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Comparative Study of the Japanese Seismic Design Specifications vs. Caltrans' SDC

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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 seismic design of 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 20−13).

The Japanese team provided the following documents:

1) Specifications for Highway Bridges, part V: seismic design (December 1996).
2) Sample design of a 4-span continuous highway bridge in Japanese language4).
3) Sample design of a 4-span continuous highway bridge in English5).

The sample design indicated the use of rubber bearings to isolate the superstructure from the substructure piers. It seems that this type of isolation is common in Japan's bridges. Only specific sections of the Japanese Specifications common to Caltrans and Japan were studied, such as, concrete structures.

In general, there are some philosophical differences between the two criteria, and they will be pointed out later in this report.

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) (Page 5*).

In general, the initial sizing of the bridge members is done by using equivalent static loads in a process called "Seismic Coefficient Method". Then the seismic analysis con-

*Note: Page numbers are shown for the Japanese Specifications in ( ) and SDC in [ ].

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tinues according to one or combination of the following methods:

Pushover Analysis: Ductility Design Method

Dynamic Analysis: Computer Analysis, Complex Analysis (page 4)

It should be noted that SDC is applicable to Ordinary Standard Bridges, while the Japanese Specifications cover Ordinary Standard and Non-standard bridges. Such bridges may be constructed with C-bent, with Isolation bearings and dampers, or with steel piers.

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 non-linear displacement demand is less than the linear displacement demand). 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 (table c.6−1 page 66), 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 (page 68). The stiffness degradation of the columns or piers (from cycle to cycle) should be captured which results in larger displacement in the nonlinear range.

It should be noted that in the Japanese Ductility Design Method the seismic coefficient reduction factor of $1/(2\mu-1)^{0.5}$ is applied (page 60).

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. The Japanese Specifications require different design methods for functional or safety performance requirements. The functional performance in the Japanese Specifications requires the structure to remain elastic under highly probable seismic motion, while SDC allows limited plasticity in the structure. Both SDC and the Japanese Specifications agree on "no collapse" requirements for the safety evaluation of Ordinary Standard bridges.

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 minimum structure period is 0.4 second for Caltrans bridges, but usually structures have periods of more than 0.7 second while in the Japanese Specifications there is no limit for minimum period for the structure. 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 as shown in Figures 1 through 6.

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 deign 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

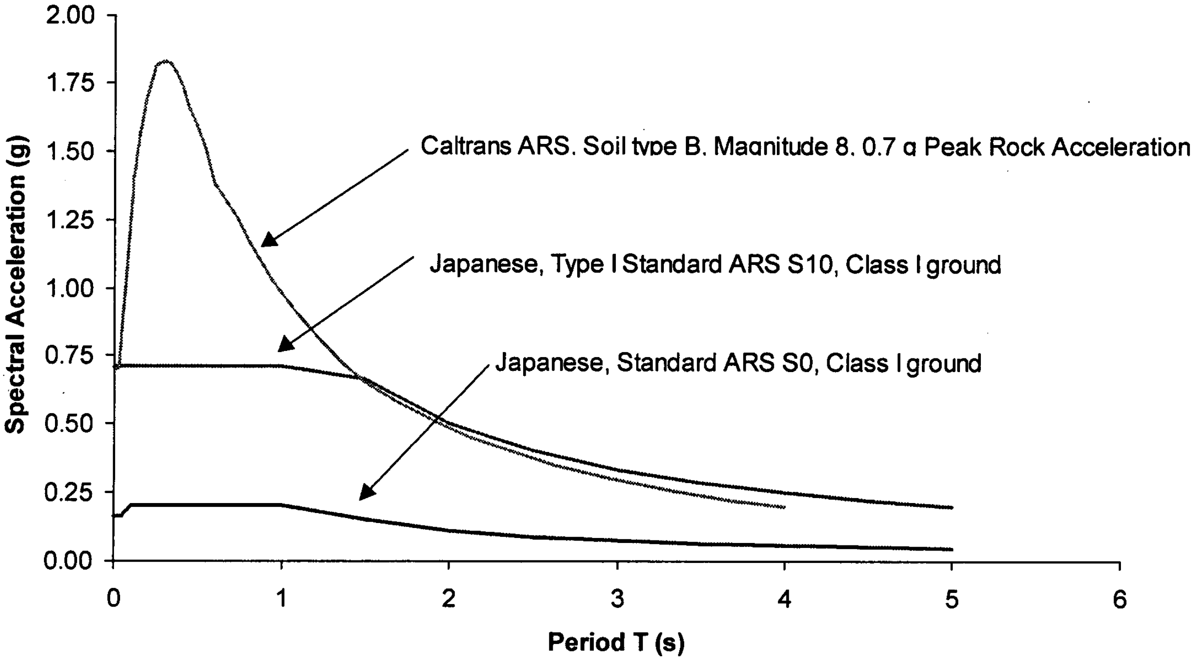

Figure 1- Caltrans ARS vs. Japaness ARS

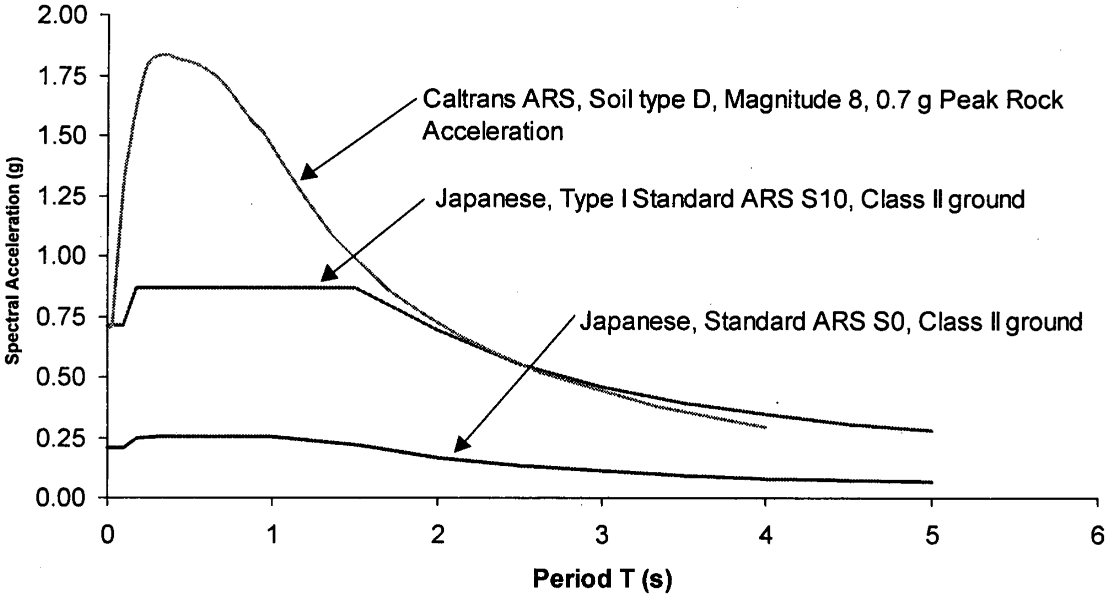

Figure 2- Caltrans ARS vs. Japaness ARS

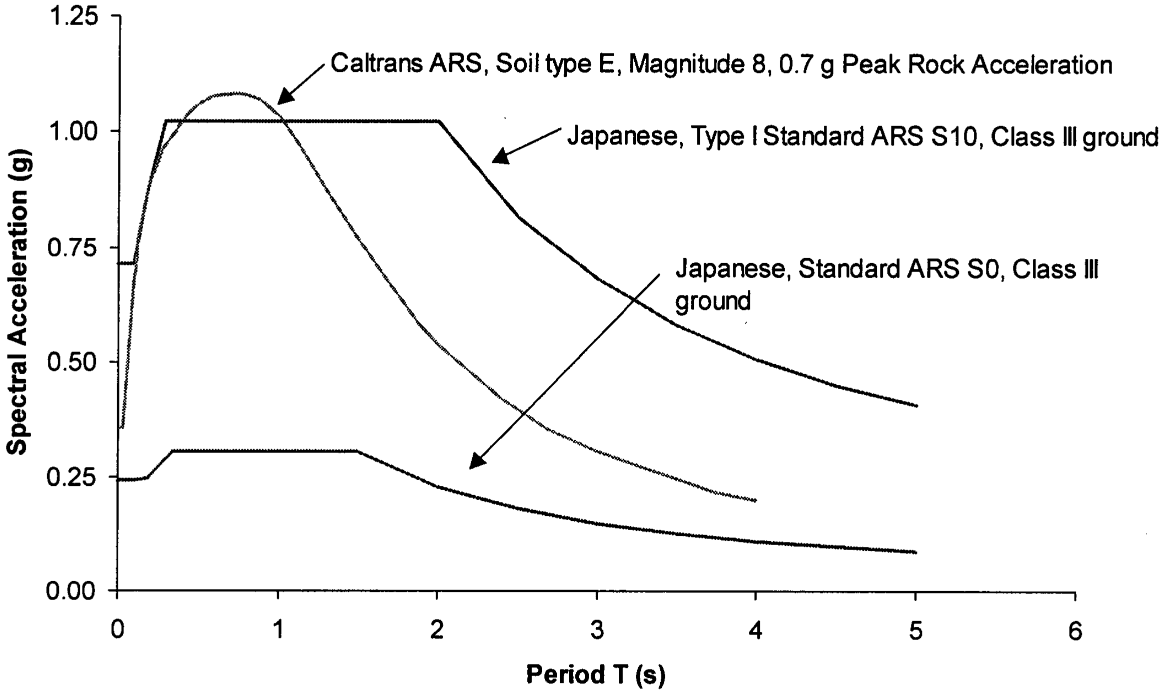

Figure 3- Caltrans ARS vs. Japaness ARS

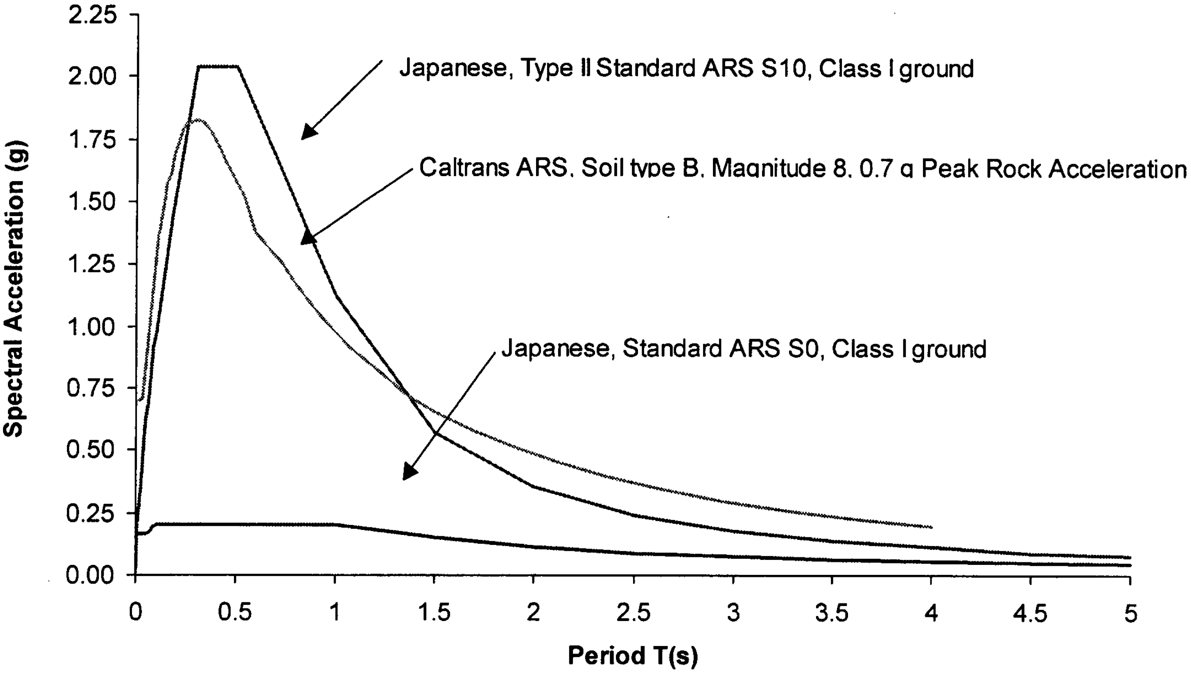

Figure 4- Caltrans ARS vs. Japaness ARS

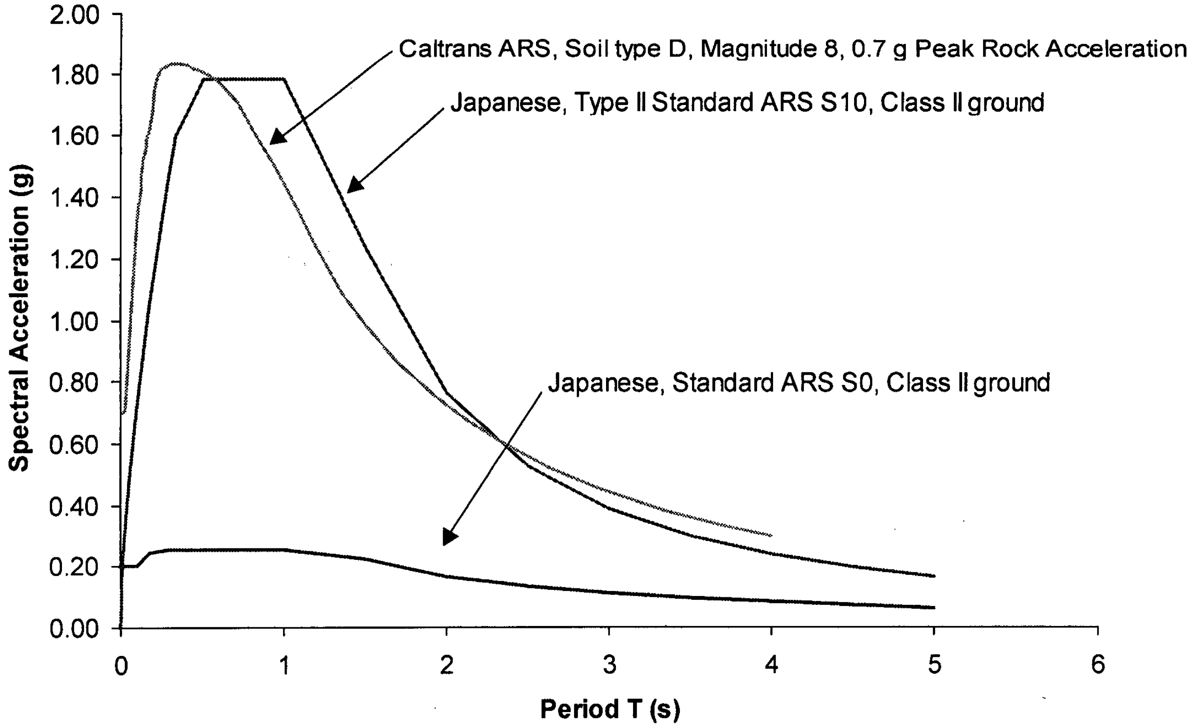

Figure 5- Caltrans ARS vs. Japaness ARS

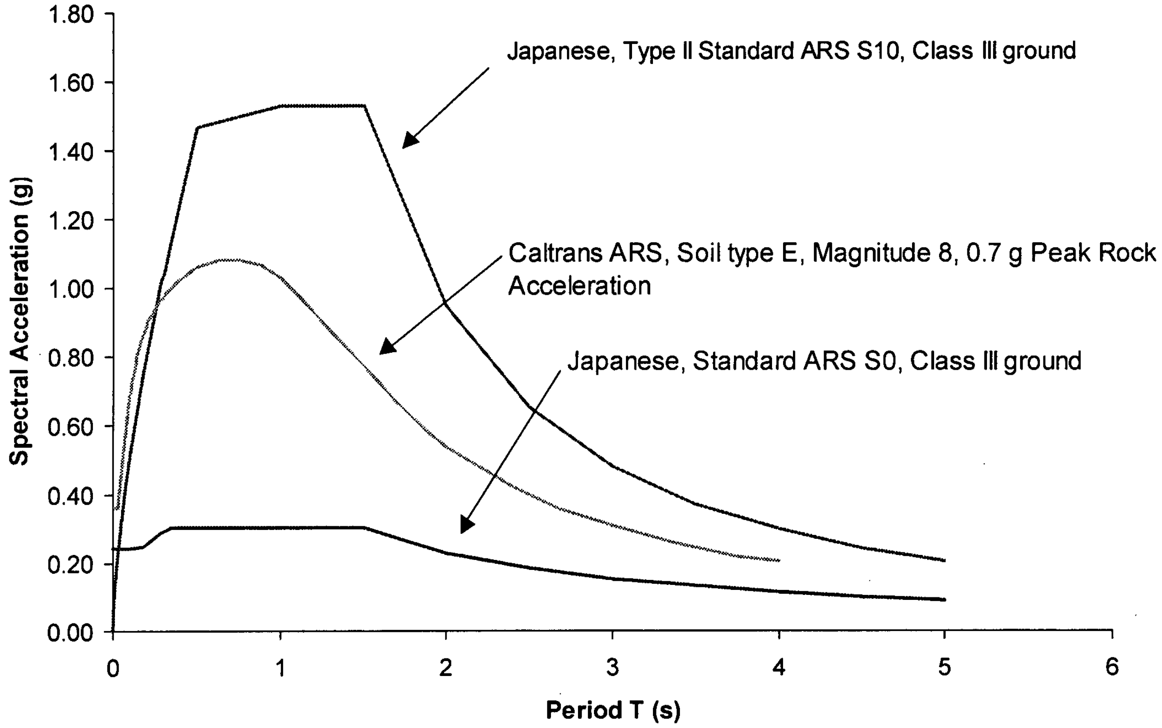

Figure 6- Caltrans ARS vs. Japaness ARS

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) (Elastic Analysis) (Chapter 4)

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 Japanese Specifications the forces are mostly used. The fundamental period of the structure is calculated by using Rayleigh's method. The members are sized based on the calculated seismic loads. The SCM ARS curves (see Figures 1 through 6) each have a long flat portion which forces majority of structures to be designed for high forces. The cross section of members are sized based on these large force, resulting in members with large cross sections.

k_h — Design seismic coefficient $= c_z\ k_{ho}$
c_z — modification factor for zone (page 38)
k_{ho} — Seismic coefficient from chart.

Ductility Design Method (DDM) (Pushover Analysis) (chapter 5)

This method was added to the Japanese Seismic Design Specifications after the 1995 Hyogon-Ken Nanbu (Kobe) earthquake. The intention was to satisfy the deformation performance requirements of the structure. The method is used both for checking and as a design method, as applied to all members, except for the abutments. In this method the equal energy principal is used to predict the displacements. The predicted displacements are compared with the drift limitation of 1% for "class B" bridges. It should be noted that there are no drift limits for "class A" bridges (Standard bridges). It seems that the drift limit of 1% may control most of the "class B" bridges, as evident in the sample design. The minimum applied force should be $0.4C_z$ (page 61, Japanese Specifications).

The following two requirements shall be met in the DDM:

1 — The strength capacity of the pier shall exceed the demand load

P_a — Ultimate horizontal strength of pier $\geqq k_{he}$ W

k_{he} — design seismic coefficient

W — contributing dead load

2 — The allowable residual displacement shall exceed the residual displacement.

$\delta_R \leqq \delta_{Ra}$

δ_R — Residual displacement of the pier

δ_{Ra} — Allowable residual displacement.

Dynamic Analysis (Complex bridges)(Chapter 6)

This is a dynamic analysis method using a computer software (see table C-6.1 of the Japanese Specifications). This method can be used to verify the results of Seismic Coefficient Method or the Ductility Design Method (page 68)

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

A — Nonlinear Dynamic Analysis—In this method the nonlinear members are identified by the linear analysis, then only the necessary members are modeled as nonlinear member.

B — Linear Dynamic Analysis Using the Equivalent Linearization Method—The members are modeled as linear members that will enter non linear zone with equivalent stiffness and equivalent damping constants.

C — Combination of Linear analysis with the Ductility Design method—The members are modeled as linear members that will enter non linear zone with yield stiffness and finding the nonlinear response using the equal energy assumption based on the ductility design method (Page 69). This method is very close to SDC Elastic Dynamic Analysis (EDA) [Page 5-1].

Note that method "A" above is mostly used by the Japanese designers.

The input motion for Dynamic Analysis used to verify the Seismic Coefficient Method or the Ductility Design Method is modified by the damping modification and zone factors (Page 70, page 73).

The basic damping reduction formula for both the Japanese Specifications and SDC are the same. SDC specifies a 5% damped elastic ARS curve for the Ordinary Standard concrete bridges [Page 2—3].

Design

The Japanese Specifications are limited in the area of joint shear, effective width of superstructure, hinges, etc.

Superstructure

The Japanese Specifications and SDC both require the superstructure to remain elastic.

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 (page 115 fig c-9. 2.2)

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 of steel (Fig. 9—3.2).

E—In calculation of the confined concrete stress, the stress is factored (α) based on section shape (page 121).

F—The maximum allowable volumetric ratio of lateral reinforcement (ρ) is 1.8 percent (Page 122).

G—The ultimate concrete strain is factored (β) based on the section shape (page 121).

H—The ultimate concrete strain is dependent on the seismic motion type (Fig 9-4.1).

I—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.

J—The reduction of main reinforcement within the column/pier height is not permitted (page 134).

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.

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.
4) Design Summary of Sakuradai Viaduct, prepared privately by S. Toma (in Japanese).
5) Design Summary of Sakuradai Viaduct, prepared privately by S. Toma (in English).