20.35 SEISMIC DESIGN REQUIREMENTS FOR CONCRETE OPEN SPANDREL ARCH BRIDGES

20.35.1 GENERAL

This policy addresses the seismic design of concrete open spandrel arch bridges. It covers requirements for seismic analysis and design of arch ribs, spandrel columns, and transverse struts.

20.35.2 DEFINITIONS

Open Spandrel Arch Bridge — A bridge system that uses a combination of spandrel columns and arch ribs to transfer the load from the bridge superstructure to the foundation – see Figure 20.35.2-1.

Strut — A horizontal member connecting arch ribs and used for stability.

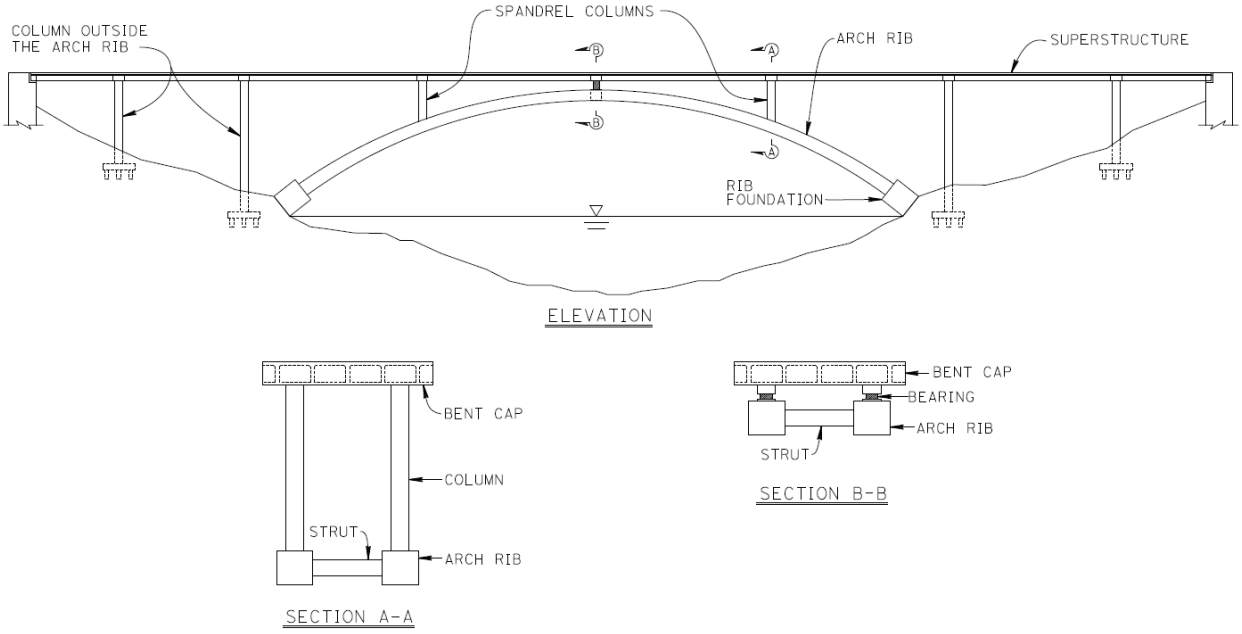


Figure 20.35.2-1 Open Spandrel Arch Bridge

20.35.3 NOTATION

CPM = Capacity protected member

NTHA = Nonlinear time history analysis

SCM = Seismic critical member

SDC = Caltrans Seismic Design Criteria

20.35.4 SEISMIC REQUIREMENTS

All components of the arch bridge shall meet the requirements of the current Caltrans Seismic Design Criteria (SDC), as amended by this Structure Technical Policy. Preliminary analysis may be conducted using the Elastic Dynamic Analysis procedure, as specified in the SDC. Nonlinear Time History Analysis (NTHA) shall be used to finalize the design and verify that the bridge meets the design requirements. Per the SDC, arch bridges are considered non-standard because of their unusually complex features and require a Project-Specific Design Criteria in accordance with STP 1.3.

20.35.4.1 Arch Ribs

Arch ribs shall be designed as seismic critical members (SCMs) and shall satisfy the requirements for SCMs as specified in the SDC, except as stated in this STP.

- A minimum of two arch ribs shall be required for each bridge.
- The displacement ductility demand value for arch ribs shall be limited to 2.0.
- The required strength of the arch rib shall be based on demands from NTHA.
- Arch ribs shall be designed to be greater than both the overstrength demands ($1.2M_p$) of the spandrel columns and the overstrength demands of the transverse struts.
- The potential plastic hinge length shall be taken as three times the rib transverse cross-section dimension measured from the top of the foundation.
- Plastic hinging shall be limited to locations adjacent to the rib foundations.
- The maximum axial force due to dead load in the potential plastic hinge region shall be $0.25f'_cA_g$, where f'_c is the specified compressive strength of the rib concrete, and A_g is the gross cross-sectional area of the arch rib in the potential plastic hinge region.

Arch rib cross-sections shall satisfy the following requirements:

- Solid rib cross-sections shall be used within the potential plastic hinge regions.
- Solid rib cross-sections shall be used at transverse strut and spandrel column locations and shall extend a minimum of 1 foot on either side of a strut or spandrel column. Hollow rib cross-sections may be used elsewhere, when necessary to reduce rib weight.
- Where hollow arch ribs are provided, the section around the cavity shall be confined to prevent implosion.

Transverse confinement reinforcement within the potential plastic hinge region shall satisfy the following requirements:

- The minimum transverse reinforcement ratio for butt-welded circular hoops shall be 0.008.
- The maximum longitudinal spacing of transverse reinforcement shall be equal to the lesser of six times the smallest longitudinal bar diameter or 6.0 inches.
- Plastic hinge regions shall have a curvature ductility capacity that is at least 1.5 times the NTHA curvature ductility demand at the same location.

20.35.4.2 Other Components of the Bridge

Spandrel Columns

Spandrel columns shall satisfy the SDC requirements for SCMs. In addition, plastic hinge regions in spandrel columns shall have a curvature ductility capacity that is at least 1.5 times the curvature ductility demand from NTHA.

The base of spandrel columns shall be fixed. Spandrel column tops can be fixed, pinned, or have reduced moment connections to provide substantial lateral support by all columns.

The balanced stiffness requirements for SCMs, as provided in the SDC, shall not apply to spandrel columns. Other bridge columns that are not supported by the arch ribs shall satisfy the SDC requirements for balanced stiffness.

The ratio of spandrel column shear length to the larger column cross-section dimension shall be greater than or equal to 4.0. The shear length is the column length from the point of maximum moment to the adjacent point of zero moment.

NTHA results must show that the curvature ductility demand on any spandrel column is not more than 50 percent larger than other spandrel bents.

Only vertical spandrel columns shall be allowed.

Transverse Strut

Arch ribs shall be tied together transversely with at least one transverse strut, typically at the arch crown, to ensure lateral stability. Additional struts may be required depending on the length of the arch ribs. The need for additional struts shall be determined in the final design based on NTHA analyses, including out-of-plane buckling, lateral slenderness, and load distribution. Construction and erection stability shall also be considered.

Transverse struts can form plastic hinges at both ends of the strut. Transverse struts shall have a curvature ductility capacity that is at least 1.5 times the curvature ductility demand from NTHA.

Spandrel Bent Caps and Arch Rib foundations

Spandrel bent caps and arch rib foundations shall be designed as CPMs.

Other Bridge Members

Other bridge members shall be designed as specified in the SDC.

20.35.5 REFERENCES

1. Caltrans. (2025). *Caltrans Seismic Design Criteria*, Version 2.1. California Department of Transportation, Sacramento, CA.
2. Caltrans. (2025). BDM 20.24. Nonlinear Time History Analysis of Bridges, California Department of Transportation, Sacramento, CA.
3. Caltrans. (2023). BDM 1.5. *Project-Specific Design Criteria*, California Department of Transportation, Sacramento, CA.
4. Kawashima, K., and Mizoguti, A. (2000). *Seismic Response of a Reinforced Concrete Arch Bridge,* 12th World Conference on Earthquake Engineering, Auckland, NZ.
5. McCallen, D., Noble, C., and Hoehler, M. (1999). *The Seismic Response of Concrete Arch Bridges,* Final Report to the California Department of Transportation, Sacramento, CA.
6. Moehle, J., and Miller, D. (2019). *Ductile Behavior of Reinforced Concrete Arch Ribs,* Phase 1 Report to the California Department of Transportation, Sacramento, CA.