The Next Generation of Codes for Seismic Isolation and Supplemental Damping

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on behalf of
ASCE 7-16 SSC TC-12

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Committee History and Timeline

• Update from ASCE 41-06 to ASCE 41-13.  
  *October 2011 to December 2012*

• Expansion of members to participate in the update of the NEHRP provisions for new buildings (BSSC PUC).  
  *July 2012 to May 2014*

• Further expansion to TC-12 of the SSC of ASCE 7 to develop provisions for Chapters 17 and 18 of ASCE 7-16.  
  *February 2013 to 2015*
TC-12 Committee Members

ASCE 41 – 8 Members
— Ron Mayes – SGH, Chair
— Ian Aiken – SIE
— Martin Button – Button Engineering
— Amir Gilani – Miyamoto International
— Bob Hanson – past TC-12
— Robert Pekelnicky – Degenkolb
— Mark Sinclair – Consultant
— Andy Taylor – KPFF – past TC-12

BSSC PUC / NEHRP – 4 Additions
— Bob Bachman – past TC-12
— Mike Constantinou – past TC-12
— Charlie Kircher – past TC-12 Chair
— Andrew Whittaker – past TC-12

TC-12 SSC – 11 Additions
— Ady Aviram – SGH
— Cameron Black – SIE
— Anthony Giammona – NYA
— Amarnath Kasalanati – DIS
— Troy Morgan – Exponent
— Keri Ryan – UNR
— Matt Skokan – Saiful Bouquet
— Rene Vignos – Forell/Elsesser
— Gordon Wray – Degenkolb
— Victor Zayas – EPS
— Reid Zimmerman – KPFF
Evolution of Proposals – Chapters 17 and 18

• ASCE 41-13 provisions were the starting point
• 16 individual proposals went before the BSSC PUC twice (October 2012, February 2013)
• 2 stand-alone proposals, one each for Chapters 17 and 18
• Stand-alone proposals were balloted twice and passed the BSSC PUC in May 2014
• These are the 2015 NEHRP provisions
• 2 stand-alone Chapter 17 and 18 proposals (more changes) were successfully balloted by ASCE 7-16 SSC in July 2014 and by ASCE 7-16 Main Committee in October 2014
Seismic Isolation
Chapter 17
Objectives – Seismic Isolation Provisions

- To make the design and implementation process
  - easy
  - economic
  - uniform
  - consistent with current practice
- To encourage and expand the use of seismic isolation technology

When these revisions are published in ASCE 7-16 ...

it will be over 30 years since the first application of seismic isolation technology in the USA
Major Changes to ASCE 7-10 Chapter 17 Provisions to Reduce Implementation Costs

• ELF procedure is applicable to a much wider range of projects – eliminates the need for NLRHA.

• Design is based on $MCE_R$ event only – eliminates the need to perform analyses at both DBE and $MCE_R$.

• Simplified approach for incorporating 5% eccentricity in NLRHA – reduces the number of NLRHA cases by 80%.

• Reduction in the required number of Peer Reviewers

• Steel OCBF superstructure and Ordinary Steel Grid above isolators are permitted
Relaxed permissible limits and criteria for the use of the equivalent lateral force (ELF) design procedure

- No limit on $S_1$
- Isolated period limit increased from 3.0 to 5.0 seconds
- Eliminate height limits provided no tension / uplift on isolators

This relaxation of limits means that many seismically isolated structures (both superstructure and isolation system) can be analyzed and designed without the need for NLRHA.
Chapter 17 – Major Changes from ASCE 7-10

**Vertical Distribution of Base Shear in ELF**

- New method for determining the vertical distribution of lateral forces associated with the ELF method of design
- Based on work of Professor Keri Ryan, extended by TC-12
- Nearly 10,000 NLRHAs
  - Results are closer to NLRHA, therefore better represent reality
  - Addresses the situation of a short structure with a heavy base mat
  - Effect of hysteresis loop shape
- Permits comparison of story shears across systems with different characteristics.
  - *This is an important consideration for performance-based design!*
Effect of Hysteresis Loop Shape

Bilinear Model

\[ T_{\text{eff}} = 2 \text{ sec} \]
\[ \beta_{\text{eff}} = 10\% \]

Smoothed Model

\[ T_{\text{eff}} = 2 \text{ sec} \]
\[ \beta_{\text{eff}} = 10\% \]

Bilinear Model

\[ T_{\text{eff}} = 3.5 \text{ sec} \]
\[ \beta_{\text{eff}} = 25\% \]

Smoothed Model

\[ T_{\text{eff}} = 3.5 \text{ sec} \]
\[ \beta_{\text{eff}} = 25\% \]
Comparison of Systems with Different Characteristics

Two Systems that produce the same base shear ... 
one with stiffer isolators and low damping (5%) 
one with softer isolators and high damping (35%)
Chapter 17 – Major Changes from ASCE 7-10

Eliminate DBE Analysis and Design Requirements

• Analysis and Design procedure changed from the DBE / MCE\textsubscript{R} events to the MCE\textsubscript{R} event.

• Currently displacements are based on the MCE\textsubscript{R} event and the structural design forces are based on the DBE level. \textit{It was assumed that the structure will remain essentially elastic for the MCE.}

• The structural design forces will now be determined from the MCE\textsubscript{R} elastic design forces reduced by an R\textsubscript{i} factor

• The R\textsubscript{i} factor is the same as the current value of 3R/8 with a maximum value of 2. \textit{This will ensure that the structure does remain essentially elastic at the MCE level.}
Comparison of Elastic Base Shear Forces

Upper / Lower Bound Factors: Stiffness 1.15 / 0.85; Strength 1.60 / 0.85

![Graph showing the ratio of ASCE 7-16 to ASCE 7-10 for different values of T (k2) and Qd/W.](image)
Remove Conservatism in Base Shear Calculation

Current code: \[ V = K_{\text{max}} \times D_{\text{max}} \]
Proposal: \[ V = K_{\text{max}} \times D_{\text{min}} \] or \[ V = K_{\text{min}} \times D_{\text{max}} \]

Figure: Example nominal, upper-bound and lower-bound bilinear hysteretic properties of typical isolator bearing.
Accidental Eccentricity

- Allows rational amplification factors to be established that bound the effects of accidental mass eccentricity
- Separate factors for isolator displacement, story drift and story shear
- Run models for inherent eccentricity only, then ...
  - Apply appropriate amplification factors to computed response

Rotation of Ground Motion Records

- not required
Chapter 17 – Major Changes from ASCE 7-10

Requirements for Design Review

- ASCE 7-10 requires review by “independent engineering team”
- New language requires review by “one or more” RDPs
  - Commentary indicates one reviewer is suitable for smaller projects
Chapter 17 – Major Changes from ASCE 7-10

Structural Systems

• Steel OCBF superstructure permitted
  – Height limited to 160 feet
  – $R_I = 1$
  – $D_{T_{\text{max}}}$ increased by 1.2
  – additional seismic detailing requirements of AISC 341-10 Section F1.7 apply

• Steel Grid permitted immediately above isolators with Ordinary moment connections (elastic at $MCE_R$)
  – seismic detailing requirements of AISC 341-10 Sections E1.6a and E1.6b apply
More Major Changes to ASCE 7-10 Provisions

• Isolator Properties – variation explicitly addressed
• Qualification Testing – requirements for new manufacturers
• Prototype Testing – dynamic testing preferred
  – slow speed testing OK with correction factors for heating effects
• Production Tests – results tied back to nominal ± specification tolerance to close Analysis / Design / Test loop
• Permanent Residual Displacements considered
Isolator Properties

• Use of nominal properties in the design process of typical isolation systems can be based on prior prototype test results provided by manufacturer(s)

• Upper and Lower Bound properties for analysis and design
  – property variation (\(\lambda\)) factors
  – based on the AASHTO concept, but with building-specific values provided by Professor Constantinou based on tests and experience
  – upper bound property = nominal property \(\times \lambda_{\text{max}}\)
  lower bound property = nominal property \(\times \lambda_{\text{min}}\)

• Default \(\lambda\) factors without approved tests – \(\lambda_{\text{max}} > 1.8, \lambda_{\text{min}} < 0.6\)

• With approved tests, manufacturer-specific \(\lambda\) factors are permitted
Start with Nominal Isolator Properties – likely from Past Prototype Tests
Upper and Lower Bound Properties for Design

• Include allowance for specification / production tolerance
• Consideration of variation due to testing conditions
  – Rate of Loading
  – Heating due to cyclic dynamic motion
  – Load history / first cycle effects
• Consideration of variation due to environmental conditions
  – Ambient temperature
  – Aging
• Formal methodology for combining individual variations
Variation in Isolator Properties

Figure: Example nominal, upper-bound and lower-bound bilinear hysteretic properties of typical isolator bearing.

Current code: \[ V = K_{\text{max}} \times D_{\text{max}} \]

Proposal: \[ V = K_{\text{max}} \times D_{\text{min}} \] or \[ V = K_{\text{min}} \times D_{\text{max}} \]
Supplemental Damping
Chapter 18
Chapter 18 – Changes from ASCE 7-10

Selection of Analysis Methodology

• Shifts the emphasis from the current equal treatment for
  – Equivalent Lateral Force Procedure
  – Response Spectrum Procedure
  – Nonlinear Response History Procedure

• Consistent with the majority of current practice, steers the RDP towards NLRHA
  – Still permits other procedures under the same conditions as present

• Chapter is reorganized - ELF and RSA procedures and their acceptance criteria moved to new “Alternate Procedures” section at end
Chapter 18 – Changes from ASCE 7-10

**Damper Nominal and Bounding Properties**

Parallels Corresponding Chapter 17 Provisions

- Use of nominal properties in the design process of typical dampers specified by the manufacturer(s) based on prior prototype testing
- Upper and Lower Bound properties for analysis and design
  - property variation ($\lambda$) factors
  - Established by RDP based on tests
  - upper bound property = nominal property $\times \lambda_{\text{max}}$
  - lower bound property = nominal property $\times \lambda_{\text{min}}$
- Minimum variation defined – $\lambda_{\text{max}} > 1.2$, $\lambda_{\text{min}} < 0.85$
Chapter 18 – Changes from ASCE 7-10

Retained DBE and MCE\(_R\)

Differs from Chapter 17 Provisions

- Analyses at both the DBE and at the MCE\(_R\) earthquake levels
- Results from the DBE analysis used to design the seismic force-resisting system (SFRS)

- Results from the MCE\(_R\) analysis used to design the damping system (DS). Added penalty for force-controlled actions.
- Drift checks performed at MCE\(_R\) and include accidental eccentricity. No accidental eccentricity required at DBE.
Chapter 18 – Changes from ASCE 7-10

Reduce Number of NLRHA Runs
Parallels Corresponding Chapter 17 Provisions

Accidental Eccentricity at $MCE_R$
- Allows rational amplification factors to be established that bound the effects of accidental mass eccentricity
- Run models for inherent eccentricity only, then ...
  - Apply appropriate amplification factors to computed response

Rotation of Ground Motion Records
- not required

Inherent damping limited to 3% unless justification provided
Chapter 18 – Changes from ASCE 7-10

**Added Low Redundancy Penalty**

- **IF**
  - fewer than four energy dissipation devices are provided in any story in either principal direction; OR
  - fewer than two devices are located on each side of the center of stiffness of any story in either principal direction
- **THEN**
  - All energy dissipation devices shall be capable of sustaining displacements equal to 130% of the maximum calculated displacement in the device under MCE$_R$
  - A velocity-dependent device shall be capable of sustaining the force and displacement associated with a velocity equal to 130% of the maximum calculated velocity for that device under MCE$_R$
Chapter 18 – Changes from ASCE 7-10

Requirements for Design Review
Identical to Corresponding Chapter 17 Provisions

• Number of peer reviewers required on a supplemental damping project now specified as “one or more”

• Peer reviewer is not required to observe the prototype tests
Damper Testing

Corresponding Chapter 17 Provisions Philosophically Similar

• Tightened the definition for “similar” units for prototypes
• Prototype tests performed at a frequency of $1 / (1.5T_1)$
  – 10 cycles at a displacement of $0.33 \text{ MCE}_R$
  – 5 cycles at a displacement of $0.67 \text{ MCE}_R$
  – 3 cycles at a displacement of $1.0 \text{ MCE}_R$
  – Repeat $1.0 \text{ MCE}_R$ test at a higher frequency if it does not generate a force equal to the maximum force from analysis
• Properties deduced from prototype and production testing are explicitly tied back to properties assumed in Analysis and Design
Thank you for your attention ...

Questions?
Slides Not Used
Comparison of Story Shears from York and Ryan with NLRHA Results

(a) 3-story building

(b) 6-story building

(c) 9-story building

Normalized Story Force $F/V_b$

Normalized Story Shear $V/V_b$

RHA  Eq. with $T_s$  Eq. with $T_s/T_d$
Comparison of Elastic Base Shear Forces

Upper / Lower Bound Factors: Stiffness 1.15 / 0.85; Strength 1.60 / 0.85

MCE\textsubscript{R} S\textsubscript{1} = 1.5

MCE\textsubscript{R} S\textsubscript{1} = 1.0
Simplify Accidental Mass Eccentricity for NLRHA

• Allows amplification factors to be established that bound the effects of accidental mass eccentricity
• Four eccentric mass cases on final models need not be analyzed
• Instead …
  – Run with inherent mass eccentricity using lower bound properties
  – Determine critical 2 cases for accidental eccentricity (no analysis!)
  – Run 2 accidental cases using lower bound isolator properties
  – Establish amplification factors for displacement, drift and shear
• Final models run for inherent eccentricity only, then …
  – Apply appropriate amplification factors to computed response
• ALSO … Rotation of ground motion records not required
Chapter 17 – Major Changes from ASCE 7-10

Requirements for Design Review

- ASCE 7-10 requires review by “independent engineering team”
- New language requires review by “one or more” RDPs
  - Commentary indicates one reviewer is suitable for smaller projects
- Reviewer is no longer required to witness prototype testing
Prototype Testing

• Tightened definition of “similar” units

• If prototypes are required, testing typically occurs later in the design process than it used to ...

• Prototype test properties now tied to range established for design, excluding environmental factors
  – nominal test properties must fall within assumed nominal ± specification tolerance
  – observed variation in tested properties must fall within assumed variation range due to test conditions

• Provides a closed loop back to Analysis / Design properties
Chapter 17 – More Changes from ASCE 7-10

Extent of Production Testing

• Maintain 100% combined compression-shear testing
  – minimal cost
  – protects both owner and SE

• Acceptance criteria tied back to nominal properties
  ± specification tolerance

• Provides a closed loop back to Analysis / Design properties
Qualification Testing – New Manufacturers

• Testing must be full-speed dynamic testing

• Quantify the effects of
  – heating due to cyclic dynamic motion
  – loading rate
  – first cycle / scragging
  – ambient temperature
  – environmental conditions
  – variability of production isolator properties

• Tests by a particular manufacturer are applicable ONLY to sizes and materials used

• Reduced scale specimens permitted provided principles of scaling and similitude are used
Evidence of permanent residual displacements from:
- full-scale shake table tests at E-Defense (Ryan et al. 2012)
- analytical studies (Katsaras et al. 2008)

Susceptible isolation systems have a combination of:
- relatively long period (4 seconds or more) and
- relatively high yield / friction levels (8 to 15%)

Susceptible systems may see permanent residual displacements in the 2 to 6 inch range

Important issue that should be brought to the owner’s attention
Add Requirement to Accommodate Residual Displacements

- **17.2.6.2 Components Crossing the Isolation Interface**

  Elements of seismically isolated structures and nonstructural components, or portions thereof that cross the isolation interface shall be designed to withstand the total maximum displacement. *They shall also be designed to accommodate on a long term basis any permanent residual displacements that may occur.*
Chapter 17 – More Changes from ASCE 7-10

Calculation of Residual Displacements

- Extensive commentary summarizing evidence and conditions under which residual displacements are likely
- Includes a means of estimating permanent residual displacements as a function of isolation system properties
100% tested (*same as present*)

New EXCEPTION:

- Production damping devices need not be tested if it can be shown by other means that their properties meet the requirements of the project specifications.

- In such cases, the RDP shall establish an alternative program to assure the quality of the installed damping devices:
  - intended to cover hardware such as steel yielding devices, which would undergo inelastic action or be otherwise damaged (by design) under the prescribed production test program;
  - must production-test at least one device of each type and size.