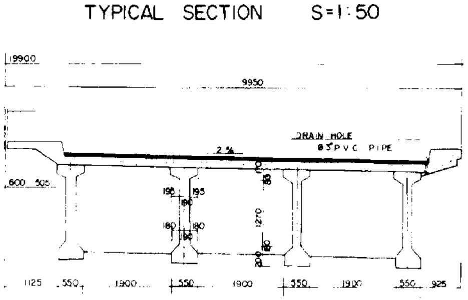


Fig. 12 Half cross section of super structure

These results indicate very clearly that conventionally designed frame structures possess considerable amount of inherent lateral strength though they may not show ductile failure mode. By improving joint details, the ductility may increase to prevent premature brittle shear failure. However, it does not make any sense if an attempt is made to lower the design earthquake load by dividing the elastic force with response modification factor corresponding to the added ductility if the structure be subject to the low intensity earthquake motion.

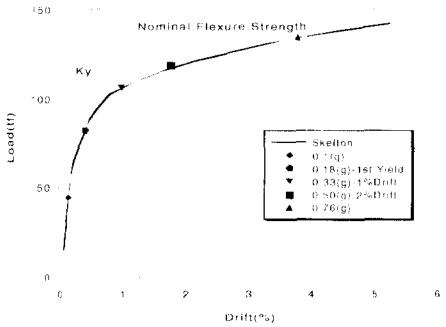


Fig. 13 Lateral load capacity of the pier model

The above observation may be valid only for the moment resisting frame structures. It may be possible that premature brittle shear failure may occur at very low level of ground motion in the case of unreinforced masonry structures. In such cases it may be necessary to reinforce masonry structures to prevent brittle failure mode. Since the short period contents of the ground motion is very rich in low seismicity continental region and since low-rise masonry structures have short natural period in general, they may be prone to damage in the event of earthquake.

5. Suggested design concept in low to moderate seismicity region

From the characteristics of seismic hazard and structural response in low or moderate seismicity regions the followings are proposed as the alternative design approach:

- Performance objectives must be defined considering characteristics of the seismic hazard level
- Performance objectives must be defined considering the anticipated structural response characteristics
- The shape of response spectrum need be determined using the records of moderate size earthquakes
- The site effects need be investigated for the low to moderate level ground motion intensity
- For the moment resisting resistant frame structures, the inherent strength must be

Table 2 Calculated responses with axial force

	1st Yield of Rebar	1.0 % Drift	2.0 % Drift	Failure
Period (sec)	1.07	1.55	2.08	2.77
Load (tons)	82	107	119	135
Displacement (cm)	5	13	26	52
Drift Ratio (%)	0.38	1.0	2.0	4.0
PGA (g)	0.18	0.33	0.50	0.76

exploited

- The ductility must not be overestimated and relied on to reduce earthquake load
- It may be more prudent to assume elastic behavior of the moment resisting structure
- For the low-rise masonry structures, reinforcement details need be necessary to provide minimum ductility.
- Response modification factor may be applied to the reinforced masonry structures.

6. Closing remarks

The seismic risk is not very high in Korea. Nevertheless, it is agreed that preparatory measures need be taken to prevent a potential earthquake disaster. The historic records, including the Royal Chronicles of the Yi Dynasty, support the decision. The seismic design or earthquake-resistant design has been introduced very recently for certain class of facilities. However, the recent earthquake accelerated the implementation of countermeasures. The basic seismic design concept that is deemed to be appropriate to the low or moderate seismicity region is proposed. However, a lot of research works have to be done to have concrete design recommendations. Especially the seismic behaviors of conventionally designed structures have to be investigated extensively. Masonry structures may have to receive more attention than moment resisting frame structures.

Acknowledgement

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