AN ALTERNATIVE PROCEDURE FOR SEISMIC EVALUATION AND STRENGTHENING OF TALL REINFORCED CONCRETE BUILDINGS LOCATED IN THE LOS ANGELES REGION

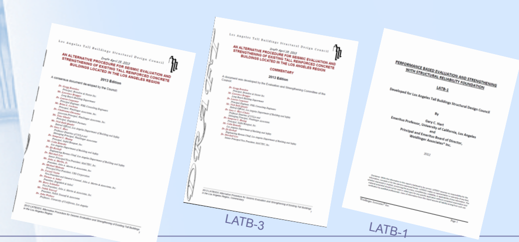
Description and Update on *Draft* Procedure

As Developed by the Evaluation and Strengthening Committee
Los Angeles Tall Buildings Structural Design Council

May 3, 2013

N. Delli Quadri

- EVALUATION AND STRENGTHENING
  - PROVISIONS
  - LATBSDC E&S COMMITTEE RESOURCE DOCUMENTS
    - COMMENTARY (LATB-3)
    - LATB-1: "Performance-Based Evaluation and Strengthening w/Reliability Foundation" - Primer on use of structural reliability methodology
    - LATB-2: Building Evaluation and Strengthening applications, examples.



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PROVISIONS

Intent

- Provide more reliable, cost effective *alternative seismic evaluation and strengthening* procedure
- Modification/elimination of some Code prescriptive requirements
- Allow use of innovative structural systems and materials
- Accommodation of Architectural features that may not otherwise be attainable

PROVISIONS *(con't)*

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PROVSIONS
•Provides a reliability based approach to evaluation and strengthening
•More accurate I.D. of relevant performance limit states and associated demands and capacity on building

APPLICABILITY
•Existing Concrete Buildings w/n Los Angeles Region
•Shearwall, Moment frame
•Specifically for >75ft, but may apply to any height

METHODOLOGY
•Relies on extensive knowledge and expertise of regional structural engineers for quantification of uncertainties
•Extensive field testing as required
•Structural member testing
•Advanced Structural Analysis
•Identification of Structural Limit States
•Peer Review

- PROCEDURE
  1. Condition Assessment
  2. Expected Value Structural Analysis
  3. Uncertainty Structural Analysis
  4. Required Design Capacity

    – I.D. of Building's
      – Structural system performance limit states
      – Structural member section limit states
        - For Each Limit State
          - Expected Value of Capacity
          - Expected Value of Demand
          - Uncertainty in Capacity and Demand

- PROCEDURE con't
  - Consistent w/ requirements for New Tall Buildings
  - Capacity Design principles
    - Used to design and strengthen for suitable yielding under nonlinear deformations
  - Requires Analysis and Strengthening to:
    Service Level EQ (50% in 30 yrs)
      Response Spectra Linear Dynamic Analysis
    Ultimate/Collapse Level MCE (2% in 50 yrs)
      Nonlinear Time-history Dynamic Analysis
  - Peer Review of
    Design Team Qualifications
    Condition Assessment/ Testing Plan
    Evaluation and Strengthening Plan
    Modeling

1. CONDITION ASSESSMENT

- Utilizes
  - ASCE 41-13, Sec 10.2 (Material Properties and Condition Assessment)
  - ACI 369R-11 (Guidelines for Seismic Rehabilitation of Existing Concrete Frame Buildings and Commentary
  - ACI 364.1R (Guide for Evaluation of Concrete Structures before Rehabilitation)
  - ACI 437R (Strength Evaluation of Existing Concrete Buildings)

Condition Assessment Plan Required, to Include:

- Material properties
- Component properties
- Structural member testing
  - Field nondestructive and destructive testing
  - Laboratory **Structural** Member Testing
- Rating Quality of Plan- *Superior, Good or Fair*
  - Approval of Peer Review Panel

1. CONDITION ASSESSMENT con't

- **Plans, Specs and Info of Constructed Bldg**
  - Mech properties of Matl's from drawings/specs per ASCE 41-13, Sec 10.2
    - No Default material properties to be used
  - Building Comprehensive condition assessment per more restrictive requirements of ASCE 41-13 and ACI 369R-11 , Sec 2.3
  - Engineer to rate quality of Information:
    - *Superior, Good, or Fair*

- **Field Non-Destructive Testing**
  - Estimating size, location, cover, corrosion, location of voids and cracks, relative concrete compression strength, concrete delamination, possible non –visible degradation
  - Not substituted for sample testing
  - Engineer to rate quality of Information:
    - *Superior, Good, or Fair*

1. CONDITION ASSESSMENT con't

- **Field Destructive Testing**
  - per ASCE 41-13 and ACI 369R-11, Sec 2.2.3
  - Concrete cores from each unique structural component, min 3 steel and conc.
    - Compressive strength, concrete stress strain curve- tension and compression strain 5 times strain at compressive strength.
    - Reinforcing bar tension/compression strength, stress strain curve-tension and compression to strain 5 times strain at tension strength
  - Material test of all structural member or connection types
  - Engineer to rate quality of Information:
    - *Superior, Good, or Fair*

1. CONDITION ASSESSMENT con't

- **Laboratory Testing of Field Obtained Structural Specimens**
  - Although not required by procedure,
    - Removal and testing of structure components reduces uncertainty

- **Laboratory Testing of Structural Components at University Laboratories**

  Not required, but encouraged
    - Needed for a complete hysteretic behavior of each component to be modeled
    - Testing be ASCE 41-13 Sec 7.6

1. CONDITION ASSESSMENT con't

- **Laboratory Testing of Structural Components at University Laboratories**
  Where inelastic force-deformation behavior, stress strain relationship not available
  - Data to be obtained from experiments consisting of physical test representative subassemblies.
  - Min 3 separate test of each unique sub assembly
  - Loading protocol consistent w/ strong impulsive ground motions due to proximity to fault rupture
- RE: FEMA 440A, FEMA695, PEER/ATC72-1
  - Engineer to rate quality of Information:
    - *Superior, Good, or Fair*
- Test results used to establish Expected Value and Coefficient of Variation of all variables in structural modeling and capacity equations

2. EXPECTED VALUE STRUCTURAL ANALYSIS

- Linear Expected Value Structural Analysis Model (3D) - for demand on serviceability limit states
  - Using Response Spectra
- Nonlinear Expected Value Structural Analysis Model (3D)– for demand on Ultimate (Strength) limit states
  - Subjected to min 7 Time-history ground motions
- Incorporates Expected Value estimates of stiffness and strength for anticipated level of EQ excitation and damage
- Includes results from Condition Assessment
- Laboratory component tests results appropriate for type of building components
- Structural engineer's best estimate of Expected Value of the Demand and Expected Value of the Capacity
  - Structural System Limit States
  - Structural Member Limit States

3. UNCERTAINTY STRUCTURAL ANALYSIS

- Quantifies Uncertainties
  - – structural model and EQ loading
- Determine Coefficient of Variation For Each Limit State
  - Combines information from:
    - Condition Assessment
    - Expected Value Structural Analysis
    - Experience and knowledge of structural Engineer of Record

Quantify Confidence in information for each limit state

Quality	Coefficient of Variation
Superior	5 to 15%
Good	15 to 25%
Fair	25 to 40%

3. UNCERTAINTY STRUCTURAL ANALYSIS con't

Capacity Uncertainty

- Coefficient of Variation of Capacity
  - $\rho_C = (\rho_{CA}^2 + \rho_{CM}^2)^{1/2}$
    - ρ_{CA} = Coefficient of Variation of Condition Assessment ≥ 0.05, <0.35
    - ρ_{CM} = Coefficient of Variation of Structural Component Capacity Analysis ≥ 0.10, <0.35

Demand Uncertainty

Coefficient of Variation of Demand

- $\rho_D = (\rho_{CA}^2 + \rho_{DS}^2)^{1/2}$
  - ρ_{DS} = Coefficient of Variation of Structural System Model ≥ 0.10

4. REQUIRED DESIGN CAPACITY

Determine For Each:

- *Serviceability Limit States,*
- *Ultimate Limit States*

Prescribed Load Capacity Reduction Factor, f_{PL}

$D_{PL} = f_{PL}\bar{C}$ *(Prescribed Limit State demand < Limit State Capacity)*

b = ***target*** *reliability index* *(Set based on EQ level and Limit State)*
(.25-2.0 @service level, 3.0-4.0 @Collapse level)

$a = D_{PL} / \bar{D}$ $(a_{service} = 1,\ a_{MCE} = 1.5)$

w/ normal random variables

$$f_{PL} = a\,(1-0.75br_C)/(1+0.75br_D)]$$

(w/ log-normal random variables

$$f_{PL} = a[\exp(-0.75b(r_C + r_D)]$$

$f_{PL:}$

Increase in the capacity reduction factor can be achieved by

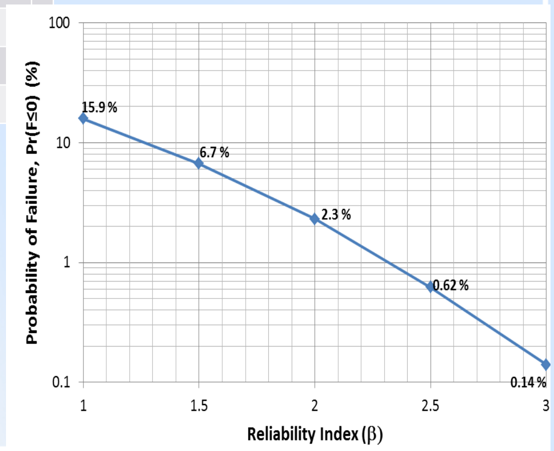
- Increasing the Capacity of the limit state by Strengthening
- Reducing the demand on the limit state
- Reducing the uncertainties: ie coefficients of variation

(c) Capacity Reduction Factors (ϕ) for β = 3 and α = 1.5

Coefficient of Variation of Demand (%)	Coefficient of Variation of Capacity (%)					
	10	15	20	25	30	35
10	0.96	0.85	0.76	0.68	0.61	0.54
15	0.85	0.76	0.68	0.61	0.54	0.49
20	0.76	0.68	0.61	0.54	0.49	0.44
25	0.68	0.61	0.54	0.49	0.44	0.39
30	0.61	0.54	0.49	0.44	0.39	0.35
35	0.54	0.49	0.44	0.39	0.35	0.31
40	0.49	0.44	0.39	0.35	0.31	0.28

TARGET Reliability Indices

	Service EQ	Collapse EQ
Limit State	Min Target b Value	Min Target b Value
Roof	0.25	3.0
Intensity	0.5	3.5
Flexure	0.5	3.5
Shear	2.0	4.0



Process Summary

Condition Assessment

- Plans Spec and Info of Constructed Building
- Testing : Field, Lab
- Quality Rating of Information

Expected Value Structural Analysis

- Linear and Nonlinear Modeling for Demand on Serviceability, Ultimate Limit States
- Quality Rating of Information

Uncertainty Structural Analysis

- Coefficient of Variation for each Limit State
- Combine Info from Condition Assessment and Expected Value Structural Analysis
- Quantify Confidence in Information for each Limit State
- Determine COV of Capacity, ϱ_C and Demand, ϱ_D

Required Design Capacity

- b, **target** reliability index
- $f_{PL,}$ Prescribed Load Capacity Reduction Factor

STATUS: Where are we now.

- Currently (May 1, 2013)
  - 90% Draft - Provisions
  - 50% Draft - Commentary - LATB-3
  - 100% Final Draft - LATB-1 (Primer on Structural Reliability)
  - 5% Draft - LATB-2 (Applications/Examples)

- Expectations:
  - Review and Comment by LATBSDC and others.
  - 100% Draft - Provisions (July 15, 2013)

•Thank You