

# Seismic Design of Precast Concrete Bridges

An Online Continuing Education Course for Engineers

**Course Number: T-5015**

**Credit: 5 Hours / 5 PDH / 5 CPD**

# Seismic Design of Precast Concrete Bridges

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Precast concrete bridge components and systems provide effective and economical design solutions for new bridge construction and for the rehabilitation of existing bridges. The use of precast components can shorten road closure times, minimize interference with traffic flow, and accomplish the objective often cited by officials to “get in, get out, and stay out.”

The seismic design of precast concrete bridges begins with a global analysis of the response of the structure to earthquake loadings and a detailed evaluation of connections between precast beams and of connections between the superstructure and the supporting substructure. Ductile behavior is desirable under earthquake loadings for both the longitudinal and transverse directions of the bridge. Further, the substructure must be made to either protect the superstructure from force effects due to ground motions through fusing or plastic hinging or to transmit the inertial forces that act on the bridge to the ground through a continuous load path.

This course is intended to augment and not replace the ***AASHTO Guide Specifications for LRFD Seismic Bridge Design (AASHTO, 2009)*** (referred to herein as the *LRFD Seismic Guide Specifications*) or any agency requirements for seismic analysis or design. The designer should verify the latest applicable standards with the owner and discuss any necessary exceptions before beginning design. For the current state-of-the-practice, the seismic design of precast concrete bridges employs an AASHTO-LRFD Type 1 design strategy and uses connections between precast concrete elements and between cast-in-place (CIP) concrete and precast concrete elements that are intended to emulate the behavior of CIP concrete connections.

Seismic design is complex. Bridges of similar characteristics in different locations may behave very differently during an earthquake. The engineer should not copy details that have been used on previous projects without a complete understanding of the reasons behind the original design.

## 1.1 Objective

The objective of this course is to present state-of-the-practice information on the seismic design of ordinary highway bridges containing precast components. Ordinary bridges are defined as:

- Well-proportioned structures with span lengths of less than 300 ft
- Structures where stiffness and frame geometry are balanced and without unusual geometry, such as splayed beams or abrupt changes in superstructure stiffness
- Structures without outrigger caps, changes in beam type, variable numbers of beams between spans, or variable beam spacing

- Structures constructed with either normal or lightweight concrete
- Structures either simply supported or continuous at piers or bents with beams either supported on dropped bent caps or made integral with bent caps
- Structures supported on elastomeric bearings, cotton duck pads, disc bearings, or other bearings and without the intentional use of seismic isolation or other energy-dissipating technology in the supports
- Structures supported on spread footings, driven piles, drilled shafts, or a combination of these foundation types

## **1.2 Potential Causes of Earthquake Damage to Bridges with Precast Components**

Precast concrete bridge failures during an earthquake have been attributed to:

- Unseating of the superstructure at abutments, hinges, intermediate supports, or expansion joints due to insufficient support length
- Column failure due to longitudinal bar buckling caused by inadequately confined reinforcement, the unraveling of spiral reinforcement, poor quality butt welds, or necking of mechanical splices
- Column failure due to lateral forces causing shear failures due to inadequate transverse reinforcement
- Column failure due to architectural flares reducing effective column height, increasing column stiffness, and attracting more load to one column than others
- Column failure due to inadequate or non-staggered lap splices, poor quality butt welds, or necking at mechanical splices in plastic hinging regions of the column
- Column failure due to barrier rail being attached to the column and thereby shortening, stiffening, and attracting more load to the column
- Joint shear failure at critical superstructure-to-substructure connections
- Columns punching through the superstructure due to inadequate shear resistance of the deck following a loss of the column bearing during liquefaction
- Moment failure at the base of a column due to lack of a top layer of reinforcement in the footing
- Inadequate transverse support or transverse stop mechanism at beam supports
- Pile-to-pile cap connection failure
- Concrete bearing failure due to the yield of elastomeric bearings or tipping of steel rocker bearings
- Inadequate detailing of reinforcement in support

### 1.3 Seismic Hazard Maps

Seismic hazard is not limited to the western United States. Although most states nationwide have not had significant levels of earthquake activity during recent history, the occurrence of past notable earthquakes demonstrates that significant earthquake hazards exist in the Missouri–Illinois–Tennessee tri-state region, in South Carolina, and along the St. Lawrence Seaway, as well as in the western United States, Alaska, Hawaii, Puerto Rico, and the U. S. Virgin Islands. The mapping of fault zones and the discovery of hidden or inactive faults have brought increased concerns. Most states include some form of seismic criteria in their bridge design policies.

Seismic maps typically depict peak ground acceleration, determined as the lesser of probabilistic and deterministic ground motion parameters. Maps for bridge applications are available from the United States Geological Service (USGS) website: <https://earthquake.usgs.gov/hazards/designmaps/>. The maps for bridges and buildings are not the same because of differences in the targeted earthquake return period, the targeted risk rather than uniform-hazard ground motion, and the use of the maximum direction rather than the geometric mean for the spectral response acceleration. Probabilistic maps are based on the strain rate for each documented event.

One of the most significant recent revisions by the *LRFD Seismic Guide Specifications* has been the adoption of seismic maps that use a 1,000-year return period (7% probability of exceedance in 75 years). The maps for bridge design on the USGS website are available in downloadable form and were created by the USGS under agreement with the American Association of State Highway and Transportation Officials (AASHTO). The USGS software provides a ground motion tool that develops peak seismic ground accelerations (PGA), spectral accelerations, and response spectra for a given postal zip code or grid location.

Prior to September 2009, the California Department of Transportation (Caltrans) used deterministic maps based on seismic records, the maximum credible event for each known fault, and a specific seismic attenuation relationship. After September 2009, the hazard maps were revised to reflect values based on hybrid deterministic-probabilistic relationships.

Earthquake motions can result in ground and hydrological response modifications that can subject bridges to forces different from, and in addition to, the forces associated with, earthquake motions alone. Ground response can result in lateral spreading and liquefaction that markedly affect the substructure and, consequently, the response of the superstructure of the bridge. Where such effects are likely, a thorough soil investigation should be completed and its results taken into account before any detailed seismic design is undertaken. In coastal areas of the western United States, subduction zone motions can give rise to tsunamis and marked ground elevation changes. The National Tsunami Hazard Mitigation Program is led by the National Oceanic and Atmospheric Administration (NOAA) and the USGS. Tsunami inundation maps are available on a state-by-state basis, and the extent of those areas should be considered for the design of coastal bridges.

## 1.5 Performance Criteria

Acceptable seismic performance criteria for precast concrete bridge structures must satisfy both safety and economic criteria. A bridge is part of a highway system, and most agencies have earthquake response and recovery plans that identify primary, secondary, and tertiary response routes within that system. Ideally, the acceptable seismic performance for bridges on a given route will vary with the priority of the route and may need to be higher than that for collapse prevention, as specified in the *LRFD Seismic Guide Specifications*. Requiring all bridges to be serviceable immediately after an earthquake is not economically feasible for most agencies. Still, preventing bridge collapse and possible loss of life should be achievable if, as required by the *LRFD Seismic Guide Specifications*, bridges are designed for a life safety performance objective considering the seismic hazard corresponding to a 7% probability of exceedance in 75 years. This course is concerned with seismic design for the collapse-prevention performance level. Higher levels of performance, with operational objectives, may be deemed necessary for a given bridge, and the research results reported and published on the internet can help provide information for desirable response guidelines for higher levels of performance.

Designing for life safety means that significant damage can result. Significant damage includes permanent offsets, damage between approach structures and the bridge superstructure, between spans at expansion joints, permanent changes in bridge span lengths, and permanent displacements at the top of bridge columns. Damage also consists of severe concrete cracking, yielding and buckling of reinforcement, major spalling of concrete, and severe cracking of the bridge deck slab. These conditions may require the closure of the bridge to repair the damages.

Partial or complete replacement of columns may be required in some cases. For sites with lateral flow due to liquefaction, piles may suffer significant inelastic deformation, and partial or complete replacement of the columns and piles may be necessary. If the replacement of columns or other components is to be avoided, a design strategy that produces minimal or moderate damage—such as seismic isolation or a control and reparability design concept—should be used. Designing for life safety means that significant disruption to service level performance is likely, resulting in the need for limited access (reduced lanes, light emergency traffic) on the bridge and possible requirements for shoring.

## 1.6 Precast Systems and Components

The precast structural systems covered by this course are as follows:

### 1.6.1 Superstructure Types

- Precast, pretensioned concrete beams with CIP concrete deck
- Precast, post-tensioned concrete spliced beams with CIP concrete deck

## **1.6.2 Substructure Components**

- Precast concrete column segments post-tensioned together in the field.
- Precast concrete bent caps (“dropped caps” where the beams sit on the top surface; also known as hammerhead caps)
- Partially precast bent caps (beams sit on a precast “yoke” that fits over columns and has stirrup extensions; the top half of the cap is CIP with deck concrete)
- Integral bent caps (CIP concrete that encapsulates beam ends; the bottom of the cap is flush with the bottom of beams)
- Precast columns on CIP footings
- Precast drop caps on precast columns
- Precast piles
- Precast pile caps
- Precast abutments
- Precast walls

## **1.6.3 Precast Systems and Components Not Addressed in this Course**

Precast segmental members and systems for bridges constructed using the balanced cantilever method are not covered by this report. Seismic design considerations for extraordinary bridges and major bridges are not covered by this course.

## **2.0 Structural System Considerations**

### **2.1 Foundations**

As more is learned about the effect of soil-structure interaction (SSI), new guidelines and procedures continue to be developed to enhance the accuracy of predictions of bridge response to seismic loading. However, practical limitations prevent the detailed incorporation of SSI effects into every project.

Where a situation warrants the development of site-specific spectra, extra effort in site investigation, laboratory testing, and modeling may be required. On very long bridges, the subsurface conditions may vary to the extent that a single-response spectrum is not an accurate representation of the soil conditions. In these cases, multiple support excitations may be required. SSI modeling may not be required if site-specific spectra are used.

In addition to SSI analyses, site stability should be considered. Issues include soil liquefaction, basin effects, soft-clay sites, and slope hazards. Investigation into soil liquefaction includes analysis for lateral spread, loss of support, and dynamic settlement, as well as mitigation of such effects through site improvements. Large site amplification effects are possible for soft-clay sites. Slope failure has been recognized as one of the major causes of bridge collapse due to earthquakes.

## 2.2 Response Characteristics of Precast Concrete Bridge Systems

The structural response of a precast bridge varies from hinged in the case of simply supported beams to emulative fixity for bridges with monolithic cast-in-place beam–cap–column details. The desired seismic structural response is collapse prevention of the superstructure. This response can be accomplished by forcing damage into the columns, which are then more easily repaired or replaced than the superstructure. For precast concrete construction, bent cap detail is a key to the implementation of that strategy. Four bent cap–beam connection concepts A through D are presented and discussed in the following four sections. Each provides progressively more ability to drive plastic hinging into the columns.

### 2.2.1 Concept A

This connection is used directly on the top of the column. It is used for live loads and seismic loads. Structures exhibit jointed behavior. Structures are widely used for performance of bearings and

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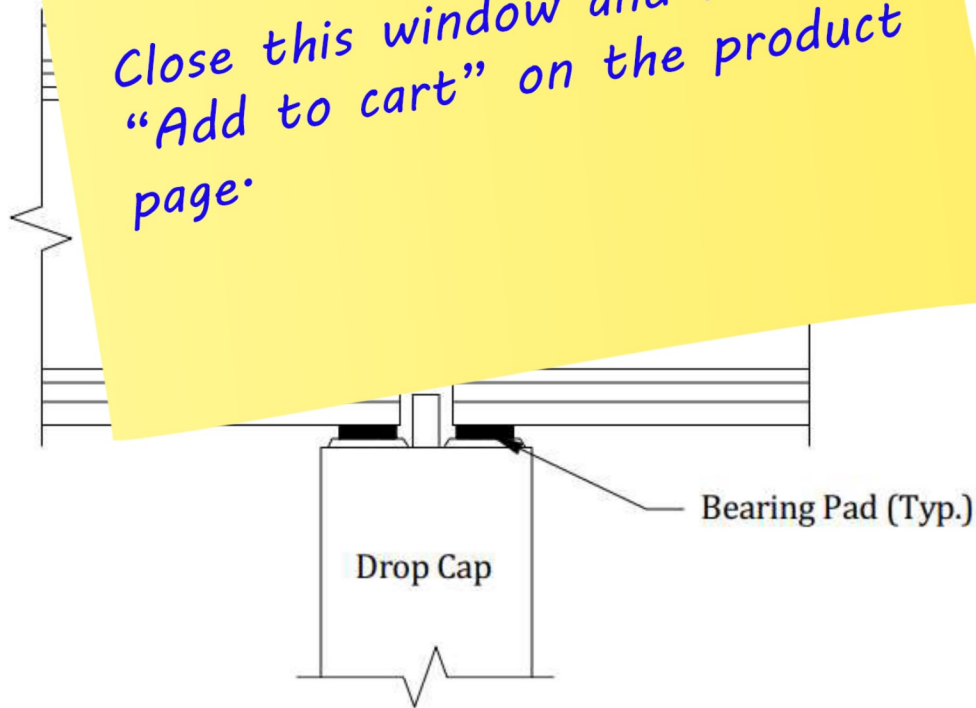


Figure 2.2.1-1- Precast Beams on a Drop Cap—Simply Supported