CALTRANS SDC PROCEDURE

Robert Matthews
H&N Infrastructure

OVERVIEW

- APPLICABILITY OF SDC
- PRELIMINARY STRUCTURE SIZING
- LOCAL MEMBER DUCTILITY
- STAND-ALONE FRAME DESIGN
- GLOBAL BRIDGE DESIGN
- COMPONENT DESIGN
- FOUNDATION FLEXIBILITY EFFECTS
- ANALYSIS TOOLS

APPLICABILITY OF SDC

1. BRIDGE CATEGORIZED AS "ORDINARY" PER MTD 20-11

   A. Not a post-earthquake lifeline
   B. Replacement does not produce a major economic impact

2. BRIDGE CLASSIFIED AS "STANDARD" PER MTD 20-11 AND SDC 1.1

   A. No significant irregular geometry such as high skew
   B. No unusual framing such as outrigger bents
   C. No unusual geologic conditions such as liquefaction

3. EQUAL DISPLACEMENT RULE APPLIES

   A. Bridge behaves essentially like a single degree of freedom system
   B. Fundamental structure period between 0.7 seconds and 3.0 seconds

4. OTHER BRIDGES REQUIRE PROJECT-SPECIFIC CRITERIA PER MTD 20.11

PRELIMINARY STRUCTURE SIZING

1. DETERMINE PRELIMINARY STRUCTURE DIMENSIONS

   A. Structure depth per Caltrans "Comparative Bridge Costs" or BDS Table 8.9.2

   B. Column width ≅ superstructure depth (use next lower standard column size)

   C. Minimum bent cap width per SDC 7.4.2.1

   $$B_{cap} = D_c + 2'(600\,mm)$$

   D. Attempt to balance frames and columns in accordance with SDC 7.1

2. PERFORM RESPONSE SPECTRA ANALYSIS (RSA) OF THE BRIDGE STRUCTURE IN THE LONGITUDINAL AND TRANSVERSE DIRECTIONS.

   A. Use 100%/30% combination rule (SDC 2.1.2)

   B. Preliminary reinforced concrete properties may be used

      i. Use $I_g/2$ for columns

      ii. Use I_g for prestressed girders

PRELIMINARY STRUCTURE SIZING (CONTINUED)

3. DETERMINE PRELIMINARY COLUMN DESIGN USING LOADS FROM TARGET DUCTILITY VALUES OF SDC 2.2.4

   A. Divide RSA forces by R = 4 for single columns or multi-columns in longitudinal direction

   B. Use maximum longitudinal bar size per SDC 8.2.3.1

   C. Check minimum confinement per SDC 8.2.5 and BDS equation 8-62

LOCAL MEMBER DUCTILITY

1. PERFORM MOMENT-CURVATURE (M-ϕ) ANALYSIS OF COLUMNS USING MATERIAL PROPERTIES FROM SDC 3.2

   A. Calculate curvature at yield, ϕ_y, and at failure, ϕ_u, based on axial dead load in column

   B. Calculate cracked moment of inertia, I_{cr}

2. DETERMINE MINIMUM LOCAL MEMBER DUCTILITY

   A. Calculate plastic hinge length, L_p , (SDC 7.6.2)

   B. Calculate displacement capacity per SDC 3.1.3

   C. Calculate ductility per SDC 3.1.4

3. INCREASE CONFINEMENT REINFORCING AS REQUIRED TO MEET MINIMUM LOCAL MEMBER DUCTILITY REQUIREMENTS OF SDC 3.1.4.1

STAND-ALONE FRAME DESIGN

1. DETERMINE STAND-ALONE DISPLACEMENT DEMAND PER SDC 5.4

   A. Perform equivalent static analysis (ESA) or response spectra analysis (RSA) of representative bent(s) in the transverse direction

   B. Use member properties per SDC 5.6.1

      i. Use Icr from M-ϕ analysis and $0.2J_g$ for columns

      ii. Use I_g for prestressed girders

   C. Check SDC 4.2 to verify that P-Δ effects can be ignored

   D. Magnify displacement demands by amplification factor from ATC-32 Section 3.21.10.1 for low period structures. Note that use of this factor is not specifically addressed in the SDC. Refer to Memo to Designers 20-1, page 7 for further information.

Amplification factor $R_d = \left(1 - \frac{1}{R}\right)\frac{T^*}{T} + \frac{1}{R} \geq 1$

R = Force reduction factor from preliminary column sizing

T^* = Period centered at peak of response spectrum

STAND-ALONE FRAME DESIGN (CONTINUED)

2. DETERMINE STAND-ALONE DISPLACEMENT DUCTILITY PER SDC 2.2.3 TO SATISFY SDC 2.2.4

3. DETERMINE STAND-ALONE DISPLACEMENT CAPACITY

   A. Use equations from SDC 3.1.3 to calculate displacement capacity of single column bents

   B. Perform nonlinear static (push-over) analysis of representative multi-column bent(s) in the transverse direction.

      i. Use member properties per SDC 5.6.1

      ii. Use moment hinge in push-over analysis to determine collapse deflection of bents

4. VERIFY THE DISPLACEMENT CAPACITY EXCEEDS DISPLACEMENT DEMAND IN THE TRANSVERSE DIRECTION (SDC 4.1.1)

GLOBAL BRIDGE DESIGN

1. DETERMINE GLOBAL DISPLACEMENT DEMAND PER SDC 5.3

   A. Perform equivalent static analysis (ESA) or response spectra analysis (RSA) of the bridge structure in the longitudinal and transverse directions

   B. Use 100%/30% combination rule (SDC 2.1.2)

   C. Use member properties per SDC 5.6.1

   D. Check SDC 4.2 to verify that P-Δ effects can be ignored

   E. Magnify displacement demands by amplification factor from ATC-32 Section 3.21.10.1 for low period structures.

2. DETERMINE GLOBAL DISPLACEMENT DUCTILITY PER SDC 2.2.3 TO SATISFY SDC 2.2.4

GLOBAL BRIDGE DESIGN (CONTINUED)

3. DETERMINE GLOBAL DISPLACEMENT CAPACITY

    A. Perform nonlinear static (push-over) analysis of bridge frame(s) in longitudinal direction.

        i. Use member properties per SDC 5.6.1

        ii. Use moment hinge in push-over analysis to determine collapse deflection of frame(s)

4. VERIFY THE DISPLACEMENT CAPACITY EXCEEDS DISPLACEMENT DEMAND IN THE LONGITUDINAL AND TRANSVERSE DIRECTIONS (SDC 4.1.1)

COMPONENT DESIGN

1. CALCULATE DESIGN LOADS

   A. Calculate overstrength moment, $M_o = 1.2M_p$ (SDC 4.3.1)
   B. Calculate overstrength shear, V_o (SDC 2.3.2)

2. DESIGN REINFORCING FOR DUCTILE CONCRETE MEMBERS

   A. Check shear capacity per SDC 3.6 to exceed overstrength shear demand
   B. Check minimum development length into cap beam per SDC 8.2

3. DESIGN CAPACITY-PROTECTED MEMBERS

   A. Use material properties per SDC 3.2.1

      i. Use nominal material strength with strength reduction factor, ϕ , for shear
      ii. Use expected material strength with no reduction factor for moment

   B. Design bent caps for dead load plus overstrength moment

      i. Use effective bent cap width per SDC 7.3.1.1

$$B_{eff} = B_{cap} + 12t$$

ii. Design joint shear reinforcing per SDC 7.4

a. Check principal tension stress to see if additional joint reinforcing is required (SDC 7.4.4.1)

b. Provide minimum transverse column reinforcing into the cap per SDC 7.4.4.2

c. Design joint shear reinforcing (if required) per SDC 7.4.4.3

Vertical stirrup area, $A_s^{jv} = 0.2A_{st}$

Horizontal tie area, $A_s^{jh} = 0.1A_{st}$

Horizontal side reinforcement, $A_s^{sf} \geq 0.1A_{cap}^{top\,or\,bottom}$

For skews > 20°, add J-dowels, $A_s^{j-bar} = 0.08A_{st}$

Transverse reinforcement, $\rho_s = 0.4\dfrac{A_{st}}{l_{ac}^2}$

C. Design superstructure

i. Design for dead load plus M_o

a. Use effective superstructure width per SDC 7.2.1

$B_{eff} = D_c + 2D_s$ for closed soffits

$B_{eff} = D_c + D_s$ for open soffits

COMPONENT DESIGN (CONTINUED)

ii. Design for vertical acceleration if PGA > 0.5G (SDC 7.2.2)

a. Design flexural capacity based on continuous mild reinforcing (neglecting prestressing steel) to resist 0.25G (net up or down)

b. Design girder side reinforcing to resist 1.25G by shear friction and continue reinforcing 25 feet (7 meters) beyond the face of the bent cap.

D. Design foundation for dead load plus M_o , V_o

i. Use minimum pile footing thickness per SDC 7.7.1.3

$$D_{ftg} \geq \frac{L_{ftg}}{2.5} \text{ where } L_{\mathrm{ftg}} = \text{distance from face of column to edge of footing}$$

ii. Check footing joint shear per SDC 7.7.1.4

COMPONENT DESIGN (CONTINUED)

E. Design abutment components

   i. Seismic loading to include bearing loads per SDC 7.5

   ii. Size shear keys for 75% of the lateral pile capacity per SDC 7.8.4

   iii. Size abutment seat width per SDC 7.8.3

FOUNDATION FLEXIBILITY EFFECTS

CALTRANS REQUIREMENTS

- MTD 20-1 - The effects of foundation flexibility shall be considered in the seismic design and analysis of all bridges.

- SDC 2.2.1 - The global displacement demand estimate shall include the effects of soil/foundation flexibility if they are significant.

SOIL CLASSIFICATION (SDC 6.2.2)

1. Competent Soil – "Foundations surrounded by competent soil ... (have) an insignificant impact on the overall dynamic response of the bridge and is typically ignored in the demand and capacity assessment. "

    - Standard penetration, upper layer (0-10 ft, 0-3 m) N = 20 (Granular soils)
    - Standard penetration, lower layer (10-30 ft, 3-9 m) N = 30 (Granular soils)
    - Undrained shear strength, s_u > 1500 psf (72 KPa) (Cohesive soils)
    - Shear wave velocity, v_s > 600 ft/sec (180 m/sec)
    - Low potential for liquefaction, lateral spreading, or scour

FOUNDATION FLEXIBILITY EFFECTS (CONTINUED)

2. Poor Soil - The presence of poor soil classifies a bridge as non-standard, thereby requiring project-specific design criteria that address soil structure interaction (SSI) related phenomena.

   - Standard penetration, N<10

3. Marginal Soil - Marginal defines the range on soil that cannot readily be classified as either competent or poor. The course of action for bridges in marginal soil will be determined on a project-by-project basis.

FOUNDATION FLEXIBILITY EFFECTS (CONTINUED)

<u>CONCERNS</u>

- The displacement demand calculated using a linear elastic bridge model is not compatible with the displacement capacity calculated using a static nonlinear (pushover) bridge model.

- Caltrans SDC requires that a bridge have a displacement capacity which exceeds the displacement demand calculated using linear elastic material properties. Empirical studies have shown that the so-called "equal displacement" rule is appropriate for single degree-of-freedom structures with initial vibration period, T, greater than the peak of the response spectrum. ATC 32 Section 3.21.10.1 provides amplification factors for displacement demand of lower period structures based on empirical studies without foundation flexibility.

- The foundation stiffness used in the bridge models may have a significant effect on the response acceleration and displacement of the structure. The foundation is capacity-protected and does not deflect beyond the load level corresponding to the plastic hinging of the columns, therefore use of a linear foundation spring in the demand model does not seem appropriate.

FOUNDATION FLEXIBILITY EFFECTS (CONTINUED)

RECOMMENDATIONS

1. Initial recommendation

   A. Geotechnical engineer to classify soil as competent, poor or marginal per SDC 6.2.2

   B. Ignore foundation flexibility when designing for structures with pile foundations in competent soil.

   C. Other structures will require studies to determine project-specific criteria based on sensitivity of structure design to foundation flexibility.

2. Study effects of foundation flexibility on structure design

   A. Develop various foundation flexibility options

      i. Initial stiffness linear springs
      ii. Secant stiffness linear springs
      iii. Non-linear springs

FOUNDATION FLEXIBILITY EFFECTS (CONTINUED)

3. Perform analysis with various combinations of foundation flexibility

   A. Use of initial or secant stiffness for demand model
   B. Use of linear secant stiffness or nonlinear spring for capacity model

4. Compare structure effects

   A. Response acceleration
   B. Deflection demand
   C. Deflection capacity

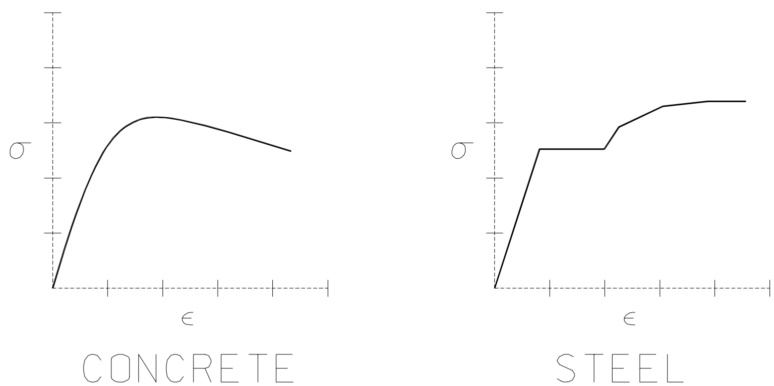
5. Final recommendations based on results of studies.

   A. Pile foundation springs
   B. Spread footing foundation springs
   C. Extended pile foundation springs

Holmes & Narver
Infrastructure Structural Group

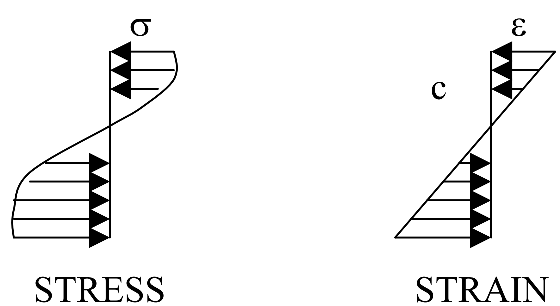
MOMENT-CURVATURE ANALYSIS

- Moment-curvature determined from iterative section analysis using nonlinear stress-strain material properties of concrete and reinforcing steel



- Moment, M, determined from section stress distribution

- Curvature, $\phi = \varepsilon/c$, in radians / (length unit) determined from section strain distribution



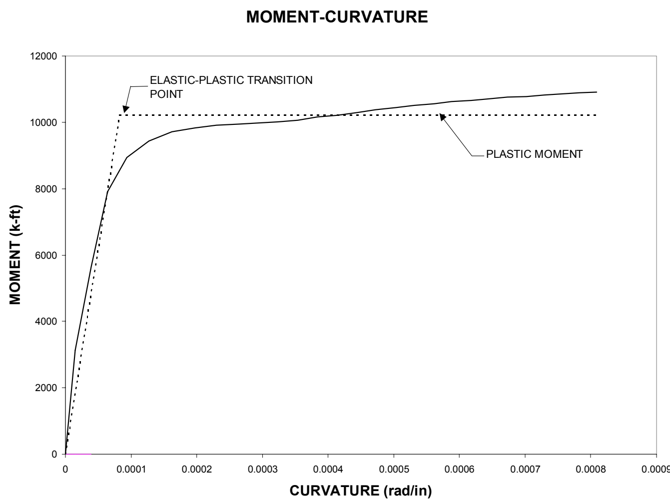
MOMENT-CURVATURE ANALYSIS (CONTINUED)

Holmes & Narver
Infrastructure Structural Group

- Cracked moment of inertia, Icr, determined from curvature at first yield of reinforcing

$$I_{cr} = \frac{M}{E\phi}$$

- Plastic moment, Mpl, determined from average moment after first yield



- Idealized yield curvature at elastic-plastic transition point

$$\phi_y^i = \phi_y \frac{M_{pl}}{M_y}$$

- Ultimate curvature at point when failure strain of concrete or reinforcing is reached

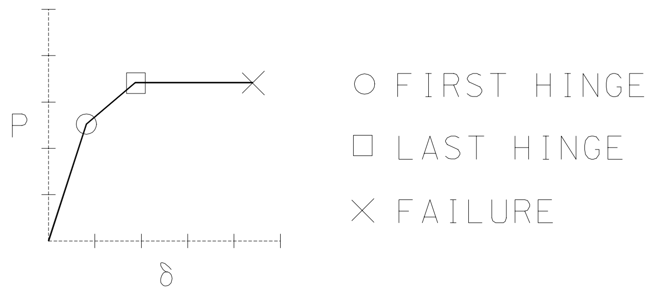
- Computer tools include XSECTION (Caltrans), CONSEC (H&N), UCFyber (ZEVENT) and SEQMC (SEQAD)

ANALYSIS TOOLS (CONTINUED)

Holmes & Narver
Infrastructure Structural Group

STATIC NONLINEAR (PUSH-OVER) ANALYSIS

- Push-over analysis used to determine ultimate (collapse) deflection of a frame



- Computer tools include, wFRAME (Caltrans), SAP2000 Nonlinear and SC-PUSH3D (SC Solutions)

- Incremental static analysis may also be used with conventional hand calculations or programs by inserting moment hinges as each joint goes plastic.

- wFRAME and incremental static analysis require additional hand calculations to determine collapse deflection beyond formation of final hinge

- SAP2000 Nonlinear determines ultimate deflection