Existing Buildings 04
Modelling Parameters and Acceptance Criteria

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Session 43

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and
S-04 Team Leader, JV of NKY-Protek-Sheltech

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Course Title: Existing Buildings
Track 4
Modelling Parameters and Acceptance Criteria

- **Course Topics:**

1. Implementing different deficiencies of the existing buildings in their modelling parameters.
2. The factors controlling the Modelling Parameters and Acceptance Criteria.
3. Different standard shapes of Modelling Parameters and their characteristics.
4. Introducing the tables of structural systems for deriving their Modelling Parameters and Acceptance Criteria values.
5. Importance of using different analysis methods in systematic evaluation.

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10 CONCRETE . . . .
10.1 Scope . . . .
10.2 Material Properties and Condition Assessment
10.3 General Assumptions and Requirements . . .
10.4 Concrete Moment Frames . . . .
10.5 Precast Concrete Frames . . . .
10.6 Concrete Frames with Infills . . . .
10.7 Concrete Structural Walls . . . .
10.8 Precast Concrete Structural Walls . . . .
10.9 Concrete Braced Frames . . . .
10.10 Cast-in-Place Concrete Diaphragms . . . . . .
10.11 Precast Concrete Diaphragms . . . .
10.12 Concrete Foundations . . . .

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10.2 Material Properties and Condition Assessment

Properties of In-Place Materials and Components

Table 6-1. Data Collection Requirements

	Level of Knowledge					
Data	**Minimum**		**Usual**		**Comprehensive**	
Performance Level	Life Safety (S-3) or lower		Damage Control (S-2) or lower		Immediate Occupancy (S-1) or lower	
Analysis Procedures	LSP, LDP		All		All	
Testing	No tests[a]		Usual testing		Comprehensive testing	
Drawings	Design drawings	Field survey drawings prepared in absence of design drawings	Design drawings	Field survey drawings prepared in absence of design drawings	Design drawings	Field survey drawings prepared in absence of design drawings
Condition Assessment[b]	Visual	Comprehensive	Visual	Comprehensive	Visual	Comprehensive
Material Properties	From design drawings (or documents)[c]	From default values	From design drawings (or documents) and tests	From usual tests	From design drawings (or documents) and tests	From comprehensive tests
Knowledge Factor (κ)[d]	0.9[e,f]	0.75	1.00	1.00	1.00	1.00

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Table 10-1. Factors to Translate Lower-Bound Material Properties to Expected Strength Material Properties

Material Property	Factor
Concrete compressive strength	1.50
Reinforcing steel tensile and yield strength	1.25
Connector steel yield strength	1.50

Table 10-2. Default Lower-Bound Compressive Strength of Structural Concrete, lb/in.^{2} (MPa)

Time Frame	Footings	Beams	Slabs	Columns	Walls
1900–1919	1,000 to 2,500 (7 to 17)	2,000 to 3,000 (14 to 21)	1,500 to 3,000 (10 to 21)	1,500 to 3,000 (10 to 21)	1,000 to 2,500 (7 to 17)
1920–1949	1,500 to 3,000 (10 to 21)	2,000 to 3,000 (14 to 21)	2,000 to 3,000 (14 to 21)	2,000 to 4,000 (14 to 28)	2,000 to 3,000 (14 to 21)
1950–1969	2,500 to 3,000 (17 to 21)	3,000 to 4,000 (21 to 28)	3,000 to 4,000 (21 to 28)	3,000 to 6,000 (21 to 40)	2,500 to 4,000 (17 to 28)
1970–present	3,000 to 4,000 (21 to 28)	3,000 to 5,000 (21 to 35)	3,000 to 5,000 (21 to 35)	3,000 to 10,000 (21 to 70)	3,000 to 5,000 (21 to 35)

Table 10-3. Default Lower-Bound Tensile and Yield Properties of Reinforcing Steel for Various Periods

		Structural[a]	Intermediate[a]	Hard[a]				
	Grade	33	40	50	60	65	70	75
	Minimum Yield, lb/in.^{2} (MPa)	33,000 (230)	40,000 (280)	50,000 (350)	60,000 (420)	65,000 (450)	70,000 (485)	75,000 (520)
Year	Minimum Tensile, lb/in.^{2} (MPa)	55,000 (380)	70,000 (485)	80,000 (550)	90,000 (620)	75,000 (520)	80,000 (550)	100,000 (690)
1911–1959		x	x	x		x		
1959–1966		x	x	x	x	x	x	x
1966–1972			x	x	x	x	x	
1972–1974			x	x	x	x	x	
1974–1987			x	x	x	x	x	
1987–present			x	x	x	x	x	x

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Data Collection

Building Specifications

Structural Component Survey

Material Testing

Geotechnical Survey

As-built Drawings

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κ = Knowledge factor

Table 7-6. Calculation of Component Action Capacity: Linear Procedures

Parameter	Deformation Controlled	Force Controlled
Existing material strength	Expected mean value with allowance for strain hardening	Lower bound value (approximately mean value minus 1σ level)
Existing action capacity	κQ_{CE}	κQ_{CL}
New material strength	Expected material strength	Specified material strength
New action capacity	Q_{CE}	Q_{CL}

Table 7-7. Calculation of Component Action Capacity: Nonlinear Procedures

Parameter	Deformation Controlled	Force Controlled
Deformation capacity (existing component)	$\kappa \times$ Deformation limit	N/A
Deformation capacity (new component)	Deformation limit	N/A
Strength capacity (existing component)	N/A	$\kappa \times Q_{CL}$
Strength capacity (new component)	N/A	Q_{CL}

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Table 10-5. Effective Stiffness Values

Component	Flexural Rigidity	Shear Rigidity	Axial Rigidity
Beams—nonprestressed[a]	$0.3E_{cE}I_g$	$0.4E_{cE}A_w$	—
Beams—prestressed[a]	$E_{cE}I_g$	$0.4E_{cE}A_w$	—
Columns with compression caused by design gravity loads $\geq 0.5A_g f'_{cE}$[b]	$0.7E_{cE}I_g$	$0.4E_{cE}A_w$	$E_{cE}A_g$
Columns with compression caused by design gravity loads $\leq 0.1A_g f'_{cE}$ or with tension[b]	$0.3E_{cE}I_g$	$0.4E_{cE}A_w$	$E_{cE}A_g$ (compression) $E_{sE}A_s$ (tension)
Beam–column joints	Refer to Section 10.4.2.2.1		$E_{cE}A_g$
Flat slabs—nonprestressed	Refer to Section 10.4.4.2	$0.4E_{cE}A_g$	—
Flat slabs—prestressed	Refer to Section 10.4.4.2	$0.4E_{cE}A_g$	—
Walls—cracked[c]	$0.35E_{cE}A_g$	$0.4E_{cE}A_w$	$E_{cE}A_g$ (compression) $E_{sE}A_s$ (tension)

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Implementing different deficiencies

2. Where existing deformed straight bars, hooked bars, and lap-spliced bars do not meet the development requirements of (1) above, the capacity of existing reinforcement shall be calculated using Eq. (10-1):

$$f_s = 1.25\left(\frac{l_b}{l_d}\right)^{2/3} f_{yL} \le f_{yL/E} \qquad \text{(10-1a)}$$

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Table 10-7. Modeling Parameters and Numerical Acceptance Criteria for Nonlinear Procedures—Reinforced Concrete Beams

			Modeling Parameters[a]			Acceptance Criteria[a]		
						Plastic Rotation Angle (radians)		
			Plastic Rotation Angle (radians)		Residual Strength Ratio	Performance Level		
Conditions			*a*	*b*	*c*	IO	LS	CP
Condition i. Beams controlled by flexure[b]								
$\frac{\rho-\rho'}{\rho_{bal}}$	Transverse reinforcement[c]	$\frac{V^d}{b_w d\sqrt{f'_{cE}}}$						
≤0.0	C	≤3 (0.25)	0.025	0.05	0.2	0.010	0.025	0.05
≤0.0	C	≥6 (0.5)	0.02	0.04	0.2	0.005	0.02	0.04
≥0.5	C	≤3 (0.25)	0.02	0.03	0.2	0.005	0.02	0.03
≥0.5	C	≥6 (0.5)	0.015	0.02	0.2	0.005	0.015	0.02
≤0.0	NC	≤3 (0.25)	0.02	0.03	0.2	0.005	0.02	0.03
≤0.0	NC	≥6 (0.5)	0.01	0.015	0.2	0.0015	0.01	0.015
≥0.5	NC	≤3 (0.25)	0.01	0.015	0.2	0.005	0.01	0.015
≥0.5	NC	≥6 (0.5)	0.005	0.01	0.2	0.0015	0.005	0.01
Condition ii. Beams controlled by shear[b]								
Stirrup spacing ≤ $d/2$			0.0030	0.02	0.2	0.0015	0.01	0.02
Stirrup spacing > $d/2$			0.0030	0.01	0.2	0.0015	0.005	0.01
Condition iii. Beams controlled by inadequate development or splicing along the span[b]								
Stirrup spacing ≤ $d/2$			0.0030	0.02	0.0	0.0015	0.01	0.02
Stirrup spacing > $d/2$			0.0030	0.01	0.0	0.0015	0.005	0.01
Condition iv. Beams controlled by inadequate embedment into beam–column joint[b]								
			0.015	0.03	0.2	0.01	0.02	0.03

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Implementing different deficiencies

Table 10-6. Component Ductility Demand Classification

Maximum Value of DCR or Displacement Ductility	Descriptor
<2	Low ductility demand
2 to 4	Moderate ductility demand
>4	High ductility demand

Example:

columns, lap-spliced transverse reinforcement shall be assumed to be not more than 50% effective in regions of moderate ductility demand and ineffective in regions of high ductility demand, and

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10.4 Concrete Moment Frames . . . .

10.4.1 Types of Concrete Moment Frames . . . .
10.4.1.1 Reinforced Concrete Beam–Column Moment Frames . . . . .
10.4.1.2 Post-tensioned Concrete Beam–Column Moment Frames . . . . .
10.4.1.3 Slab–Column Moment Frames. . . . .
10.4.2 Reinforced Concrete Beam–Column Moment Frames . . . .
10.4.2.1 General . . . .
10.4.2.2 Stiffness of Reinforced Concrete Beam–Column Moment Frames . . . . .
10.4.2.3 Strength of Reinforced Concrete Beam–Column Moment Frames . . . . .
10.4.2.4 Acceptance Criteria for Reinforced Concrete Beam–Column Moment Frames
10.4.2.5 Retrofit Measures for Reinforced Concrete Beam–Column Moment Frames .
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10.4.4.4 Acceptance Criteria for Slab–Column Moment Frames. . . . . . .
10.4.4.5 Retrofit Measures for Slab–Column Moment Frames. . . . . . .

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The most important contributions of Systematic Evaluation

Table 10-7. Modeling Parameters and Numerical Acceptance Criteria for Nonlinear Procedures—Reinforced Concrete Beams

Conditions			Modeling Parameters[a] Plastic Rotation Angle (radians) a	b	Residual Strength Ratio c	Acceptance Criteria[a] Plastic Rotation Angle (radians) Performance Level IO	LS	CP
Condition i. Beams controlled by flexure[b]								
$\frac{\rho-\rho'}{\rho_{bal}}$	Transverse reinforcement[c]	$\frac{V^d}{b_w d \sqrt{f'_{cE}}}$						
≤0.0	C	≤3 (0.25)	0.025	0.05	0.2	0.010	0.025	0.05
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≥0.5	C	≤3 (0.25)	0.02	0.03	0.2	0.005	0.02	0.03
≥0.5	C	≥6 (0.5)	0.015	0.02	0.2	0.005	0.015	0.02
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≤0.0	NC	≥6 (0.5)	0.01	0.015	0.2	0.0015	0.01	0.015
≥0.5	NC	≤3 (0.25)	0.01	0.015	0.2	0.005	0.01	0.015
≥0.5	NC	≥6 (0.5)	0.005	0.01	0.2	0.0015	0.005	0.01
Condition ii. Beams controlled by shear[b]								
Stirrup spacing ≤ d/2			0.0030	0.02	0.2	0.0015	0.01	0.02
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Condition iii. Beams controlled by inadequate development or splicing along the span[b]								
Stirrup spacing ≤ d/2			0.0030	0.02	0.0	0.0015	0.01	0.02
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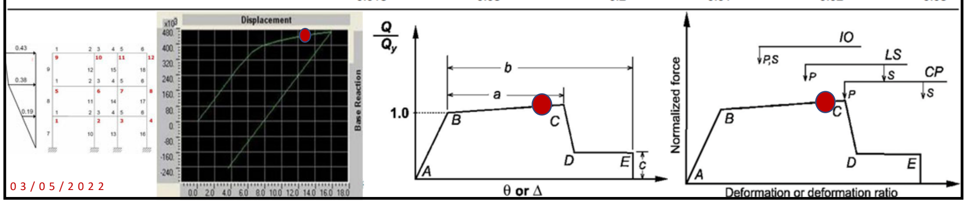
Condition iv. Beams controlled by inadequate embedment into beam–column joint[b]								
			0.015	0.03	0.2	0.01	0.02	0.03



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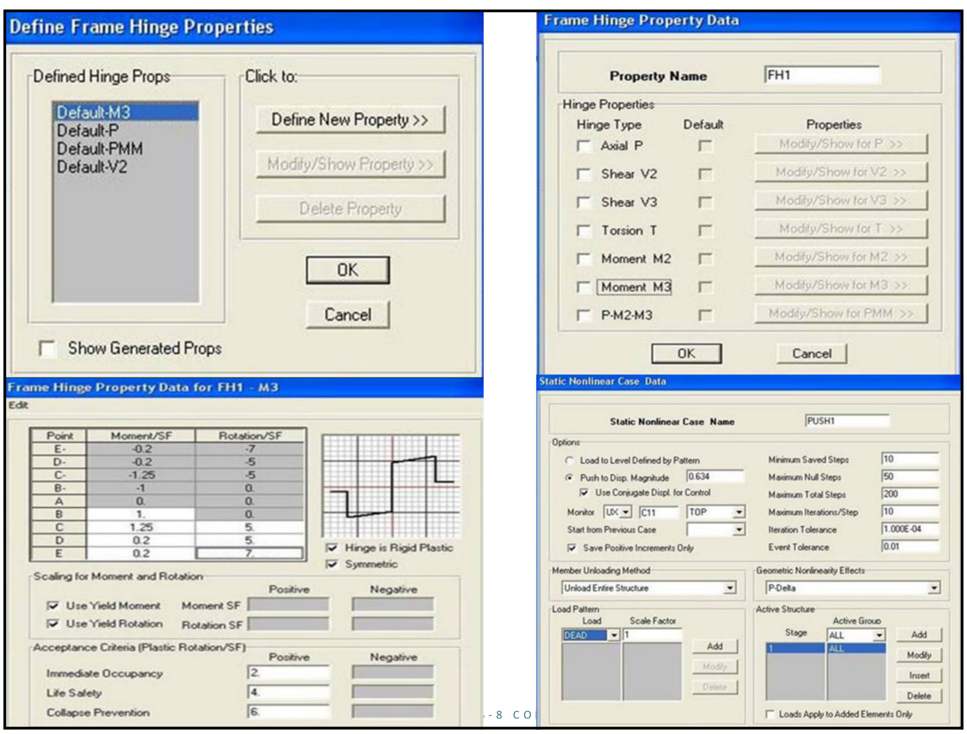

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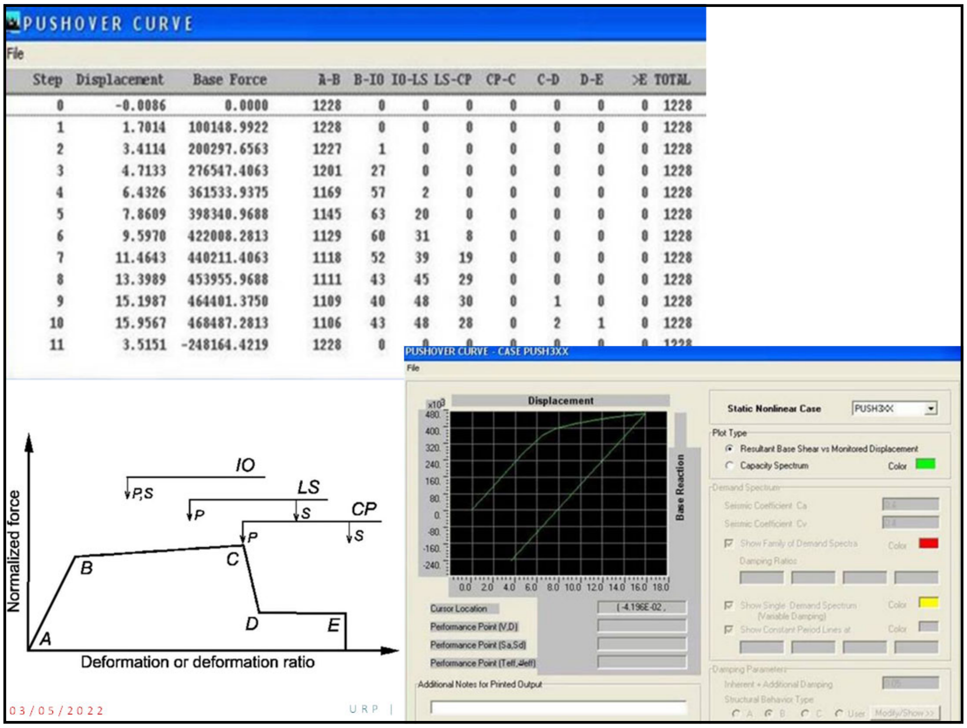

PUSHOVER CURVE

Step	Displacement	Base Force	A-B	B-IO	IO-LS	LS-CP	CP-C	C-D	D-E	>E	TOTAL
0	-0.0086	0.0000	1228	0	0	0	0	0	0	0	1228
1	1.7014	100148.9922	1228	0	0	0	0	0	0	0	1228
2	3.4114	200297.6563	1227	1	0	0	0	0	0	0	1228
3	4.7133	276547.4063	1201	27	0	0	0	0	0	0	1228
4	6.4326	361533.9375	1169	57	2	0	0	0	0	0	1228
5	7.8609	398340.9688	1145	63	20	0	0	0	0	0	1228
6	9.5970	422008.2813	1129	60	31	8	0	0	0	0	1228
7	11.4643	440211.4063	1118	52	39	19	0	0	0	0	1228
8	13.3989	453955.9688	1111	43	45	29	0	0	0	0	1228
9	15.1987	464401.3750	1109	40	48	30	0	1	0	0	1228
10	15.9567	468487.2813	1106	43	48	28	0	2	1	0	1228
11	3.5151	-248164.4219	1228	0	0	0	0	0	0	0	1228

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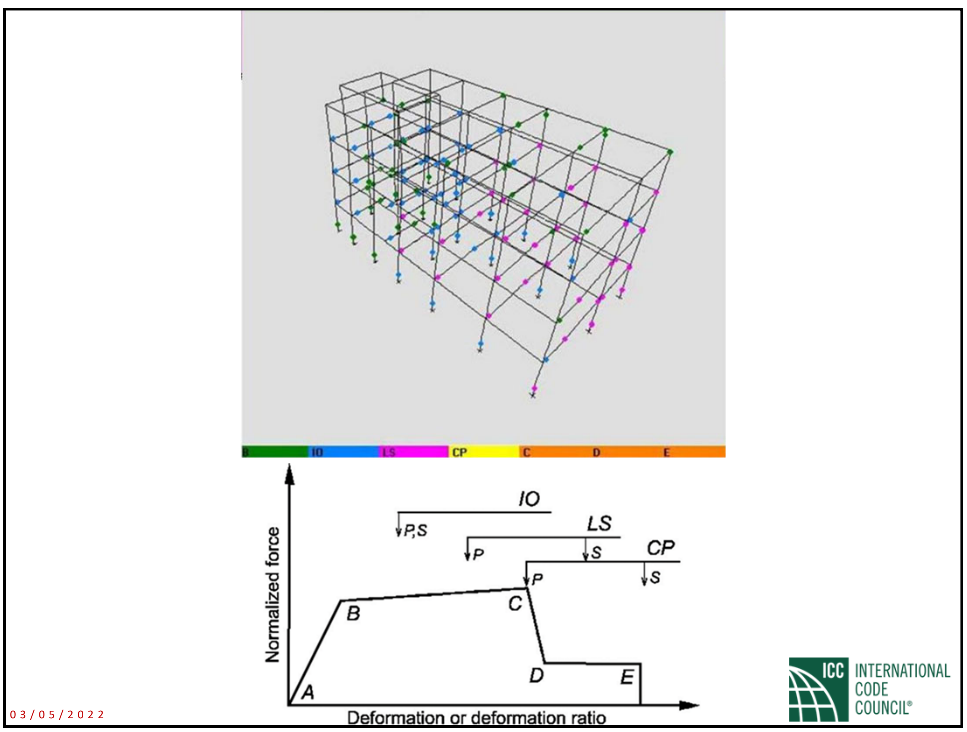

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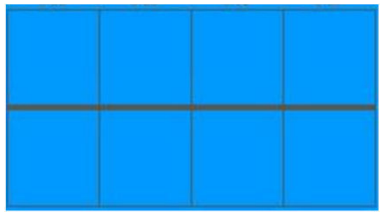
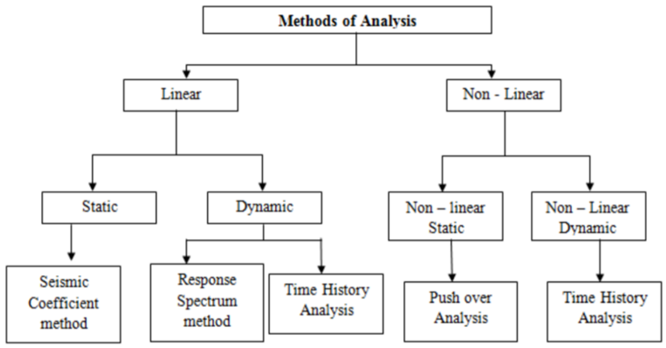


4-story, 6-story, 8-story and 10-story



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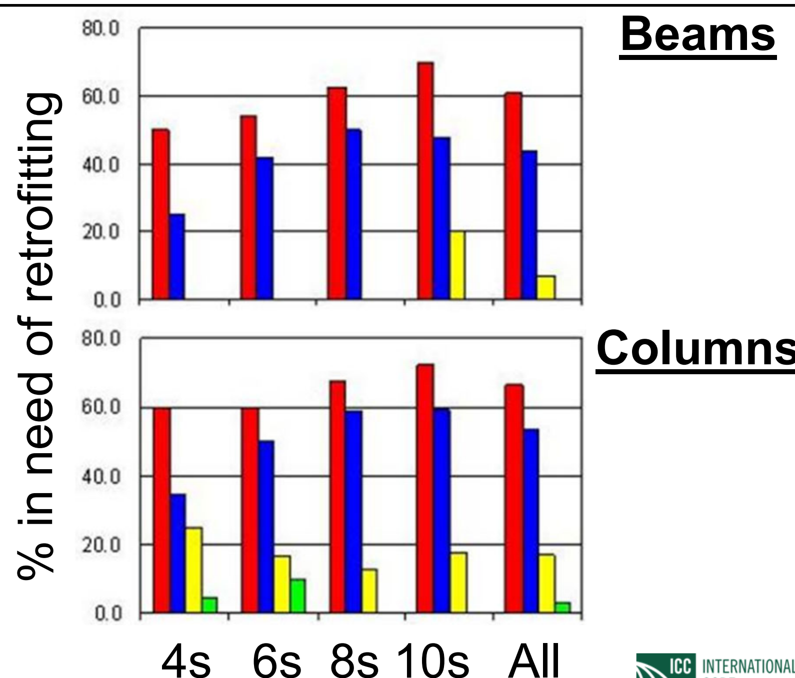

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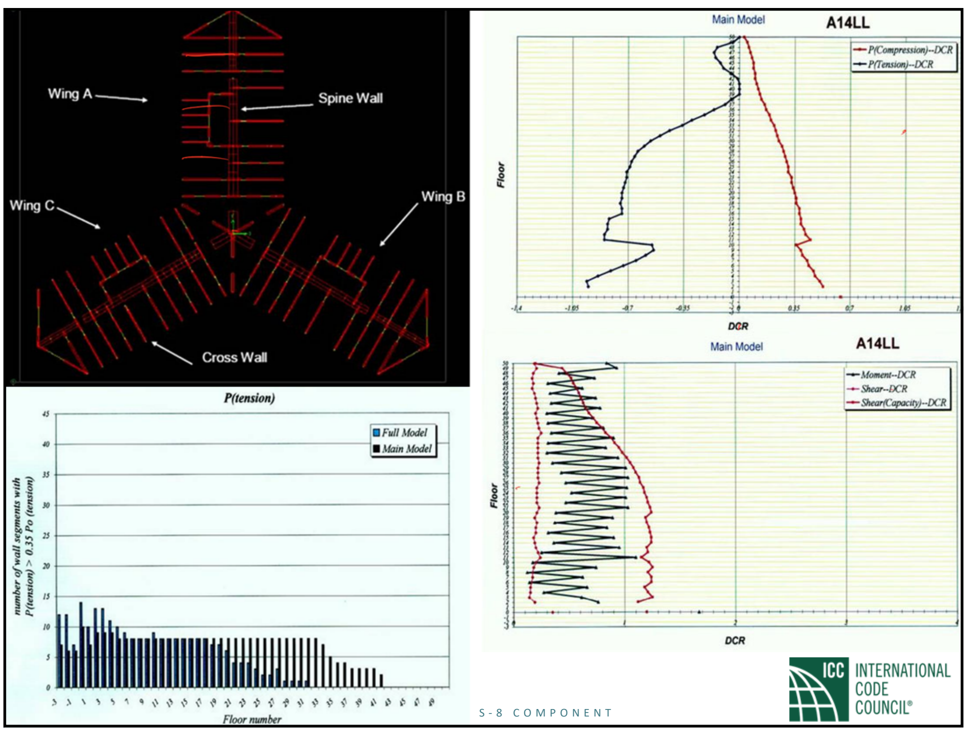
Wing A
Spine Wall
Wing C
Wing B
Cross Wall
Main Model
A14LL
P(Compression)--DCR
P(Tension)--DCR
Floor
DCR
Main Model
A14LL
Moment--DCR
Shear--DCR
Shear(Capacity)--DCR
Floor
DCR
P(tension)
Full Model
Main Model
number of wall segments with P(tension) > 0.35 Po (tension)
Floor number
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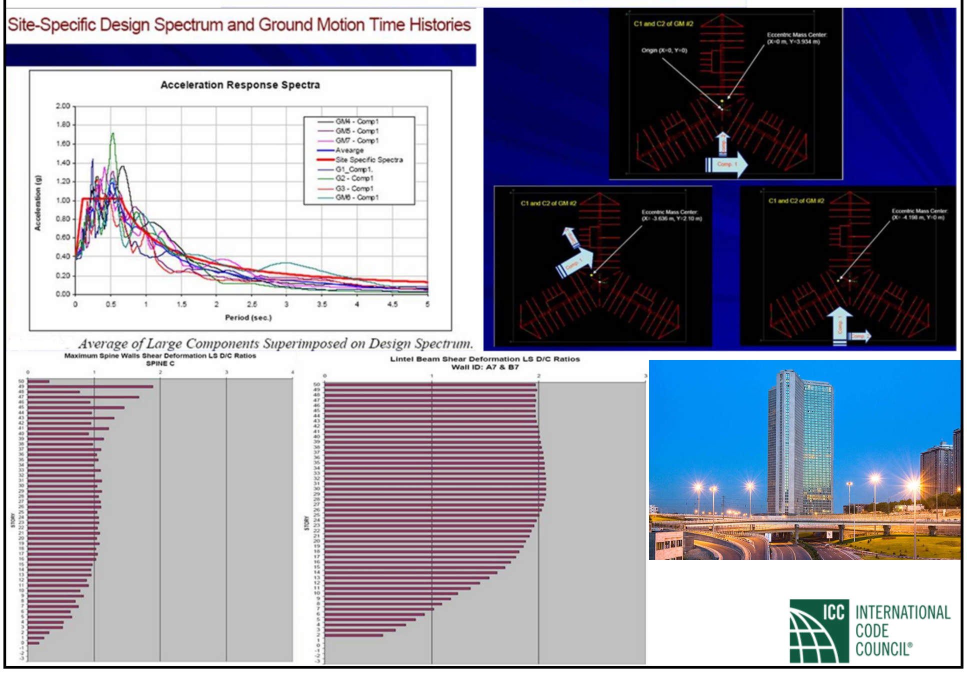
Nonlinear Time History Analyses



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Existing Buildings

a) Seismic Evaluation

- Fragility Curves and Vulnerability functions
- Visual Screening
- Rapid Vulnerability Assessment (RVA)
- Preliminary Engineering Assessment (PEA)
- ✓ Detailed Engineering Assessment (DEA)

ASCE 41-17

- TIER 1 Screening
- TIER 2 Deficiency-Based Evaluation and Retrofit
- ✓ TIER 3 **Systematic** Evaluation and Retrofit

And many more methods …

b) Seismic Retrofitting Technique Selection and Detailing

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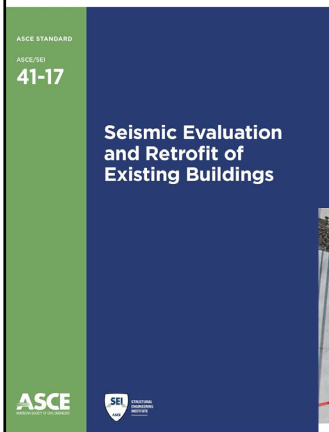
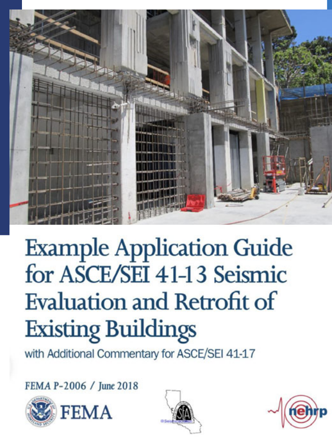
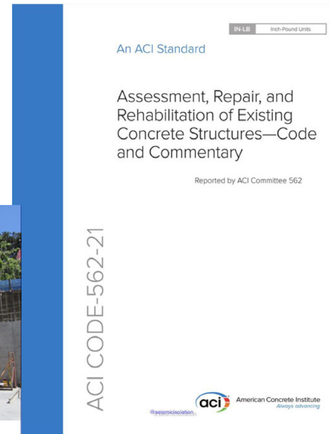
Seismic Evaluation of Existing Buildings







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Seismic Retrofitting Technique Selection and Detailing

Deficiency		Rehabilitation Technique				
Category	Deficiency	Add New Elements	Enhance Existing Elements	Improve Connections Between Elements	Reduce Demand	Remove Selected Components
Global Strength	Insufficient number of frames or weak frames	Concrete/masonry shear wall [12.4.2] Steel braced frame [12.4.1] Concrete or steel moment frame Steel moment frame	Increase size of columns and/or beams [12.4.5]		Remove upper story or stories [24.2] Seismically isolate [24.3] Supplemental damping [24.4]	
Global Stiffness	Insufficient number of frames or frames with inadequate stiffness	Concrete/masonry shear wall [12.4.2] Steel braced frame [12.4.1] Concrete or steel moment frame	Increase size of columns and/or beams [12.4.5] Fiber composite wrap of gravity columns [12.4.4] Concrete/steel jacket of gravity columns [12.4.5] Provide detailing of all other elements to accept drifts		Supplemental damping [24.4]	Remove components creating short columns
Configuration	Soft story or weak story	Add strength or stiffness in story to match balance of floors				
	Re-entrant corner Torsional layout	Add floor area to minimize effect of corner Add balancing walls, braced frames, or moment frames		Provide chords in diaphragm		

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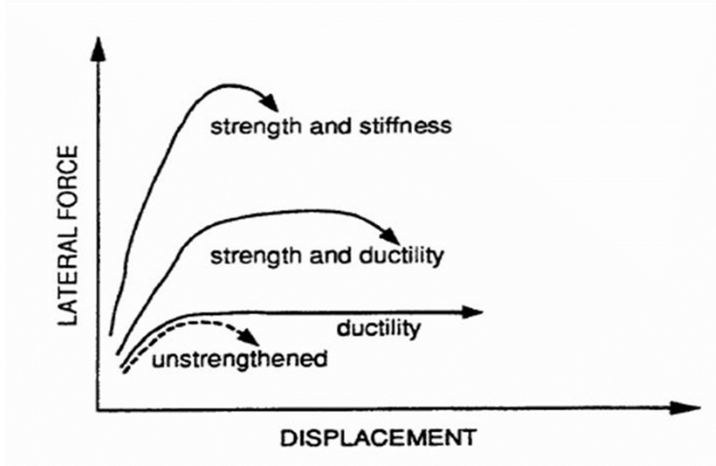
Seismic Retrofitting Technique Selection and Detailing



Concepts of Seismic Strengthening.

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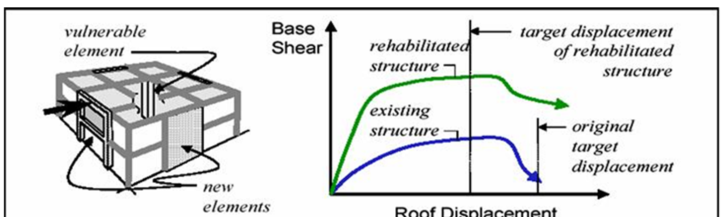
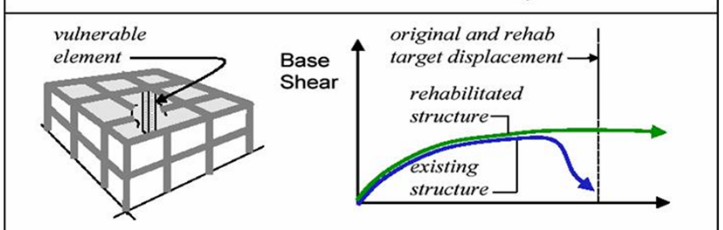
Seismic Retrofitting Technique Selection and Detailing



Global modification of the structural system



Local modification of structural components

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Seismic Retrofitting Technique Selection and Detailing

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Seismic Retrofitting Technique Selection and Detailing

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Summary 1/5

- The major innovation of “systematic assessment and retrofitting approaches”.

Table 10-7. Modeling Parameters and Numerical Acceptance Criteria for Nonlinear Procedures—Reinforced Concrete Beams

			Modeling Parameters[a]			Acceptance Criteria[a]		
						Plastic Rotation Angle (radians)		
			Plastic Rotation Angle (radians)		Residual Strength Ratio	Performance Level		
Conditions			a	b	c	IO	LS	CP
Condition i. Beams controlled by flexure[b]								
$\frac{\rho-\rho'}{\rho_{bal}}$	Transverse reinforcement[c]	$\frac{V^d}{b_w d\sqrt{f'_{cE}}}$						
≤0.0	C	≤3 (0.25)	0.025	0.05	0.2	0.010	0.025	0.05
≤0.0	C	≥6 (0.5)	0.02	0.04	0.2	0.005	0.02	0.04
≥0.5	C	≤3 (0.25)	0.02	0.03	0.2	0.005	0.02	0.03
≥0.5	C	≥6 (0.5)	0.015	0.02	0.2	0.005	0.015	0.02
≤0.0	NC	≤3 (0.25)	0.02	0.03	0.2	0.005	0.02	0.03
≤0.0	NC	≥6 (0.5)	0.01	0.015	0.2	0.0015	0.01	0.015
≥0.5	NC	≤3 (0.25)	0.01	0.015	0.2	0.005	0.01	0.015
≥0.5	NC	≥6 (0.5)	0.005	0.01	0.2	0.0015	0.005	0.01
Condition ii. Beams controlled by shear[b]								
Stirrup spacing ≤ $d/2$			0.0030	0.02	0.2	0.0015	0.01	0.02
Stirrup spacing > $d/2$			0.0030	0.01	0.2	0.0015	0.005	0.01
Condition iii. Beams controlled by inadequate development or splicing along the span[b]								
Stirrup spacing ≤ $d/2$			0.0030	0.02	0.0	0.0015	0.01	0.02
Stirrup spacing > $d/2$			0.0030	0.01	0.0	0.0015	0.005	0.01
Condition iv. Beams controlled by inadequate embedment into beam–column joint[b]								
			0.015	0.03	0.2	0.01	0.02	0.03

- Most difficult and time-consuming part of a “systematic evaluation” project.

Building Configuration

Material Testing

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Summary 2/5

- The “systematic evaluation” approach toward deficient elements in a building.

Table 10-7. Modeling Parameters and Numerical Acceptance Criteria for Nonlinear Procedures—Reinforced Concrete Beams

			Modeling Parameters[a]			Acceptance Criteria[a]		
						Plastic Rotation Angle (radians)		
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≥0.5	C	≤3 (0.25)	0.02	0.03	0.2	0.005	0.02	0.03
≥0.5	C	≥6 (0.5)	0.015	0.02	0.2	0.005	0.015	0.02
≤0.0	NC	≤3 (0.25)	0.02	0.03	0.2	0.005	0.02	0.03
≤0.0	NC	≥6 (0.5)	0.01	0.015	0.2	0.0015	0.01	0.015
≥0.5	NC	≤3 (0.25)	0.01	0.015	0.2	0.005	0.01	0.015
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Stirrup spacing > $d/2$			0.0030	0.01	0.2	0.0015	0.005	0.01
Condition iii. Beams controlled by inadequate development or splicing along the span[b]								
Stirrup spacing ≤ $d/2$			0.0030	0.02	0.0	0.0015	0.01	0.02
Stirrup spacing > $d/2$			0.0030	0.01	0.0	0.0015	0.005	0.01
Condition iv. Beams controlled by inadequate embedment into beam–column joint[b]								
			0.015	0.03	0.2	0.01	0.02	0.03

- Modelling Parameters presented in the tables of existing building codes are only provided for the deformation-controlled actions.

  Force-controlled actions should remain linear.

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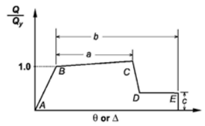
Summary 3/5

- "Modelling Parameters"



Nonlinear capacity curve of a Deformation-Controlled action

Table 10-7. Modeling Parameters and Numerical Acceptance Criteria for Nonlinear Procedures—Reinforced Concrete Beams

Conditions			Modeling Parameters[a]: Plastic Rotation Angle (radians) a	b	Residual Strength Ratio c	Acceptanc… Plastic Rotation… Performa… IO	
Condition i. Beams controlled by flexure[b]							
$\frac{\rho-\rho'}{\rho_{bal}}$	Transverse reinforcement[c]	$\frac{V^d}{b_w d\sqrt{f'_{cE}}}$					
≤0.0	C	≤3 (0.25)	0.025	0.05	0.2	0.010	0.
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≥0.5	C	≤3 (0.25)	0.02	0.03	0.2	0.005	0.
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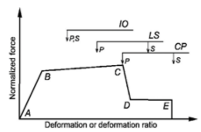
≤0.0	NC	≤3 (0.25)	0.02	0.03	0.2	0.005	0.

- "Acceptance Criteria"



Limits of performance levels for a Deformation-Controlled action

…Nonlinear Procedures—Reinforced Concrete Beams

…odeling Parameters[a]: …ngle (radians) b	Residual Strength Ratio c	Acceptance Criteria[a]: Plastic Rotation Angle (radians), Performance Level: IO	LS	CP
0.05	0.2	0.010	0.025	0.05
0.04	0.2	0.005	0.02	0.04
0.03	0.2	0.005	0.02	0.03
0.02	0.2	0.005	0.015	0.02

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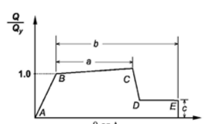
Summary 4/5

- Larger or smaller values for "Modelling Parameters".



Level of
Ductile behaviour

Table 10-7. Modeling Parameters and Numerical Acceptance Criteria for Nonlinear Procedures—Reinforced Concrete Beams

Conditions			Modeling Parameters[a]: Plastic Rotation Angle (radians) a	b	Residual Strength Ratio c	Acceptanc… Plastic Rotation… Performa… IO	
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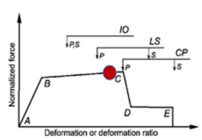
≤0.0	C	≥6 (0.5)	0.02	0.04	0.2	0.005	0.
≥0.5	C	≤3 (0.25)	0.02	0.03	0.2	0.005	0.
≥0.5	C	≥6 (0.5)	0.015	0.02	0.2	0.005	0.
≤0.0	NC	≤3 (0.25)	0.02	0.03	0.2	0.005	0.

- Larger or smaller values for "Acceptance Criteria".



More chance of
Satisfying the performance level

…Nonlinear Procedures—Reinforced Concrete Beams

…odeling Parameters[a]: …ngle (radians) b	Residual Strength Ratio c	Acceptance Criteria[a]: Plastic Rotation Angle (radians), Performance Level: IO	LS	CP
0.05	0.2	0.010	0.025	0.05
0.04	0.2	0.005	0.02	0.04
0.03	0.2	0.005	0.02	0.03
0.02	0.2	0.005	0.015	0.02

Summary 5/5

- Main usage of non-destructive tests.

Uniformity of the material

- The "Knowledge factor" is being used to modify component capacities.

Capacities of the existing components

Table 7-7. Calculation of Component Action Capacity: Nonlinear Procedures

Parameter	Deformation Controlled	Force Controlled
Deformation capacity (existing component)	$\kappa \times$ Deformation limit	N/A
Deformation capacity (new component)	Deformation limit	N/A
Strength capacity (existing component)	N/A	$\kappa \times Q_{CL}$
Strength capacity (new component)	N/A	Q_{CL}

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Course Title: Existing Buildings
Track 4
Modelling Parameters and Acceptance Criteria

- **Course Outcomes:**

1. Understand the relation between level of deficiency in an element with values of different modelling parameters for that element.
2. Can derive the modelling parameters for different structural systems from the tables.
3. Have an idea about alternative ways of estimating the modelling parameters and acceptance criteria for members of a structural system.
4. Recognize the performance level of a building based on the values of acceptance criteria of the elements of the system.
5. Understand consequence of different analysis methods in systematic evaluation.

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Questions?
Thank you

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