Capacity Design of RC Bridge Columns for Seismic Loading

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ABSTRACT

Recently, a tendency for development of seismic approach of foreign countries is capacity design development. Capacity design is rational seismic design concept of capacity protection considering not only earthquake magnitude, but also behavior of structure. For that reason, the most bridge seismic design specifications contain capacity protection provisions explicitly or implicitly. The capacity protection is normally related with slenderness effect of the columns, force transfer in connections between columns and adjacent elements, and shear design of columns. It intends to prevent brittle failure of the structural components of bridges, so that the whole bridge system may show ductile behavior and failure during earthquake events. The objectives of this paper are to deduce needed provisions for the moderate seismicity regions such as Korea after studying current seismic design codes and to establish rational criteria provisions of seismic design for future revision of seismic design specifications.

1. INTRODUCTION

The current seismic design criteria of the Korea Design Specification for Highway Bridge based on special provisions for moderate seismicity regions out of seismic criteria of AASHTO specifications. Therefore, it is insufficient provisions for capacity design. Consequently, it is desirable that capacity design provisions should be added for reasonable seismic design according to design concept. Seismic design for capacity protection intends to prevent brittle failure of the structural components of bridges, so that the whole bridge system may show ductile behavior and failure during earthquake events. It may provide the least guarantee to mitigate human casualties and serious property damages. Therefore, the most bridge seismic design specifications contain capacity protection provisions, explicitly or implicitly. The capacity protection is normally related with slenderness effect of the columns, force transfer in connections between columns and adjacent elements, and shear design of columns. One of the important capacity protections is the shear design of columns. The bridge columns should be designed so that shear failure be prohibited to insure ductile behavior.

The objectives of this paper are to deduce needed provisions for the moderate seismicity regions such as Korea after studying current seismic design codes and to establish rational seismic design criteria provisions for future revision of seismic design specifications. And also, researches related to capacity protection of bridge columns are briefly introduced.

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2. CAPACITY DESIGN

The object of capacity protection is to guarantee ductile behavior and failure of the bridge columns, preventing abrupt brittle failure. To insure this behavior, the column itself and the adjacent elements should not fail abruptly until the columns provide full plastic rotation capacity.

Brittle behavior of the columns is normally related with slenderness effect of the columns, force transfer in connections between columns and adjacent elements, and shear design of columns. The following factors contribute to the consideration of preventing brittle failure.

2.1 Slenderness Effect

Secondary moment, i.e. P-Δ moment, is produced in slender columns. This length effect of columns may result in brittle failure. As the slenderness ratio of the column increases, the P-Δ moment increases. The increased P-Δ moment results in decreasing lateral force capacity of the columns. It may cause brittle failure due to instability. Therefore, the most bridge seismic design specifications contain the provisions for slenderness effect, explicitly or implicitly.

2.2 Connections

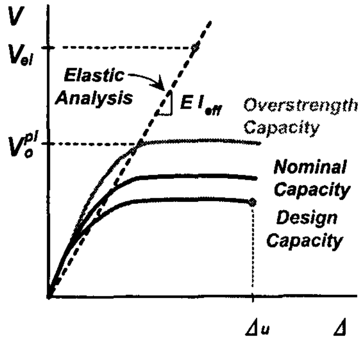
The force produced by the mass and the acceleration of bridge superstructure should be transferred to the ground without brittle failure of any structural component. One of the critical components is the connection between column and adjacent element. Therefore, the most bridge seismic design specifications contain the related provisions, explicitly or implicitly. Two types of design approaches are normally adopted in the bridge seismic design specifications, either or both. The first approach is to use reduced response modification factor for connection. Half the response modification factor of the columns is normally adapted for connections, foundations, and piles. It results in increasing seismic demand for the elements. The second approach is to use the flexural overstrength of the column which is the maximum feasible force transferred from the columns.

2.3 Shear Failure

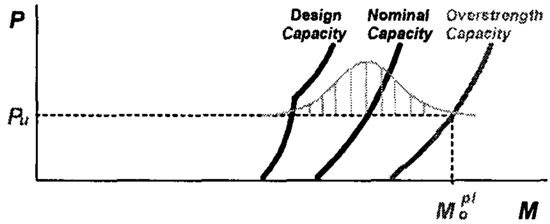
The bridge column itself also should not fail abruptly until the column provides full plastic rotation capacity. It means that shear failure of the column should be prevented to result in ductile flexural failure. Therefore, the most bridge seismic design specifications contain the related provisions, explicitly or implicitly.

3. COMPARISON OF CAPACITY DESIGN CRITERIA

To ensure that inelastic deformations occur only in designated and properly detailed plastic end regions, it is necessary to determine the maximum feasible moment capacity of the plastic hinges and to design the rest of the structure for the actions corresponding to gravity loads plus this flexural overstrength. The capacity design concept is commonly used in the seismic design specifications such as AASHTO, CALTRANS, EC 8-part 2, and New Zealand Code. As the design flexural strength is the lowest reliable strength, actual ultimate flexural strength of the member is always larger than the design strength. Therefore, in order to avoid shear failure and secure the ductile flexural failure of the member, a larger flexural strength than the design strength or the nominal strength should be used to determine the demand for shear design. The corresponding shear force to the maximum feasible flexural strength is used as the design load. Some seismic design codes prescribe that the design shear force *Vu* shall be the lesser of the shear forces resulting from plastic hinging or calculated elastic seismic forces in columns. Even though using the calculated elastic seismic forces *Vel* as the design shear force may result in conservative design in most case, it may not be rational, considering the actual behavior and capacity of the columns as shown in Figure 1.



(a) Lateral force capacity



(b) Flexural strength

Figure 1. Maximum feasible strength

The flexural overstrength may be obtained by moment-curvature analysis considering the above factors or by simplified constant overstrength factor. The overstrength equations or the overstrength constant to calculate the maximum feasible strength are different in each code. ATC-32 prescribes overstrength that plastic flexural overstrength used $1.7f_{ck}$ and $1.25f_y$, or overstrength factor 1.4 for references. ATC/MCEER (2001) prescribes overstrength factor 1.5 or overstrength equation. CALTRANS (2004) prescribes 1.2 times overstrength factor of plastic flexural strength. However, it is insufficient provisions for capacity design in the current seismic design criteria of the Korea Design Specification for Highway Bridge. The decided method for rational overstrength of RC columns should be prescribed to decide design forces considering Korean construction conditions for capacity design. In other words, by analysing the overstrength for used concrete and reinforcement in field, analytical the decided method or overstrength factor need to be presented.

Lee, Jae-Hoon et al. conducted an analytical research on overstrength factor in 2002(Lee, 2003). This research continues in 2004 to provide reasonable overstrength factor considering Korean construction circumstances. It has searched material strength of old bridge columns in Korea. Total 5,336 data of concrete compressive strength were surveyed using nondestructive test and compared with the design characteristic strength as shown in Figure 2. Based on these data and the data for steel strength, the overstrength factor will be re-evaluated to propose to the Korean Bridge Design Specifications(2000) for future revision of seismic design specifications.

And also, the bridge seismic design specifications such as Eurocode 8 - Part 2 and AASHTO-LRFD contain design shear force provisions considering axial force, but seismic design criteria of the Korea Design Specification did not be mentioned. It seems illogical and uneconomical to use elastic shear force by design shear force. It is rational method that design shear force need to be decided take into account the overstrength.

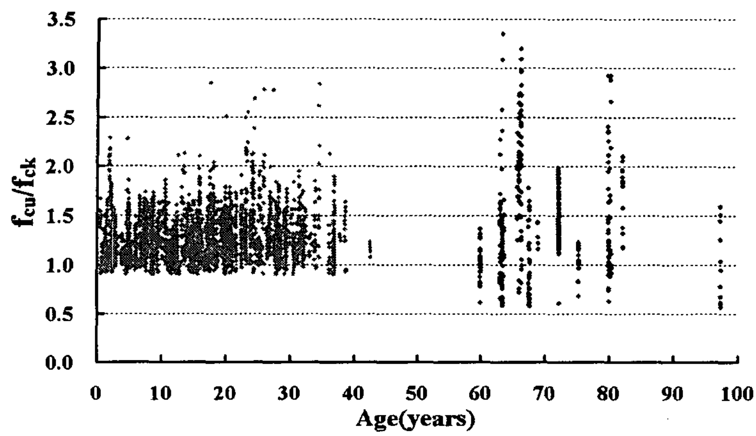


Figure 2. Concrete compressive strength ratio of old bridge columns in Korea

Eurocode 8 - Part 2 and AASHTO-LRFD contain design shear force provisions of plastic hinge region according to capacity design under seismic action, but seismic design criteria of the Korea Design Specification did not mention. Shear strength of concrete contribution is different under stationary loads, so that plastic hinge region of column undergo cyclic loading under seismic loading. For that reason, design shear strength of plastic hinge resign need to be separately prescribed.

The most seismic codes contain separate equation of shear strength for circular section. However, the Korea Design Specification did not mention equation of shear strength for circular section, therefore, equation of shear strength for rectangular section be used for circular one.

4. CONCLUSION

It is desirable that capacity design criteria are contained for avoiding brittle failure modes until the columns provide full plastic rotation capacity, according to design intention. For induction of capacity design provisions, it should be prescribed the decisive method of design loads such as shear strength of columns, acting loads on footing, acting loads on pile. Also, it need to be prescribed reasonable overstrength factor considering Korean construction circumstances, shear force provisions of plastic hinge region, and equation of shear strength for circular section.

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