Comments on the Japanese Seismic Design Specifications by Caltrans' Engineers

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Introduction

This is a comparative study of the Caltrans Seismic Design Criteria, SDC ver 1.1 (1999)[1)] with Part V the Japan's Seismic Design Specification for Highway Bridges (December 1996)[2)]. The Seismic Design Criteria (SDC) version 1.1 is a minimum seismic design requirement for all Ordinary Standard bridges defined in MTD 20-1[3)].

The Japanese Specifications defines two categories of importance (Type A: Standard Importance; Type B: High Importance) and two performance levels for each category (Functional and Safety). It should be noted that SDC is applicable to Ordinary Standard Bridges, while the Japanese Specifications cover Ordinary Standard and Non-standard bridges.

Design Philosophy

The major difference between the two design specifications can be summarized as follows:

The SDC design is mostly based on structures with periods of 0.7 sec. or higher, therefore, the equal displacement principal is applied. The minimum structure period is 0.4 second for Caltrans bridges, while in the Japanese Specifications there is no limit for minimum period for the structure. The SDC design requires the displacement capacity to exceed the displacement demand. The displacement capacity is calculated from the curvature analysis of various bridge elements and the displacement demand is based on elastic models. The SDC requires non-linear demand models for non-standard bridges.

The Japanese Specifications does not mandate a dynamic analysis for all bridges. It is only required under special cases, such as structures with periods of 1.5 seconds and larger. Static analyses such as "Seismic Coefficient Method" or "Ductility Design Method" may be used for ordinary bridges. If a dynamic analysis is required, as outlined in the specifications, then potential nonlinear members shall be modeled as nonlinear elements. The stiffness degradation of the columns or piers (from cycle to cycle) should be captured which results in larger displacement in the nonlinear range.

Seismic Performance

The SDC and the Japanese criteria are very similar in requirements such as Functional and Safety performance. But the structure damage classifications are different in each specification. The Japanese Specifications do not allow any damage under functional for ordinary or important bridges, while SDC allows repairable damage for ordinary bridges and minimal damage for important bridges. Most of the bridges in Japan are designed as important, while as ordinary in California.

Seismic Loads

The Japanese Acceleration Response Spectrum (ARS) curves vary with each design method, soil profile, and the ground motion type. The elastic ARS curves in SDC vary with the peak rock acceleration, soil profile, earthquake moment magnitude, but not the design method. Both specification use the 5% damping and allow modification for different damping. The SDC uses the elastic spectra for its seismic design while the Japanese Specifications use the factored ARS (called Seismic Coefficient). The Seismic Coefficient factors are different for each analysis method.

The seismic load factors in the Japanese Specifications are different for each method of analysis and these factors are: zone coefficient, ductility coefficient, failure type coefficient, and type of material. The zone factor accounts for the intensity of the seismic motion changing from region to region.

Both SDC and the Japanese Specifications account for the direction of seismic motion and the skew of the bridge, however, bridges are designed in the two independent longitudinal and transverse directions.

The Japanese Specifications take the vertical force contribution into account for the design of bearings and "C" bents but there are no detailed guidelines of its use.

Analysis

The method of analysis for both criteria are very similar, they both allow Equivalent Static Analysis, linear elastic dynamic analysis, and nonlinear analysis. The nonlinear analysis is required as the special case analysis in both specifications. Both criteria restrict application of each method based on the importance and the complexity of the structure. The major difference is on application of ARS values for calculating the final seismic load. The SDC does not use any factor on the ARS while the Japanese Specifications allow different factors to be used based on analysis method for the structure. The Japanese Specifications allow three methods of analysis:

1- Seismic Coefficient Method (Elastic Analysis).
2- Ductility Design Method (Pushover Analysis).
3- Dynamic Analysis (Computer Analysis, Complex Analysis).

Seismic Coefficient Method (SCM)

This method is similar to Caltrans' Equivalent Static Analysis (ESA) method except that in ESA the displacement demands of structure are checked while in the

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Japanese Specifications the forces are mostly used. The members are sized based on the calculated seismic loads. The SCM ARS curves each have a long flat portion which forces majority of structures to be designed for high forces. The cross sections of members are sized based on these large force, resulting in members with large cross sections.

Ductility Design Method (DDM)

This method was added as a main design tool to the Japanese Seismic Design Specifications after the 1995 Hyogon-Ken Nanbu (Kobe) earthquake. The strength capacity of the pier shall exceed the demand load The allowable residual displacement for important bridges shall exceed the residual displacement 1%. It seems that the drift limit of 1% may control most of the “class B” bridges.

Dynamic Analysis

This is a dynamic analysis method using computer software. This method can be used to verify the results of Seismic Coefficient Method or the Ductility Design Method.

The following three specific methods of dynamic analyses can be used to verify the Ductility Design Method:

A- Nonlinear Dynamic Analysis

B- Linear Dynamic Analysis Using the Equivalent Linearization Method

C- Combination of Linear analysis with the Ductility Design method

Note that method “A” above is mostly used by the Japanese designers. The method “C” is very close to SDC Elastic Dynamic Analysis (EDA).

Capacity and Allowable Ductility of Reinforced Concrete Piers

In the Japanese Specifications the piers are sized based on the Seismic Coefficient Method, while the Ductility Design Method is used for the deformation capacity design and check. The major requirement is that members shall behave in flexure and not fail in shear.

The following items are related to the maximum allowable ductility:

A- For flexural failure the allowable curvature ductility may exceed 20 as shown in the sample design.

B- The maximum ductility is limited to 1 when shear controls the design.

C- There is no limit on the ductility demand.

D- In calculation of the ductility capacity the stress-strain curve for the steel does not consider hardening.

E- The maximum allowable volumetric ratio of lateral reinforcement (ρ) is 1.8 percent.

F- The stress –strain formulas are also applicable to the hollow sections in the Japanese Specifications, while SDC does not make any recommendations for this shape category.

G- The reduction of main reinforcement within the column/pier height is not permitted.

H- The C-bent is covered in the Japanese Specifications, but SDC does not have any recommendation for this type of bent.

I- The Joint shear is not covered in the Japanese Specifications as it is covered by SDC.

Bearings and Steel Piers

Bearings and Steel Piers are covered in the Japanese Specifications, however, SDC does not cover these topics in depth.

Foundations

In the Japanese Specifications no plastic hinge is allowed in foundations, however, limited displacement and limited rotation of foundations is acceptable.

For the seismic design of foundation based on The Ductility Design Method the following design issues are considered:

A- No yielding is allowed in the longitudinal direction movement of the bridge.

B- In the transverse direction movement, yielding of piles supporting the pier walls is allowed.

Seismic Detailing

The seismic detailing in the Japanese Specifications are similar to SDC, except that the “no splice zone” for main column bars is 4 times the plastic hinge length.

In the Japanese Specifications hoop ties are allowed for confinement. These hoop ties are not welded and the hooks are secured inside the bridge pier core. Hoop ties are allowed to be spliced. The maximum spacing of hoop ties within plastic hinge length is 15 cm. Intermediate hoop ties are used when the size of a section is less than 1 m and they may be used for circular sections.

In the Japanese Specifications reduction of longitudinal reinforcement at mid-height is not recommended under very strong seismic force.

Seismic Isolation design

The Japanese Specifications allow Seismic Isolation Bearings provided there is limited displacement of superstructure. It seems that the use of rubber bearings to isolate the superstructure from the substructure piers is common in Japan's bridges.

Conclusions

The similarities and the differences between the Japanese Specifications and SDC has been presented here. Caltrans' designs are based on framing of super to sub-structure, while the Japanese designs use bearings at the connection of superstructure and substructure. These methods of connections define the difference in the analysis method and method of demand calculations. SDC mostly emphasizes member design based on the displacement demand/capacity, while the Japanese Specifications concentrate on the force demand. In general SDC relies on dissipating energy through plastic hinges, while the Japanese prefer to dissipate energy through bearings and dampers. The Japanese prefer to use pier walls, therefore in the transverse direction the plastic hinge will occur in the piles, while SDC prefers the use of flexural columns for substructure to force the plastic hinges onto the columns and preferably not onto the piles.

It can be said that the Japanese Specifications are not easy to understand the design procedures, in which the matters are related to one section to another, while SDC has simple form.

References

1) Clatrans: Seismic Design Criteria, Version 1.1, California Department of Transportation, July 1999.
2) Japan Road Association: Specifications for Highway Bridges, Part V Seismic Design (December 1996), English version, August 2000.
3) Caltrans: MTD 20-1 Seismic Design Methodology, California Department of Transportation, January 1999.