DEVELOPMENT OF SEISMIC DESIGN CODES OF KOREA

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ABSTRACT

The seismic hazard of Korea is briefly described. The seismic design requirements, design earthquake levels and design response spectrum that are going to be adopted in the future code system are introduced. Characteristics of ground motion and seismic responses of structures in low to moderate seismicity regions are briefly described. The concept of limited ductility design that seems appropriate for the seismic design in Korea is explained.

1. INTRODUCTION

Korea belongs to a low to moderate seismicity region. Historic documents such as the Royal Chronicles of the Yi Dynasty (1392 AD – 1910 AD) contains many entries on the earthquake events that claimed many human casualties and serious property damages in the past 2000 years [EESK]. 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 of Construction and Transportation. 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.
In early 1998, EESK submitted the final report to the Ministry of Construction and Transportation. In that report EESK proposed two level code system based on the performance-based design concept. EESK succeeded in producing unified seismic hazard maps, which was considered to be one of the important achievements. Since the development of technical standards for various facilities, EESK proposed the higher level codes which consists of performance requirements for various facilities. Now the technical rules are either under development or under the major revision process.
Seismic design codes currently in use in Korea for the seismic design of buildings and bridges are based on UBC and AASHTO Specifications respectively. Implicit in these codes is that buildings or bridges will experience large inelastic deformation during strong earthquakes. However, the simple fact that the seismic response of structures is a function of the intensity of ground motion has been largely overlooked. Many structures without good seismic detailing may have fair amount of inherent lateral load carrying capacity. Many of them will survive earthquakes of moderate intensity without collapse. The ductility demand for maximum credible earthquake in moderate seismicity regions will not be as high as in the high seismicity regions. In this case, if the structures have seismic detailing for the moderate degree of ductility potential, then they may survive the maximum credible earthquake without collapse. Therefore the seismic design concept based on the limited ductility will be very appropriate in the low to moderate seismicity regions. Realizing the potential benefits of this approach, the earthquake engineering community of Korea will concentrate its research capacity on the limited ductility seismic design method.

2. SEISMIC HAZARD 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 [EESK]. 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 may have occurred 389 events greater than or equal to V on MMI scale [EESK]. The number of events greater than or equal to VII on MMI scale appears to be over 45 [EESK]. The temporal distribution of the frequency of the historic earthquake events is given in Figure 1. The maximum intensity seems to reach IX on MMI scale. Due to 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 Figure 2.

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 [EESK]. Figure 3, 4 and 5 are seismic hazard maps of 10% probability of exceedance in 10 years, 50 years, and 250 years, respectively. The seismic risk factors defined as the ratio of the peak ground acceleration of a given return period 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.

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 [Baag]. Attenuation rate is estimated to be faster than in Western United States but a little bit slower than in the Eastern United States [Baag].

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. SEISMIC DESIGN REQUIREMENTS

In 1998, the Ministry of Construction and Transportation of Korea determined to adopt the two-level code system recommended by the Earthquake Engineering Society of Korea (EESK). The high level criteria are basically seismic performance requirements similar to the general design requirements in *NEHRP Guideline* [Rojahn and Whittaker]. The low ones are technical rules to achieve the required seismic performance objectives. Figure 6 describes the concept of the code system. The coordination and adjustment of the seismic performance objectives and design principles across diversified facilities can be accomplished best at the conceptual level. By incorporating the high-level criteria into the law system, the protection of the society from the earthquake risk can be more strongly imposed and protection levels can be well balanced.

The high-level code consists of items of the following:

- Classification of seismic categories
- Seismic performance objectives
- Design ground motion
- Behavior limit states
- Fundamental requirements on the seismic design
- Fundamental requirements on the seismic analysis
- Fundamental requirements on the quality assurance
- Fundamental requirements on the seismic instrumentation
- Authorized specifications and standards

The facilities of which high-level criteria have been completed include building structures; highways and highway bridges; railways and high-speed railways; airport; harbor; dams; and tunnels and underground structures. Development of technical codes for the facilities is in progress.

Two seismic performance levels are defined for the seismic objectives. The facilities are classified into three categories according to their importance. The performance objectives are given in Figure 7. The intensity of design ground motion corresponding to each return period can be obtained using risk factor defined in Table 1 and the intensity of the earthquake of reference return period.

The data on the strong earthquake ground motion is still very scanty in Korea. It is premature to develop our own design response spectrum if we do not have enough data. Therefore we decided to adopt the response spectrum shape provided in 1997 UBC [ICBO, 1997] along with the new classification of soil profile types.

4. 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. Therefore it may share many common characteristics in seismic hazard with low seismicity continental region. The following discussion is based on the work of M. Power (1996).

Characteristics [Power]

In the stable continental region the seismic source show following characteristics [Power]:

- 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 [Power; Beavers and Hunt; ATC, 1995a]

- 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

5. 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 [ATC, 1995a]. The basic concept is utilizing inelastic deformation under the design earthquake [ATC, 1995a, b]. 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 [ATC, 1995b]. But as pointed out in Power (1996), Beavers and Hunt (1998), and ATC (1995b), 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 full ductility, the constructions may be unnecessarily complicated. Therefore in many cases, considerable over-design may result. On the other hand a blind use of response modification factor may cause unanticipated damage to the components or subsystems.

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 [H. S. Lee]. The scaled time history of the NS component of 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. 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. Large shear fracture developed in the test with 0.4g input level. The base shear-displacement curve is provided in Figure 8.

Similar observations can be founded in the report [NCEER, 1996a and 1996b]. A full scale prototype and 1/3 scale model of a conventionally bridge pier were tested [NCEER, 1996a and 1996b]. 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 [NCEER, 1996a]. 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 [Kim et al.]. 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 curve shown in Figure 9 is obtained with nonlinear analysis method [Kim et al.]. The horizontal load is assumed to act at the top of the pier model. The ultimate moment are obtained to be 1,755 ton-m for the model with axial force. The ultimate shear strength of the cross section is estimated exceeding 636 ton (Vc=493 ton, Vs=143 ton) without axial force. The natural period of the pier model, 0.56 sec is obtained using the elastic part of the curve with uncracked section properties. The spectral acceleration is assumed to be inversely proportional to the period. The PGA at the elastic limit is found to be 0.054 g.

Recently, EESK performed a quasi-static test of scale pier model for seismic performance evaluation of Seohae Grand Bridge [EESK, 1999]. The prototype column section has a void-hexagonal shape with 5 m x 4 m dimension and 80 cm thickness. The longitudinal steel ratio is 1.1 % and the axial load level is 9 % of axial load capacity. From re-evaluation of the pier section, it was found that insufficient confinement steel amount as much as 42 % of seismic design code requirement was provided. Moreover, non-seismic reinforcement details are used, such as longitudinal reinforcement lap-splice and transverse reinforcement lap-splice in plastic hinge region. This type of reinforcement detail is not recommended for seismic design, but Seohae Grand Bridge was designed before the Korea seismic design code was prepared. Therefore, seismic performance of the pier column has to be investigated in order to find an economical and reliable treatment to improve the seismic performance of the bridge. For one bridge model that is 4-span continuous and 12 m in height, seismic capacity is estimated as 0.035 g of PGA based on gross-section stiffness and ductility ratio of 1.0, considering non-seismic reinforcement details. However, it is found that 1/8 scale model provides higher ductility and energy absorbing capacity than expected as shown in Figure 10. Structural behavior of the column specimen is presented on the envelope curve in Figure 11. The measured ductility ratio is found to be 2.6 at the first concrete crushing state, and to be 5.8 at failure in push direction, 5.3 at failure in pull direction, respectively. It is estimated that the bridge model has the higher PGA values than 0.035 g as shown in Figure 11. Based on this experimental result, re-estimation of required damper capacity is being conducted for economic design and construction. It may not be appropriate to draw conclusions by limited test data, but this test result gives an implication for seismic reinforcement details in a low to moderate seismicity region.

The above observation may be valid only for the moment resisting frame structures. It may be possible that premature brittle shear failure occurs 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 regions and since low-rise masonry structures have short natural period in general, they may be prone to damage in the event of earthquake.

6. 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 exploited
- The ductility must not be overestimated and relied on to reduce earthquake load
- For the low-rise masonry structures, reinforcement details need be necessary to provide minimum ductility.

Since the limited ductile behavior of moment resisting frame structures is anticipated in low to moderate seismicity regions, the limited ductility seismic design will be more appropriate than the conventional full ductility design. The concept is described in Figure 12. The basic idea is to provide seismic detailing sufficient to ensure ductility factor 2 or 3. But the premature shear failure should be prevented. Development of details of limited ductility design procedure will be one of the major research topics of the Korea Earthquake Engineering Research Center (KEERC).

7. ACKNOWLEDGEMENT

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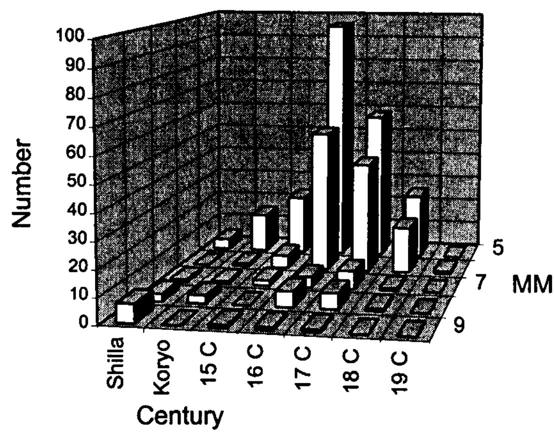

Figure 1. Frequency of historic earthquake as a function of time and MMI [Baag]

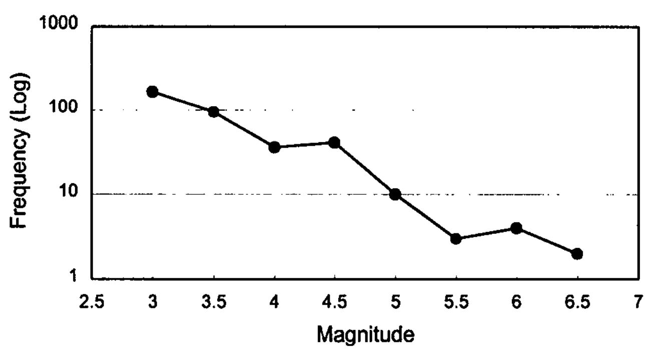

Figure 2. Magnitude-frequency relation of instrumental earthquake [Baag]

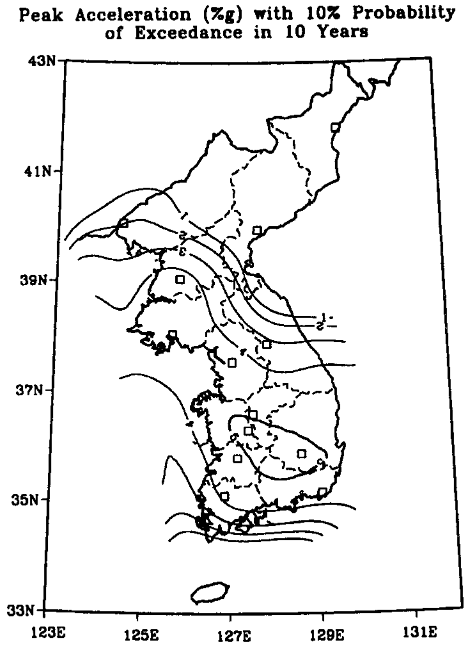

Figure 3. Seismic hazard map of 10% probability of exceedance in 10 years [EESK]

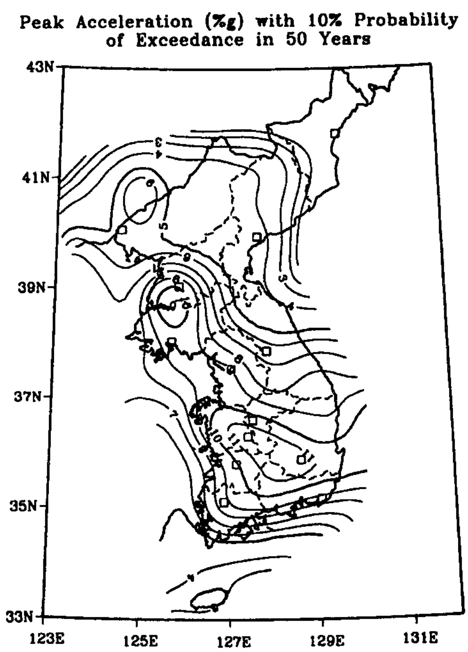

Figure 4. Seismic hazard map of 10% probability of exceedance in 50 years [EESK]

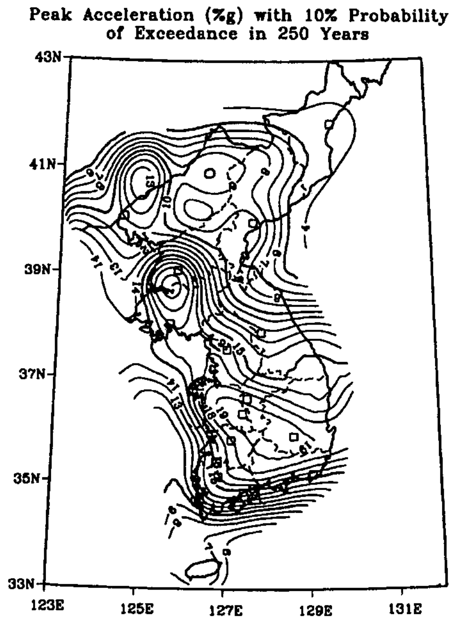

Figure 5. Seismic hazard map of 10% probability of exceedance in 250 years [EESK]

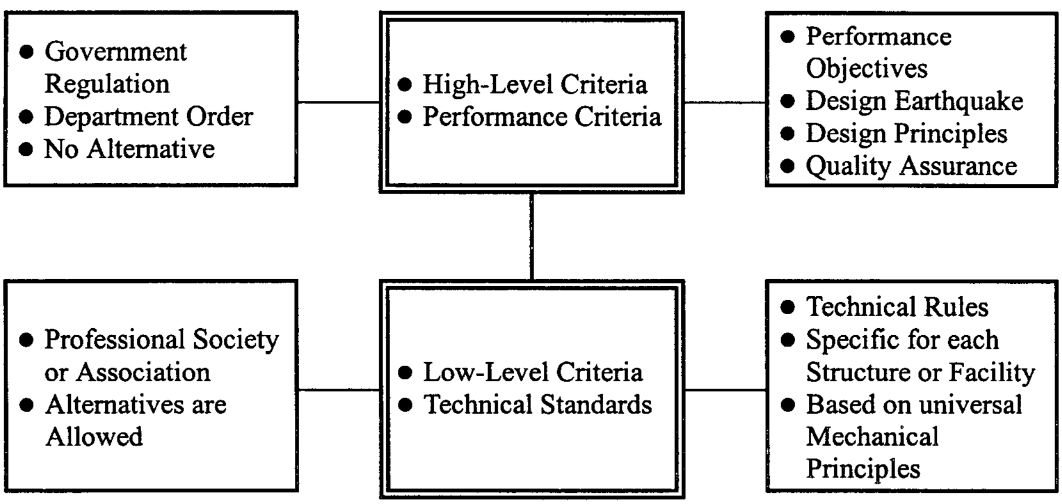

Figure 6. Two-level seismic design code system

Design Earthquake (Return Period)	Performance Level	
	Operational	Life safety
43 years	⊙	
95 years	◈	
190 years	▣	
475 years		⊙
950 years		◈
2373 years		▣

⊙ : Ordinary Structures and Facilities
◈ : Important Structures and Facilities
▣ : Safety Critical Structures and Facilities

Figure 7. Seismic performance objectives

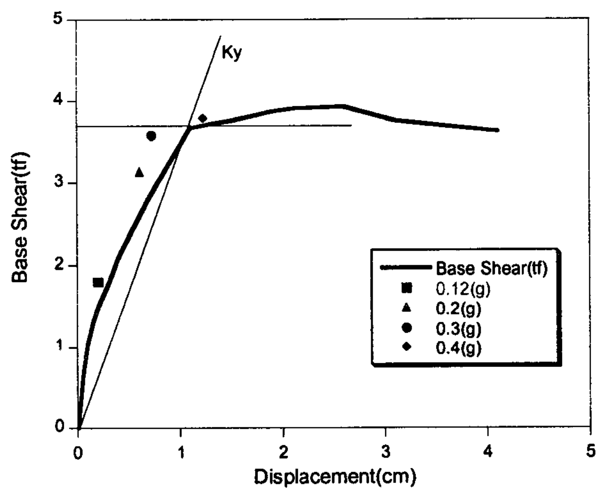

Figure 8. Base shear-displacement curve of a scaled frame model

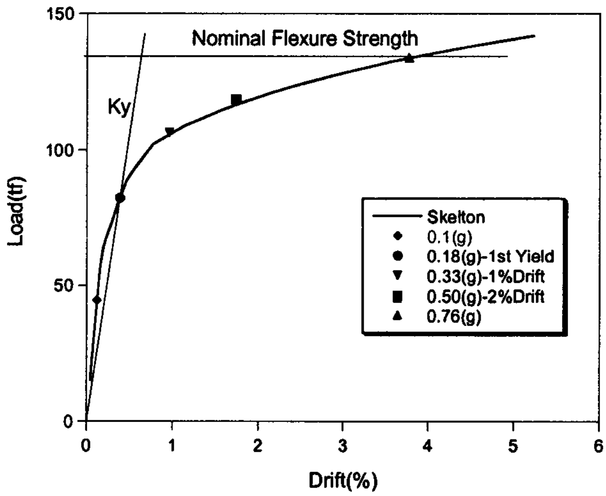

Figure 9. Load-displacement curve of a bridge model

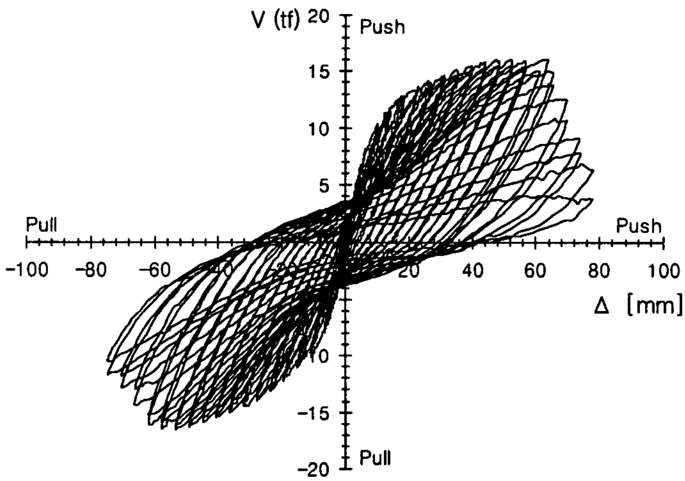

Figure 10. Measured lateral load-displacement hysteresis for Seohae Grand Bridge pier model

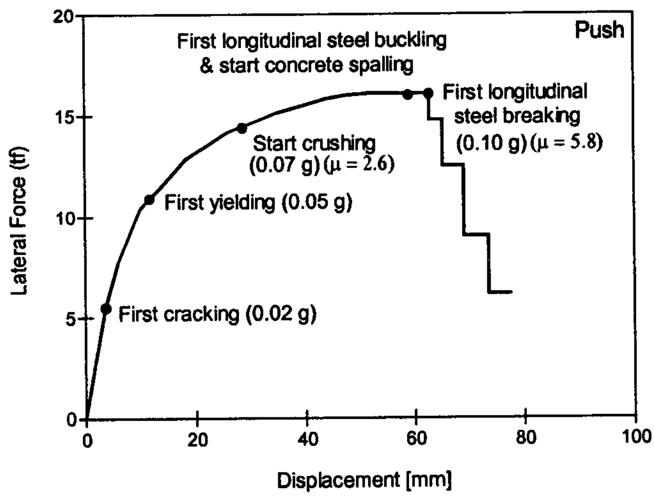

Figure 11. Lateral load-displacement envelope for Seohae Grand Bridge pier model

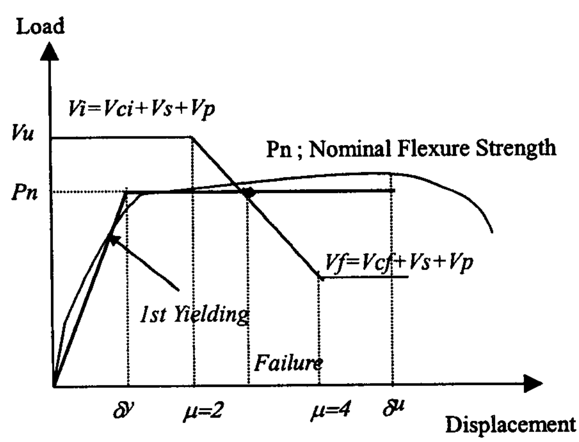

Figure 12. Conceptual model of limited ductility seismic design