UNIFIED DESIGN PROVISIONS

APPENDIX B

APPENDIX C

IMCYC
Mexico City
16 August 2005

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Unified Design Provisions for Reinforced and Prestressed Concrete Flexural and Compression Members

Appendix B – Alternative Provisions for Reinforced and Prestressed Concrete Flexural and Compression Members

Appendix C – Alternative Load and Strength Reduction Factors

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OUTLINE

Part 1 – Historical Background
Part 2 – Unified Design Provisions
Part 3 – Appendix B
Part 4 – Appendix C
Part 5 – Summary

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Part 1
HISTORICAL BACKGROUND

– *Purpose of Appendices*
– *Evolution of Design Methodologies*

PURPOSE OF APPENDICES

1. ***Introduce New Code Provisions***
   – *Appendix A – Strut-and-Tie*
   – *Appendix D – Anchoring to Concrete*

2. ***Phase Out Old Code Provisions***
   – *Appendix B – Flexure and Axial*
   – *Appendix C – Load Factor Design*

EXAMPLE ON PHASING OUT PROVISIONS
** Working Stress Design **

- *1910 to 1963 → In Body of Code*
- *1971 to 1999 → Appendix A*
- *2002 → Appendix A Removed from Code*

EVOLUTION OF DESIGN METHODOLOGIES

1. ***Working Stress Design***

Allowable Stress Design, or Service Load Design

- ***Assumes Linear Elastic Concrete Stress-Strain***
- $f_c \leq 0.40\, f_c'$
- $f_s \leq 24$ ***ksi (Grade 60)***
- ***Dead and Live Loads Are Considered of Equal Importance and Variability***

EVOLUTION OF DESIGN METHODOLOGIES

2. ***Ultimate Strength Design***

Load Factor Design (LFD)

- ***Non-Linear Concrete Stress-Strain (Equivalent Rectangular Stress Block for Ease of Use)***
- ***Tension Steel Yields Before Concrete Crushes → Ductile Behavior***
- ***Live Load More Variable Than Dead Load***
- ***Arbitrary Load Factors (ACI 318-05 App. C)***
  → ***1.4D + 1.7L (Basic Load Combination)***

EVOLUTION OF DESIGN METHODOLOGIES

3. ***LRFD Methodology***

Load and Resistance Factor Design

- ***Strength Limit State***
- ***Recognizes Variability in Loads and Resistances***
- ***Reliability Analysis – Monte Carlo Simulations***
- ***Calibrated Load and Resistance Factors (ACI 318 Sections 9.2)***
  → ***1.2D + 1.6L (Basic Load Combination from ASCE 7)***

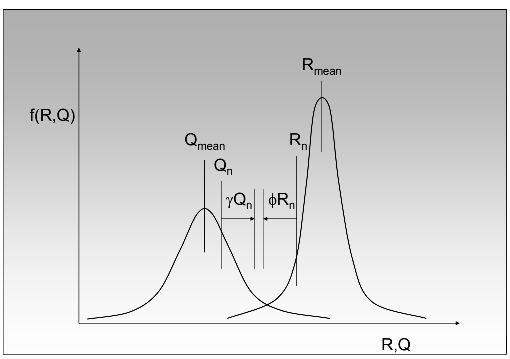
EVOLUTION OF DESIGN METHODOLOGIES

3. <u>LRFD Methodology</u>

Statistical Data

- ***Variability in Loads***
  - ***Dead, Live, Wind, Seismic***
- ***Variability in Resistances***
  - ***Concrete Compressive Strength***
  - ***Reinforcing Steel Yield Strength***
  - ***Cross-Section Geometry***
  - ***Concrete Cover***
  - ***Location of Reinforcement***

LRFD CALIBRATION



Part 2
UNIFIED DESIGN PROVISIONS FOR REINFORCED AND PRESTRESSED CONCRETE FLEXURAL AND COMPRESSION MEMBERS

Beams → Ductile Behavior

Columns → Brittle Behavior

→ Selection of ϕ Factors

WHY UNIFIED PROVISIONS NEEDED?

1999 Code and Earlier		
	R/C	P/S
Redistribution of Negative Moments in Continuous Members	8.4	18.10.4
Limits for Reinforcement of Flexural Members	10.3.3	18.8.1

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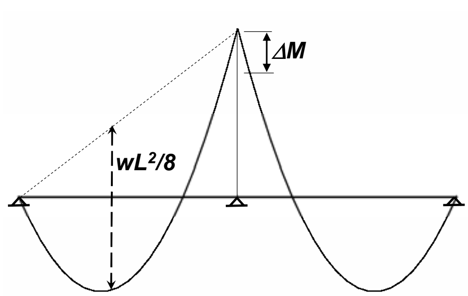
REDISTRIBUTION OF NEGATIVE MOMENTS



Bending Moment Diagram

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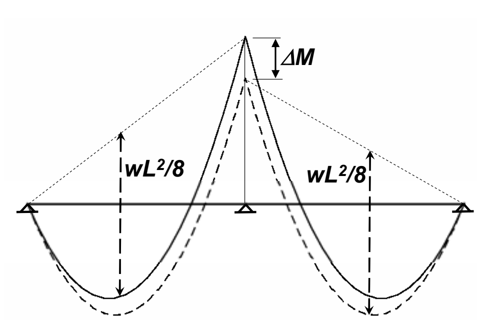
REDISTRIBUTION OF NEGATIVE MOMENTS



Bending Moment Diagram

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8.4 – REDISTRIBUTION OF NEGATIVE MOMENTS IN CONTINUOUS NONPRESTRESSED FLEXURAL MEMBERS ('99 and Earlier)

(ρ) or $(\rho - \rho') \le 0.50\rho_b$

$$\Delta M = 20\left(1 - \frac{\rho - \rho'}{\rho_b}\right) percent$$

Maximum Redistribution = 20%

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18.10.4 – REDISTRIBUTION OF NEGATIVE MOMENTS IN CONTINUOUS PRESTRESSED FLEXURAL MEMBERS ('99 and Earlier)

$$\Delta M = 20\left[1 - \frac{\omega_p - \frac{d}{d_p}(\omega - \omega')}{\rho_b}\right] percent$$

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10.3.3 – REINFORCEMENT LIMIT ('99)

- If ϕP_n < Smaller of
  - $0.10 f'_c A_g$, or
  - ϕP_b
- Then $\rho_{max} \le 0.75\rho_b$

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18.8.1 – LIMITS FOR REINFORCEMENT OF FLEXURAL MEMBERS ('99)

- ***The Following Ratios Used to Compute M_n Must Not Exceed $0.36\beta_1$***
  - ω_p
  - $[\omega_p + (d/d_p)(\omega - \omega')]$
  - $[\omega_{pw} + (d/d_p)(\omega_w - \omega_w')]$

WHY UNIFIED PROVISIONS NEEDED?

R/C	$\rho = \dfrac{A_s}{bd}$
P/S	$\rho_p = \dfrac{A_{ps}}{bd_p}$

18.0 – NOTATION ('99)

A_{ps} = area of prestressed reinforcement in tension zone

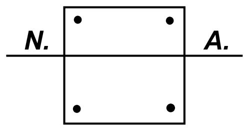
d_p = distance from extreme compression fiber to centroid of prestressed reinforcement

$$M_n = A_{ps}f_{ps}(d_p - a/2)$$

→ A_{ps} and d_p Not Compatible

TENSION ZONE

Prestressed Concrete Column or Pile



Tension Zone → Below Neutral Axis (N.A.)

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UNIFIED PROVISIONS

Background Article

Reference 8.4 by Robert F. Mast, ACI Structural Jrnl., Mar-April 1992

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UNIFIED PROVISIONS APPLICABILITY

- ***Flexural & Compression Members***
- ***R/C, P/S, and Combinations***
- ***Steel at Various Depths***
- ***Sections of Any Shape***
- ***Composite Sections***
- ***Tension-Controlled Columns***

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WALT DISNEY WORLD MONORAIL - 1971

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UNIFIED DESIGN PROVISIONS – KEY CONCEPT

Strength Reduction Factor, ϕ,
Depends on
Maximum Net Tensile Strain, ε_t,
At Nominal Strength, M_n

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2.2 - DEFINITIONS

<u>Net tensile strain</u> - The tensile strain at nominal strength exclusive of strains due to effective prestress, creep, shrinkage, and temperature.

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2.2 - DEFINITIONS

***Extreme tension steel* — The reinforcement (prestressed or nonprestressed) that is the farthest from the extreme compression fiber.**

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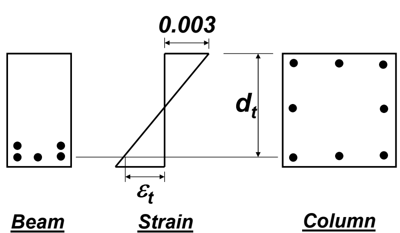
2.2 - DEFINITIONS



ε_t = Net Tensile Strain

d_t = Depth to Extreme Tension Steel

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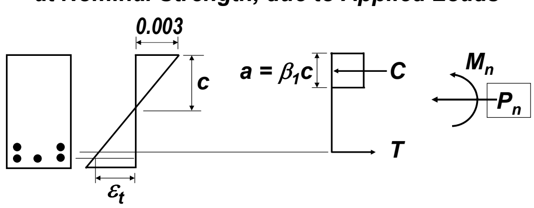
2.2 - NET TENSILE STRAIN ε_t

Extreme Tension Steel Strain at Nominal Strength, due to Applied Loads



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2.2 - DEFINITIONS

***Compression-controlled strain limit* — The net tensile strain at balanced strain conditions. See 10.3.3.**

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2.2 - DEFINITIONS

***Compression-controlled section* — A cross section in which the net tensile strain in the extreme tension steel at nominal strength is less than or equal to the compression-controlled strain limit.**

[Usually 0.002]

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2.2 - DEFINITIONS

***Tension-controlled section* — A cross section in which the net tensile strain in the extreme tension steel at nominal strength is greater than or equal to 0.005.**

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UNIFIED DESIGN PROVISIONS – KEY CONCEPT

Strength Reduction Factor, ϕ,
Depends on
Maximum Net Tensile Strain, ε_t,
At Nominal Strength, M_n

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GIVE WARNING PRIOR TO FAILURE

- ***Excessive Cracking***
- ***Excessive Deflection***

Net Tensile Strain
Is a Measure of Both

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UNIFIED DESIGN PROVISIONS

- ***Impact Chapters 8, 9, 10, and 18 of ACI 318-02 & 318-05***
- ***Former Sections of Above Chapters Are Now Placed in App. B & C where they May Continue to be Used***

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8.4 – REDISTRIBUTION OF NEG. MOMENTS IN CONTINUOUS FLEXURAL MEMBERS

- ***Based on Net Tensile Strain, ε_t***
- ***Percent Redistribution $\Delta M = 1000\varepsilon_t$***
- ***Minimum $\varepsilon_t = 0.0075$***
- ***Maximum Redistribution = 20%***
- ***Applies Equally to Both Nonprestressed & Prestressed Sections***

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R8.4 – REDISTRIBUTION OF NEG. MOMENTS IN CONTINUOUS FLEXURAL MEMBERS

- ***Moment redistribution may not be used for slab systems designed by the Direct Design Method (see 13.6.1.7).***

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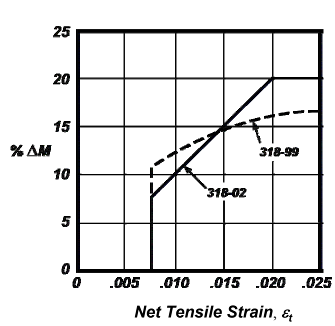
R8.4 – MOMENT REDISTRIBUTION R/C



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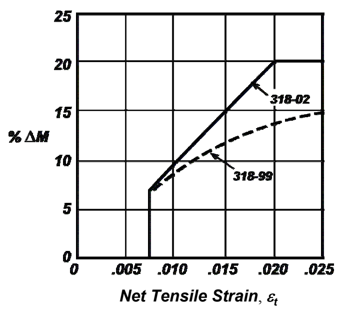
MOMENT REDISTRIBUTION IN P/S



9.2 –LOAD COMBINATIONS

$U = 1.4(D + F)$ (9-1)

$U = 1.2(D + F + T) + 1.6(L + H) + 0.5(L_r \text{ or } S \text{ or } R)$ (9-2)

$U = 1.2D + 1.6(L_r \text{ or } S \text{ or } R) + (1.0L \text{ or } 0.8W)$ (9-3)

$U = 1.2D + 1.6W + 1.0L + 0.5(L_r \text{ or } S \text{ or } R)$ (9-4)

$U = 1.2D + 1.0E + 1.0L + 0.2S$ (9-5)

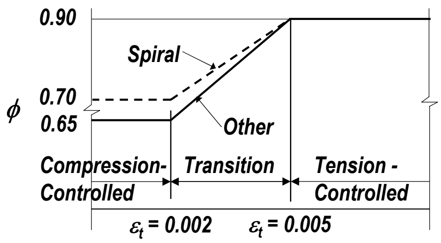
$U = 0.9D + 1.6W + 1.6H$ (9-6)

$U = 0.9D + 1.0E + 1.6H$ (9-7)

9.3 – STRENGTH REDUCTION FACTORS ϕ

	'05	'99
Tension-controlled sections	0.90	0.90
Compression-controlled sections		
Members with spiral reinforcement	0.70	0.75
Other reinforced members	0.65	0.70
Shear and torsion	0.75	0.85
Bearing on concrete (except P/T anchorage)	0.65	0.70

9.3.2 – VARIATION IN ϕ



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9.3.2 – ϕ TRANSITION REGION

- ***Spiral:*** $\phi = 0.70 + (\varepsilon_t - 0.002)(200/3)$

$$\phi = 0.70 + 0.20\left[\left(\frac{1}{c/d_t}\right) - \left(\frac{5}{3}\right)\right]$$

- ***Other:*** $\phi = 0.65 + (\varepsilon_t - 0.002)(250/3)$

$$\phi = 0.65 + 0.25\left[\left(\frac{1}{c/d_t}\right) - \left(\frac{5}{3}\right)\right]$$

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9.3.2 – FLEXURAL MEMBERS

- ***Strength Reduction Factor ϕ for Tension-Controlled Sections is Not Reduced, Even Though Required Strengths Are Reduced About 10%***
- ***But Ductility Requirements for Tension-Controlled Sections Are More Stringent Than Former 0.75ρ_b Requirements***

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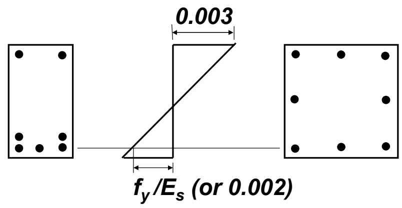
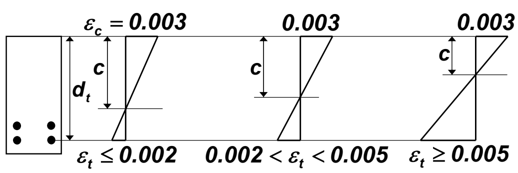
10.3.2 – BALANCED STRAIN CONDITION



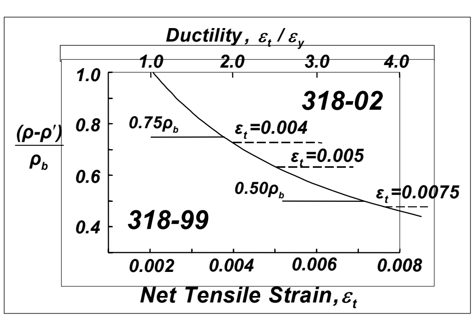
10.3.3-4 – STRAIN CONDITIONS



$\varepsilon_t \leq 0.002$ | $0.002 < \varepsilon_t < 0.005$ | $\varepsilon_t \geq 0.005$

Compression-Controlled $c \geq 0.6d_t$ | Transition | Tension-Controlled $c \leq 0.375d_t$

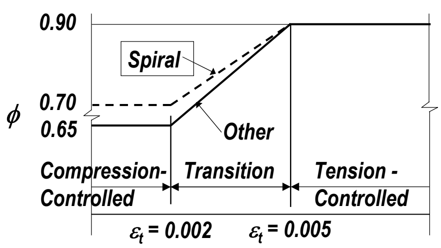
'99/'02 DUCTILTY COMPARISONS



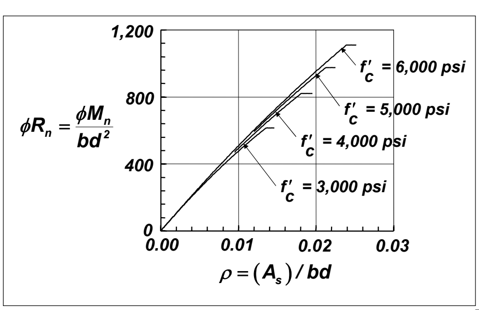
10.3.5 – MAXIMUM REINFORCEMENT FOR NONPRESTRESSED FLEXURAL MEMBERS

- Flexural Members or Members with $\boxed{P_u < 0.10 f'_c A_g}$
- Net Tensile Strain ≥ 0.004
- Replaces $0.75\rho_b$ of '99 Code
- New Limit Slightly More Restrictive
- For Rectangular Sections, New Limit Corresponds to $0.714\rho_b$ for Grade 60 Steel

9.3.2 – VARIATION IN ϕ



DESIGN STRENGTHS



EFFECT OF VARIATION IN ϕ

- ***Break in Strength in Previous Slide Occurs at Strain Limit for Tension-Controlled Sections. Adding Reinforcement Beyond this Limit Reduces ϕ, Because of Reduced Ductility, Resulting in No Gain in Design Strength***
- ***It is Better to Add Sufficient Compression Reinforcement to Raise Neutral Axis and Make Section Tension-Controlled***

18.8.1 – REINFORCEMENT LIMITS

- ***Limits Are Based on Net Tensile Strain, ε_t***

18.8.1 – REINFORCEMENT LIMITS

- ***Per 10.3.3 and 10.3.4, Prestressed Concrete Sections Are Classified as:***
  - ***Tension Controlled***
  - ***Transition, or***
  - ***Compression Controlled***
- ***ϕ Factors Given in 9.3.2***

R18.8.1 – REINFORCEMENT LIMITS

- ***Net tensile strain limits for tension-controlled sections given in 10.3.4 may also be stated in terms of ω_p as defined in the 1999 and earlier editions of the code***
- ***The net tensile strain limit of 0.005 corresponds to $\omega_p = 0.32\beta_1$ for prestressed rectangular sections***

18.10.4 - MOMENT REDISTRIBUTION

- ***Moment Redistribution Permitted If Bonded Reinforcement Is Provided At Supports***
- ***Redistribution Per 8.4 Applies Equally to Prestressed and Nonprestressed Concrete***

Part 3
APPENDIX B – ALTERNATIVE PROVISIONS FOR REINFORCED AND PRESTRESSED CONCRETE FLEXURAL AND COMPRESSION MEMBERS

8.1.2 – USE OF APPENDIX B

8.1.2 — Design of reinforced concrete using the provisions of Appendix B, Alternative Provisions for Reinforced and Prestressed Concrete Flexural and Compression Members, shall be permitted.

R8.1.2 – USE OF APPENDIX B

R8.1.2 — Designs in accordance with Appendix B are equally acceptable, **provided the provisions of Appendix B are used in their entirety**.

B.1 – SCOPE OF APPENDIX B

- ***Design for flexure and axial load***
- ***Appendix B is not a stand alone code***
- ***Appendix B sections replace corresponding sections in the body of the code***
- ***If any section in Appendix B is used, all sections in Appendix B must be used***

RB.1 – SCOPE OF APPENDIX B

…The load factors and strength reduction factors of either Chapter 9 or Appendix C are applicable.

B.1 – SCOPE OF APPENDIX B

Body of Code	*Appendix B*
Chapters 1 to 7	--
8.1 to 8.3 ~~*8.4*~~ ~~*8.4.1*~~ ~~*8.4.2*~~ ~~*8.4.3*~~ *8.5*	-- *B.8.4* *B.8.4.1* *B.8.4.2* *B.8.4.3*

B.1 – SCOPE OF APPENDIX B

Body of Code	*Appendix B*
~~*10.3.3*~~ ~~*10.3.4*~~ ~~*10.3.5*~~ *Except 10.3.5.1*	*B.10.3.3*
~~*B.18.1.3*~~	*B.18.1.3*
~~*18.8.1*~~ ~~*18.8.2*~~ ~~*18.8.3*~~	*B.18.8.1* *B.18.8.2* *B.18.8.3*

B.1 – SCOPE OF APPENDIX B

Body of Code	Appendix B
~~18.10.4~~	B.18.10.4
~~18.10.4.1~~	B.18.10.4.1
~~18.10.4.2~~	B.18.10.4.2
	B.18.10.4.3

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B.8.4 – REDISTRIBUTION OF NEGATIVE MOMENTS IN CONTINUOUS NONPRESTRESSED FLEXURAL MEMBERS

$$\Delta M = \pm 20\left(1 - \frac{\rho - \rho'}{\rho_b}\right)$$

Pr ovided ρ or $(\rho - \rho') \leq 0.50\rho_b$

where

$$\rho_b = \frac{0.85\beta_1 f_c'}{f_y}\left(\frac{87{,}000}{87{,}000 + f_y}\right)$$

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B.10.3.3 GENERAL REQUIREMENT

$$\rho \leq 0.75\rho_b$$

If $\phi P_n \leq 0.10 f_c' A_g$

$\leq \phi P_b$

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B.18.1.3 - SCOPE

- *Concerns code sections not applicable to prestressed concrete designed by Appendix B*

B.18.8 – LIMITS FOR REINFORCEMENT OF FLEXURAL MEMBERS

- *The Following Ratios Used to Compute M_n Must Not Exceed $0.36\beta_1$*
  - ω_p
  - $[\omega_p + (d/d_p)(\omega - \omega')]$
  - $[\omega_{pw} + (d/d_p)(\omega_w - \omega_w')]$

e.g. $\omega_p = \rho_p f_{ps}/f_c'$

18.10.4 – REDISTRIBUTION OF NEGATIVE MOMENTS IN CONTINUOUS PRESTRESSED FLEXURAL MEMBERS

$$\Delta M = \pm 20\left[1 - \frac{\omega_p + \frac{d}{d_p}(\omega - \omega'}{0.36\beta_1}\right] \text{percent}$$

$$\omega_p \le 0.24\beta_1$$

Part 4
APPENDIX C – ALTERNATIVE LOAD AND STRENGTH REDUCTION FACTORS

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9.1.3 – USE OF APPENDIX C

9.1.3 — Design of structures and structural members using the load factor combinations and strength reduction factors of Appendix C shall be permitted. Use of load factor combinations from this chapter in conjunction with strength reduction factors of Appendix C shall not be permitted.

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C.1 – GENERAL

- ***ACI 318-05 Appendix C includes the factored load combinations and strength reduction factors (ϕ) that were previously in Chapter 9***
- ***They are considered reliable for concrete construction.***

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C.2 – LOAD COMBINATIONS

$U = 1.4D + 1.7L$	*(C-1)*
$U = 0.75\ (1.4D + 1.7L) + (1.6W \text{ or } 1.0E)$	*(C-2)*
$U = 0.9D + (1.6W \text{ or } 1.0E)$	*(C-3)*
$U = 1.4D + 1.7L + 1.7H$	*(C-4)*
$U = 0.75\ (1.4D + 1.4T + 1.7L)$	*(C-5)*
$U = 1.4(D + T)$	*(C-6)*

C.2 – MODIFICATIONS TO LOAD COMBINATIONS

- ***If W not reduced by directionality factor, replace 1.6W with 1.3W in Equations (C-2) and (C-3)***
- ***If E is service level seismic forces, replace 1.0E with 1.4E in (C-2) and (C-3)***

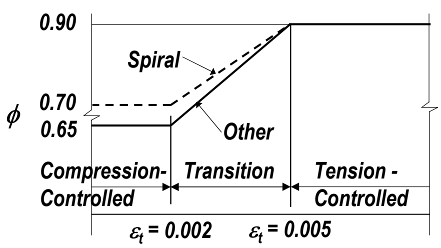
C.3 – STRENGTH REDUCTION FACTORS ϕ

	ϕ
Tension-controlled sections	*0.90*
Compression-controlled sections	
Members with spiral reinforcement	*0.75*
Other reinforced members	*0.70*
Shear and torsion	*0.85*
Bearing on concrete (except P/T anchorage)	*0.70*

C.3 – STRENGTH REDUCTION FACTORS ϕ

	ϕ
Post-tensioned anchorage zones	0.85
Strut-and-tie models	0.85
Pretensioned strand not fully developed	0.85
Plain concrete (flexure, compression, shear, bearing in Chapter 22)	0.65
Development lengths per Chapter 12	--

RC.3.2 – VARIATION IN ϕ



C.3.4 – SEISMIC DESIGN

(a) ϕ (Shear) = 0.60 When Nominal Shear Strength < Shear Corresponding to the Development of Nominal Flexural Strength

(b) ϕ (Shear in Diaphragms) $\leq$ Min. ϕ for Shear Used for the Vertical Components of the Primary LFR System

(c) ϕ (Shear in Joints and Diagonally Reinforced Coupling Beams) = 0.85

Part 5
SUMMARY

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CONCLUDING REMARKS

- ***Unified Design Provisions Apply Equally to R.C. and P/S Subject to Flexure and Axial Load***
- ***Old Provisions for Flexure and Axial Load Located in App. B***
- ***Old Factored Load Combinations Located on App. C***
- ***Legal to Design with App. B and/or C***

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ACI 318-05 DESIGN OPTIONS

Option	Body of Code	Appendix A	Appendix B	Appendix C	Appendix D
1	Yes	Yes	No	No	Yes
2	Yes w/Exceptions	Yes	Yes	No	Yes
3	Yes w/Exceptions	Yes	No	Yes	Yes
4	Yes w/Exceptions	Yes	Yes	Yes	Yes

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