Seismic Design Considerations for South Carolina Bridges

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HDR

Sunday, October 29, 2023

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40+ Countries

with ongoing projects

Our Impact

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200+ Offices around the globe

15 Countries

23 Envision®-verified projects

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Largest 100% Employee-Owned architecture /engineering firm, *National Center for Employee Ownership*, *2022*

No. 1
Healthcare Firm, *Building Design Magazine World Architecture 100 Survey, 2022*

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Top Architecture / Engineering Firms, *Building Design+Construction, Giants 300, 2022*

No. 5
Top 500 Design Firms, *Engineering News-Record, 2022*

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Top 25 in Bridges, *Engineering News-Record, 2022*

No. 7
Top 50 Designers in International Markets, *Engineering News-Record, 2022*

4
Grand Conceptor Awards, *American Council of Engineering Companies, 2010, 2011, 2017, 2018*

As of 08/17/22

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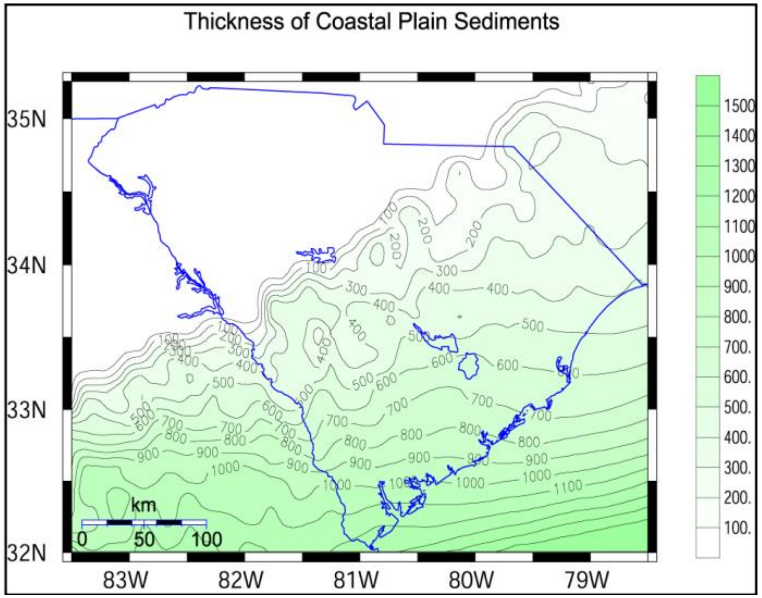
Agenda

- Geology and Seismicity of South Carolina
- Structural Design Requirements
  - Typical Design Considerations
  - Material Properties
  - Example Detailing
- Limitations and Topics for Future Study

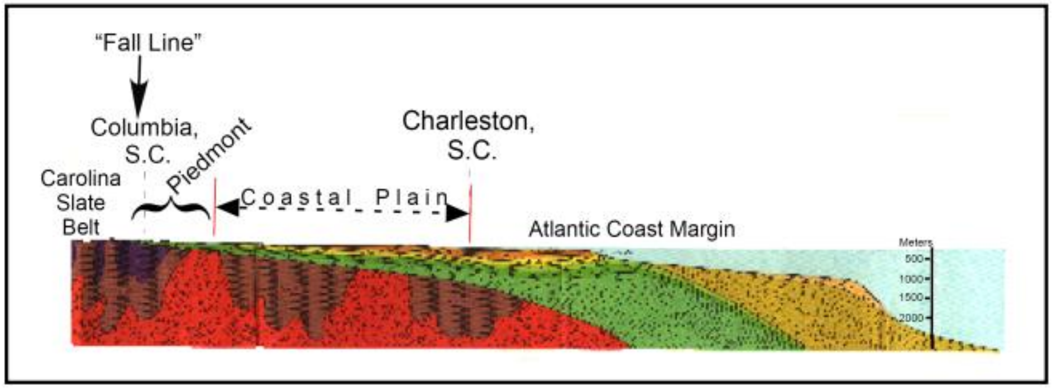
History of Seismicity in South Carolina

- Charleston Earthquake of 1886
  - Estimated 7.3 Magnitude
  - Approx. 100 dead
  - Evidence of “Sand Blows” found along SC Coastal regions

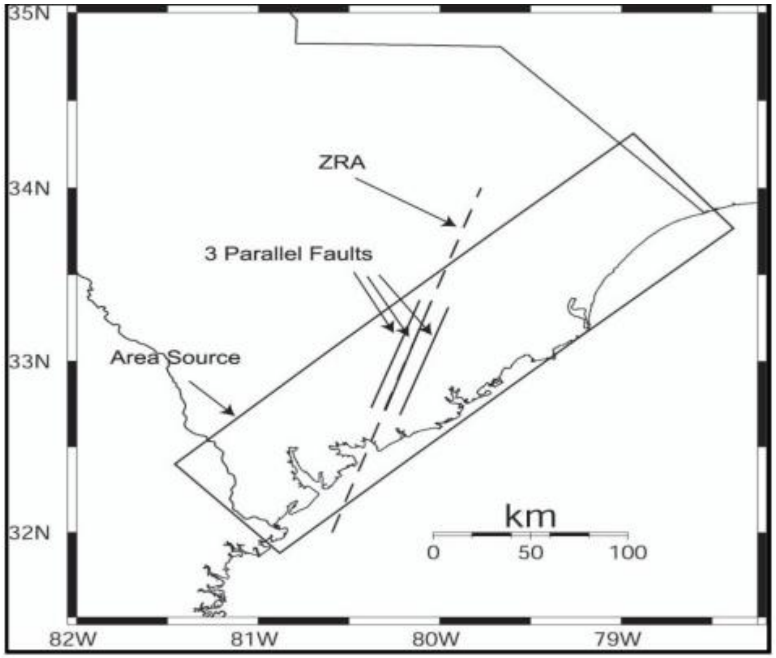
Geology of South Carolina

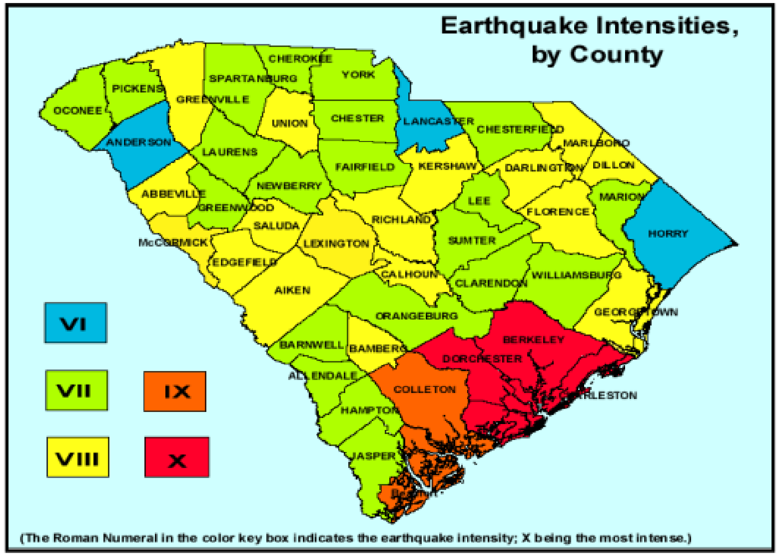


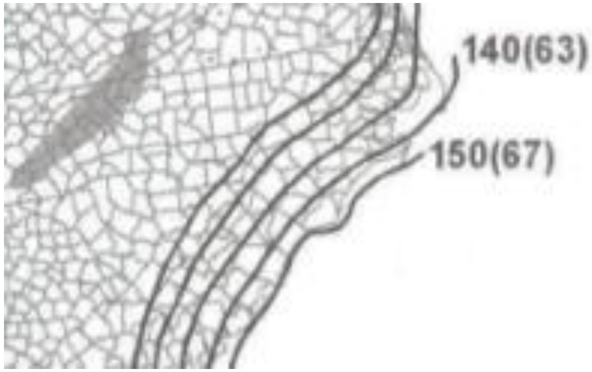
- Coastal plain has seismic response different than remainder of state. Necessitates State-specific hazard maps.
- "Fall Line" differentiates Coastal Plain from rest of SC.



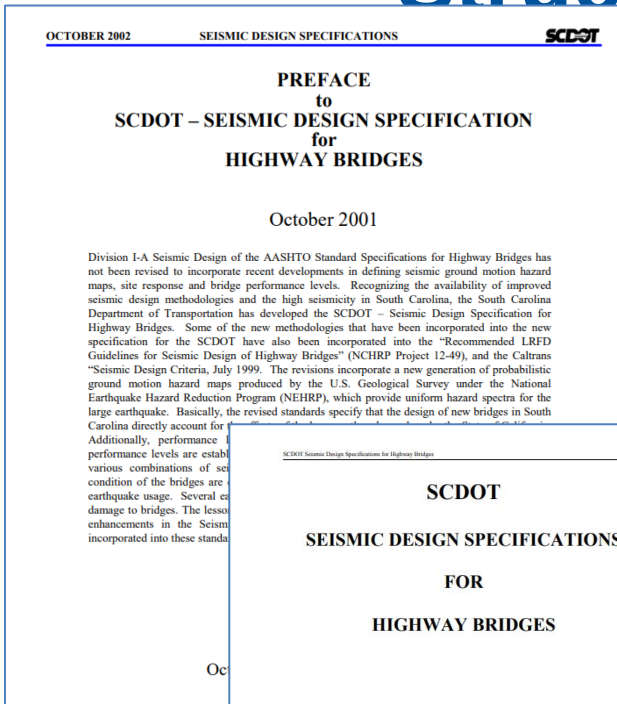
Seismicity in South Carolina







Structural Seismic Design


OCTOBER 2002 SEISMIC DESIGN SPECIFICATIONS SCDOT

PREFACE
to
SCDOT – SEISMIC DESIGN SPECIFICATION
for
HIGHWAY BRIDGES

October 2001

Division I-A Seismic Design of the AASHTO Standard Specifications for Highway Bridges has not been revised to incorporate recent developments in defining seismic ground motion hazard maps, site response and bridge performance levels. Recognizing the availability of improved seismic design methodologies and the high seismicity in South Carolina, the South Carolina Department of Transportation has developed the SCDOT – Seismic Design Specification for Highway Bridges. Some of the new methodologies that have been incorporated into the new specification for the SCDOT have also been incorporated into the "Recommended LRFD Guidelines for Seismic Design of Highway Bridges" (NCHRP Project 12-49), and the Caltrans "Seismic Design Criteria, July 1999. The revisions incorporate a new generation of probabilistic ground motion hazard maps produced by the U.S. Geological Survey under the National Earthquake Hazard Reduction Program (NEHRP), which provide uniform hazard spectra for the large earthquake. Basically, the revised standards specify that the design of new bridges in South Carolina directly account for ...
Additionally, performance l...
performance levels are establ...
various combinations of sei...
condition of the bridges are ...
earthquake usage. Several ea...
damage to bridges. The lesso...
enhancements in the Seism...
incorporated into these standa...

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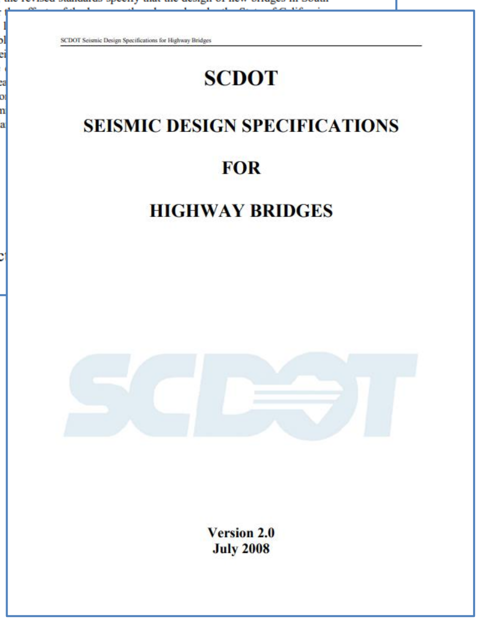

SCDOT Seismic Design Specifications for Highway Bridges

SCDOT

SEISMIC DESIGN SPECIFICATIONS

FOR

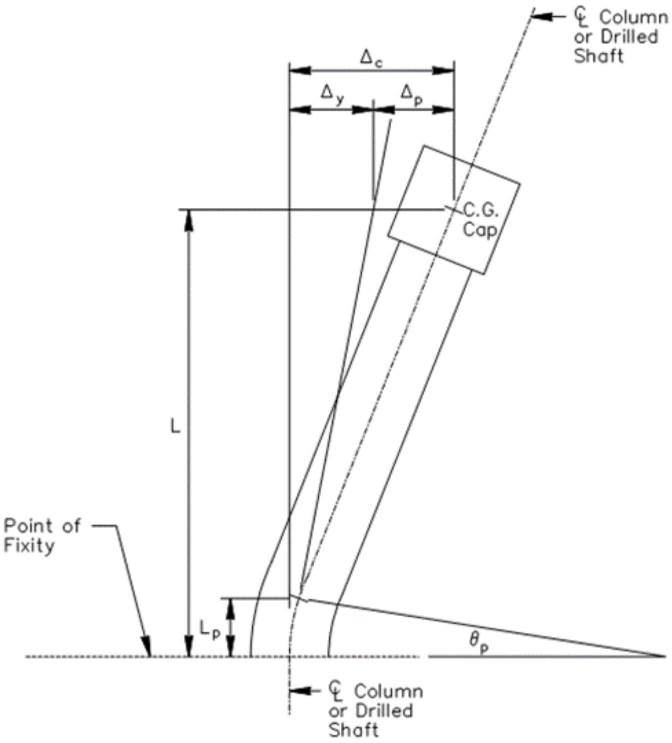
HIGHWAY BRIDGES

Version 2.0
July 2008

- So South Carolina has a significant Seismic Hazard…What do we do about it??
  - SCDOT Developed the Seismic Design Specification (SDS) in 2001 to account for refinements in Seismic Design which were not captured in the AASHTO LRFD.
  - Revised in 2008 to make detailing requirements and hazard definition more applicable to South Carolina.

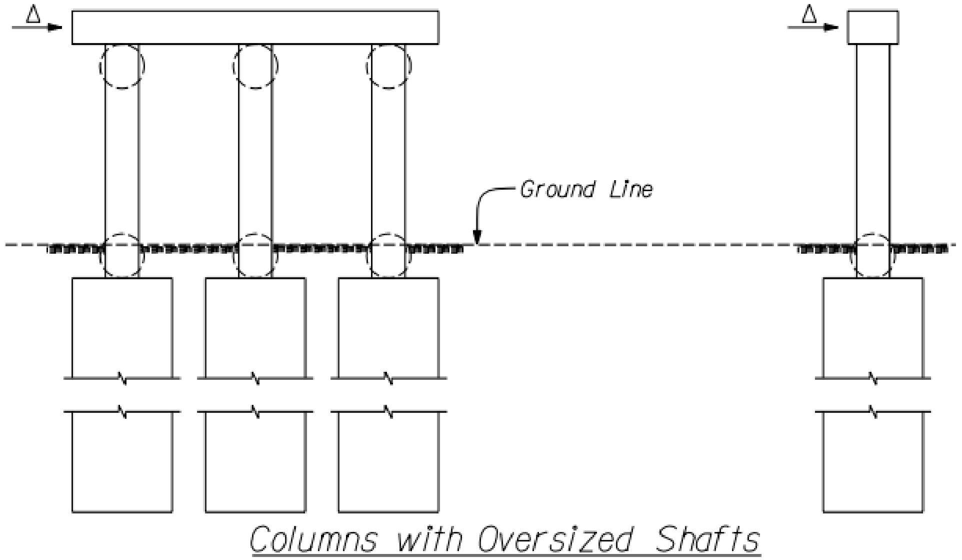
Structural Seismic Design

- Fundamentals for SCDOT Structural Seismic Design
  - SCDOT Exclusively uses Displacement-Based design
  - Satisfactory performance determined by meeting Ductility requirements for ductile elements
    - **Ductility Demand** (μ_d) is the relationship between Demand displacement (Δ_d) and displacement at yield (Δ_y); $\mu_d = \frac{\Delta_d}{\Delta_y}$;
    - **Ductility Capacity** (μ_c) is the relationship between the ultimate displacement (Δ_c) and displacement at yield (Δ_y); $\mu_c = \frac{\Delta_c}{\Delta_y}$;



Structural Seismic Design

- Ductile behavior limited to substructure elements which support Essentially Elastic Superstructure elements.
- Hinging limited to easily accessed portions of substructure elements that can be inspected and repaired



Structural Seismic Design

- Liquefaction addressed by “Bracketing” response of Liquefied condition and Non-Liquefied condition
  - Fundamental Assumptions for Liquefaction:
    - Liquefaction occurs at the onset of the Seismic Event
    - Liquefaction of the entire strata occurs concurrently
  - Assumptions are intended to be conservative but not necessarily reflect expected behavior

Structural Seismic Design

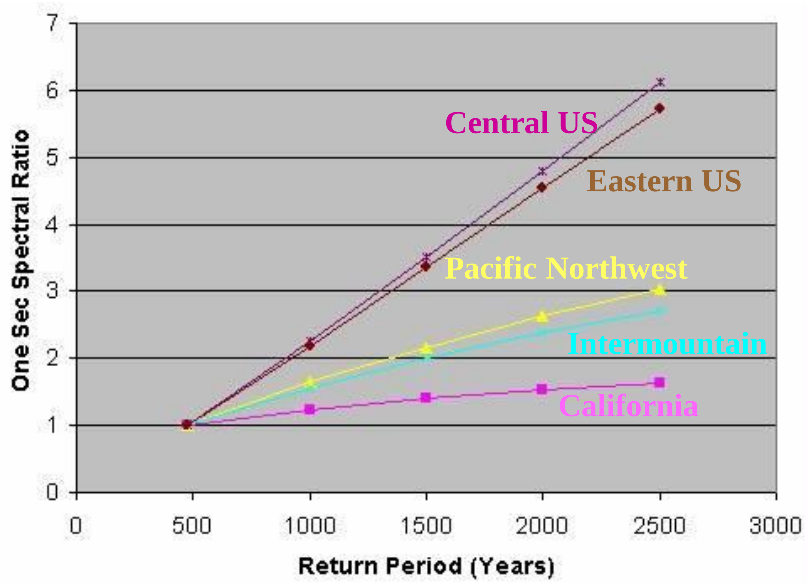


Figure above: Spectral Acceleration at various return periods Normalized to the 1-Second Spectral Acceleration.

- SCDOT Requires design for Two seismic events:
  - Safety Evaluation Earthquake (SEE) with a 3% probability of exceedance in 75 years.
  - Function Evaluation Earthquake (FEE) with 15% probability of exceedance in 75 years.
- SEE Typically governs rebar requirements and member sizes.
- FEE Typically governs base plate slot lengths and may control design of elastic elements.

Structural Seismic Design

- Seismic Design Category determined by Operational Classification and SEE Seismic Demand

Table 3.1 Bridge Operational Classification (OC)

Operational Classification (OC)	Description
I	All bridges that are located on the Interstate system or along the following roads: • US 17, US 378 from SC 441 east to I-95 • I-20 Spur from I-95 east to US 76 • US 76 from I-20 Spur east to North Carolina Additionally all bridges that meet any of the following criteria: • Structures that do not have detours • Structures with detours greater or equal to 15 miles • Structures with a design life greater than 75 years
II	All bridges that do not have a bridge OC = I and meet any of the following criteria: • A projected (20 years) ADT ≥ 500 • A projected (20 years) ADT < 500, with bridge length longer than 180' or individual span length larger than 60'
III	All bridges that do not have an OC = I or II classification.

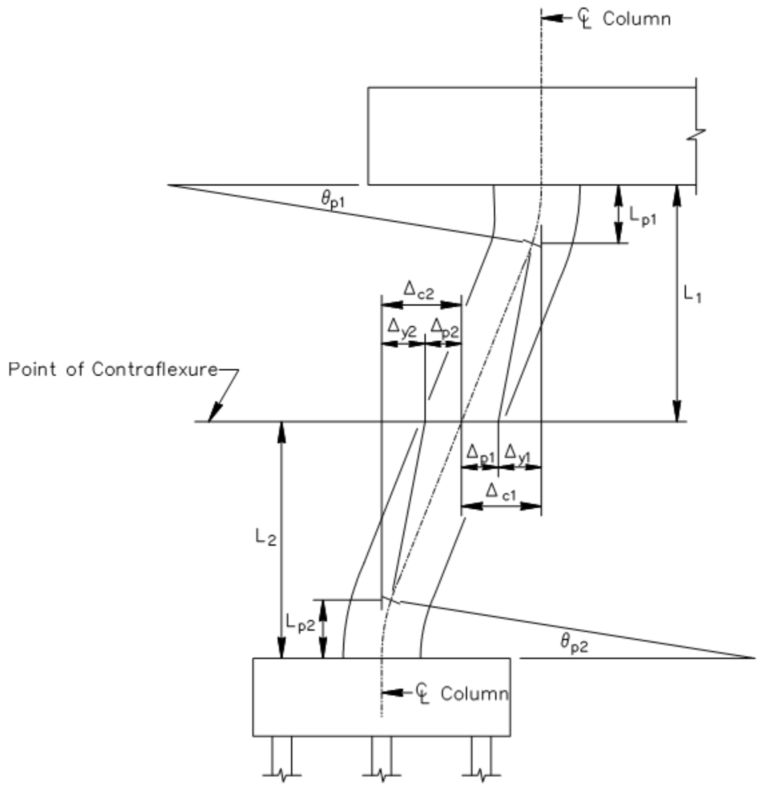
Table 3.5 Seismic Design Category (SDC)

Value of $S_{D1\text{-}SEE}$	Operational Classification (OC)		
	I	II	III
$S_{D1\text{-}SEE} < 0.30g$	B	A	A
$0.30g \leq S_{D1\text{-}SEE} < 0.45g$	C	B	A
$0.45g \leq S_{D1\text{-}SEE} < 0.60g$	C	C	B
$S_{D1\text{-}SEE} \geq 0.60g$	D	C	B

*Tables From SCDOT SDS

- State-specific guidance on Operational Classification

Structural Seismic Design



Definitions of Yield and Plastic Displacements used in determining Ductility performance

- Design Requirements based on SDC
  - SDC A: Verify Seat Widths and Superstructure to Substructure Connection capacity.
  - SDC B: Add MMSA Model to determine displacement demands. Simplified procedure for Δ_d. Check Ductilities.
  - SDC C: Use refined procedure for determining Δ_c (Pushover analysis required).
  - SDC D: Stand-Alone Frame Analysis required for determining Δ_d.

Material properties

- Rebar
  - SCDOT exclusively uses A 706 Grade 60 Rebar due to the Upper limit on bar yield and tensile stress.
  - This is meant to avoid potential contamination of sensitive areas with A 615 bars.
  - Butt-welded hoops are required in seismic applications—no spirals in reinforced concrete elements.

λ_{mo} = overstrength magnifier

= 1.2 for ASTM A 706 reinforcement

= ~~1.4 for ASTM A 615 Grade 60 reinforcement~~

From AASHTO Guide Spec

Saves on strengthening requirements for capacity protected members as compared with A 615

Material properties

- Rebar strain properties:

Table 8.4.2-1—Stress Properties of Reinforcing Steel Bars

Property	Notation	Bar Size	ASTM A 706	ASTM A 615 Grade 60
Specified minimum yield stress (ksi)	f_y	#3– #18	60	60
Expected yield stress (ksi)	f_{ye}	#3– #18	68	68
Expected tensile strength (ksi)	f_{ue}	#3– #18	95	95
Expected yield strain	ε_{ye}	#3– #18	0.0023	[illegible]
Onset of strain hardening	ε_{sh}	#3– #8	0.0150	[illegible]
		#9	0.0125	[illegible]
		#10 & #11	0.0115	[illegible]
		#14	0.0075	[illegible]
		#18	0.0050	[illegible]
Reduced ultimate tensile strain	ε_{su}^{R}	#4– #10	0.090	0.060
		#11– #18	0.060	0.040
Ultimate tensile strain	ε_{su}	#4– #10	0.120	0.090
		#11– #18	0.090	0.060

From AASHTO Guide Spec, Grade 60 Rebar

A 706 Strain properties from Guide Spec similar to SCDOT SDS

Material Properties

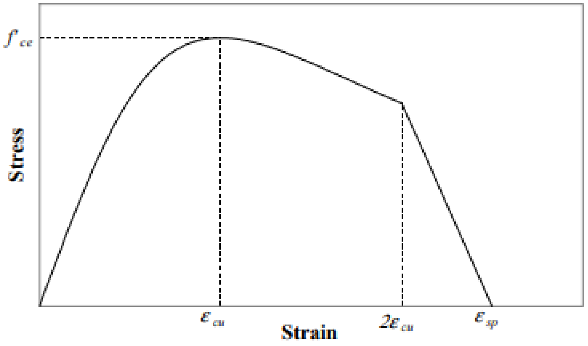


Figure 6.9 Unconfined Concrete Stress-Strain Model

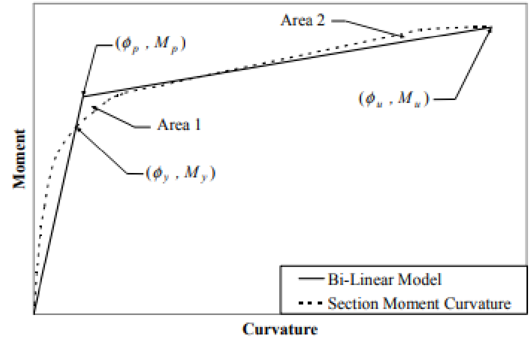


Figure 6.11 Bi-Linear Moment Curvature Curve for Reinforced Concrete Sections

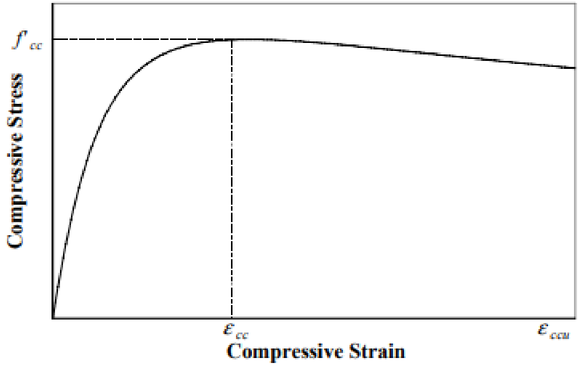


Figure 6.10 Confined Concrete Stress-Strain Model

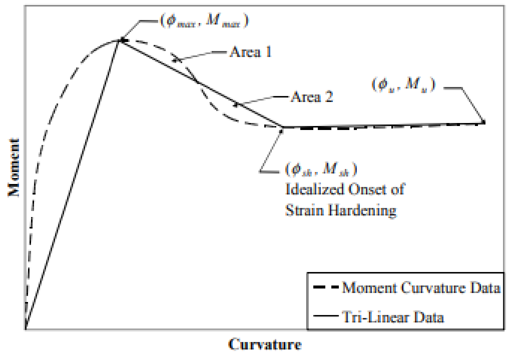
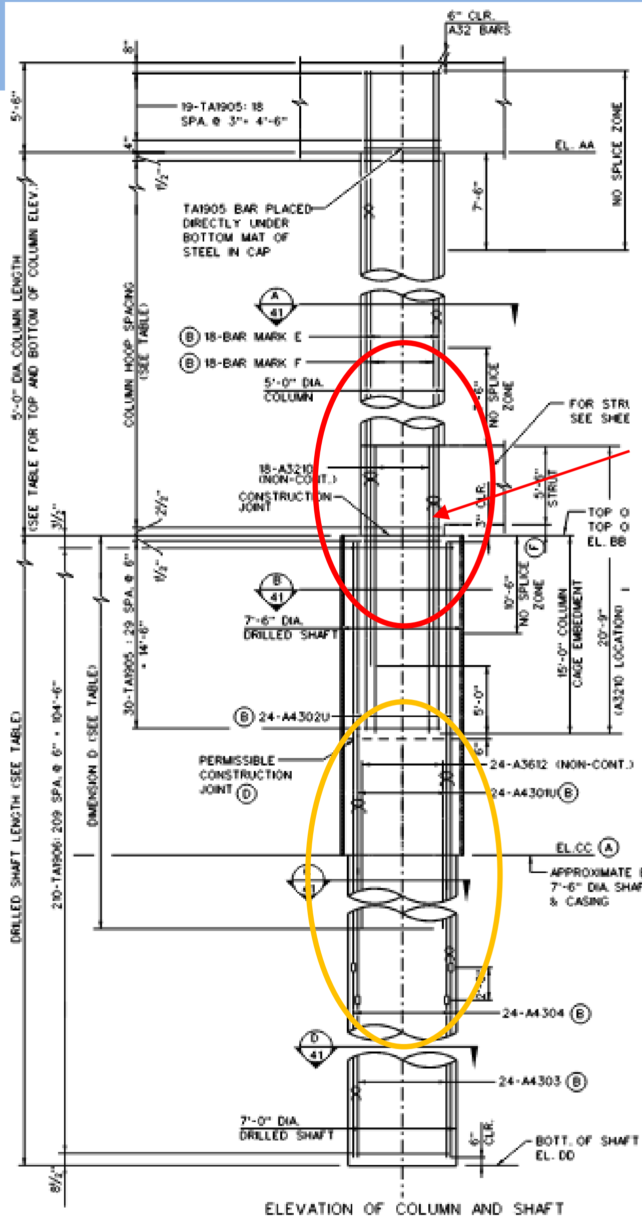


Figure 6.12 Tri-Linear Moment Curvature Curve for Prestressed Concrete Pile Sections

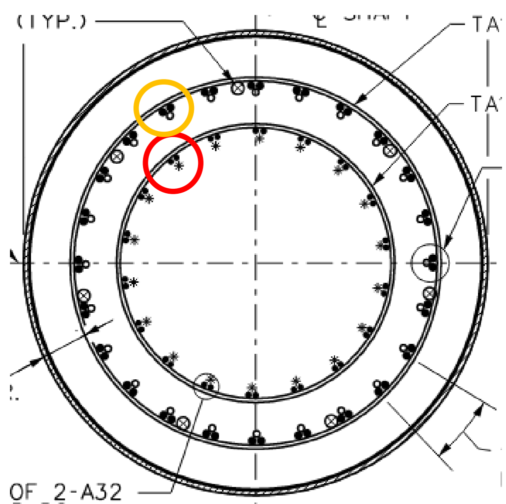
- SCDOT SDS Similar to Guide Spec and Caltrans guidance on confined and unconfined properties Reinforced concrete. Similar, but not identical, treatment for Bi-linearized M-C.
- SDS guidance for linearization of Moment curvature for P/S piles



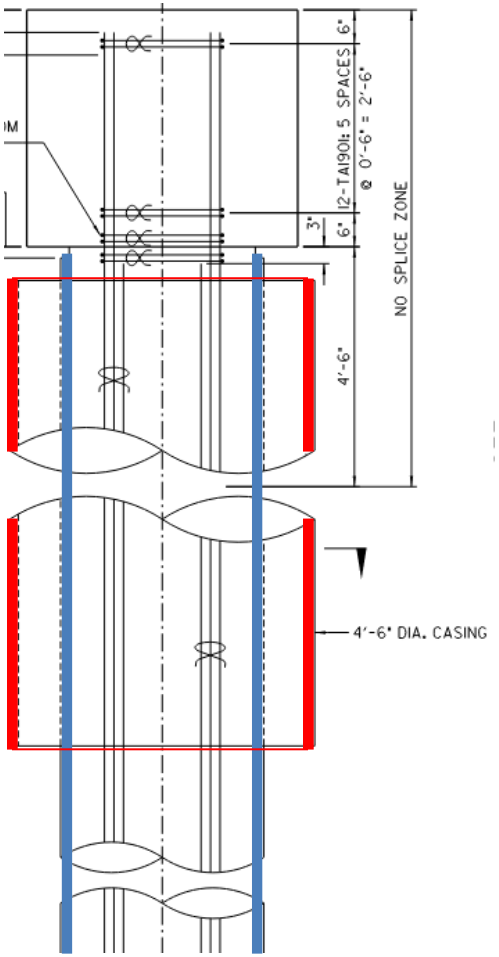
Example Detailing

Bridge had Strutted bents which caused challenges seismically:

- Steel in column was increased to meet distribution of Vessel collision loads—required further increase for capacity protection and challenges meeting ductility requirements.
- Additional steel required in column area to form “rigid joint” where column and strut meet. This forced the hinge into the column.
- Insert bars required at Max Moment regions of shaft for capacity protection.



Example Detailing



- Precast wall directly in front of end bent caused concerns relative to impact of seismic demands.
- Solution chosen was to “isolate” the top portion of the EB shafts from the wall using a larger casing.
- Space between Larger casing and Shaft filled with Styrofoam to allow movement.
- Third bar from bundle terminated prior to entering cap to accommodate SCDOT seismic requirements for embedment.

Comparison Among States

Characteristic	South Carolina	California	Nevada	Kentucky
Displacement-Based Design	Required	Required	Allowed (increasingly used)	Used on Long span or Complex Bridges
Force-Based Design	Not Allowed	Not Allowed	Permitted	Used on more conventional Bridges
Reinforcing Steel	ASTM A 706 Gr 60 used everywhere	ASTM A 706 Gr 60 Primarily used, Gr 80 used in limited applications	ASTM A 706 Gr 60 used on Substructure, Gr 75 used on Superstructure or Non-Yielding elements	ASTM A 706 Gr 60 used in plastic hinge regions, ASTM A 615 used elsewhere
Prevalence of Rectangular Columns in Seismic applications	Less common. SDS Does not clarify detailing.	Common. Circular reinforcing array (or interlocking circular arrays).	Common	Less common. Round columns typically used.

Limitations of SCDOT Specification

- Only Valid for Concrete substructure elements
  - Steel substructure elements must either remain elastic or seismic criteria must be established.
  - Prestressed piles struggle to meet SDS requirements, especially ductility capacity. Design variances are common.
  - Rectangular columns are not addressed in SDS.

Limitations of SCDOT Specification

- Yielding superstructure elements invalidate the fundamental assumptions of this specification

- Suspension, Cable-Stay, Arch type and Movable bridges are not covered by SCDOT Specification. Project specific criteira required.

Needs for Further Study

- Updates to SC Hazard Map to account for SC Geology.

- Determining a basis of approach for the combined influence of inertial effects and kinematic effects.

- Timing of Liquefaction as it relates to seismic performance.

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