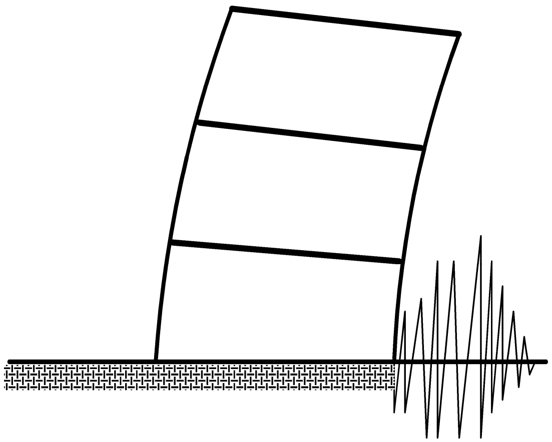


Concrete Shear Wall Design

BY WIRA TJONG, S.E

INTRODUCTION

IR. WIRA TJONG, MSCE, SE

- Front End Engineer of Fluor Enterprises' Tucson Office, with Experience in Indonesia, USA, Korea, Taiwan, and Malaysia as Expatriate
- Christian University of Indonesia (BS and ENGINEER); Virginia Tech (MS), USA; University of Wales, Swansea, UK (PhD Research Program)
- Licensed Structural Engineer in AZ, UT, and CA.
- Area of Expertise
  - Codes Requirements and Applications
  - Seismic Design for New Buildings/Bridges and Retrofit
  - Modeling and Software Development
  - Biotechnology and Microelectronic Facilities
  - California School and Hospitals

ELEMENTS OF WALL DESIGN

97 UBC AND 2002 ACI REQUIREMENTS FOR WALL DESIGN

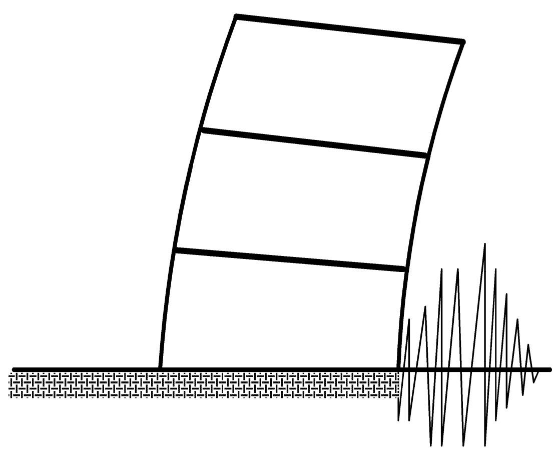
WITH EMPHASIS ON SPECIAL CONCRETE SHEAR WALL

- DEFINITION
- WALL REINFORCEMENT REQUIREMENTS
- SHEAR DESIGN
- FLEXURAL AND AXIAL LOAD DESIGN
- BOUNDARY ZONE DETERMINATION
  - SIMPLIFIED APPROACH
  - RIGOROUS APPROACH
- BOUNDARY ZONE DETAILING

DEFINITION

SHEAR WALL IS A STRUCTURAL ELEMENT USED TO RESIST LATERAL/HORIZONTAL/SHEAR FORCES PARALLEL TO THE PLANE OF THE WALL BY:

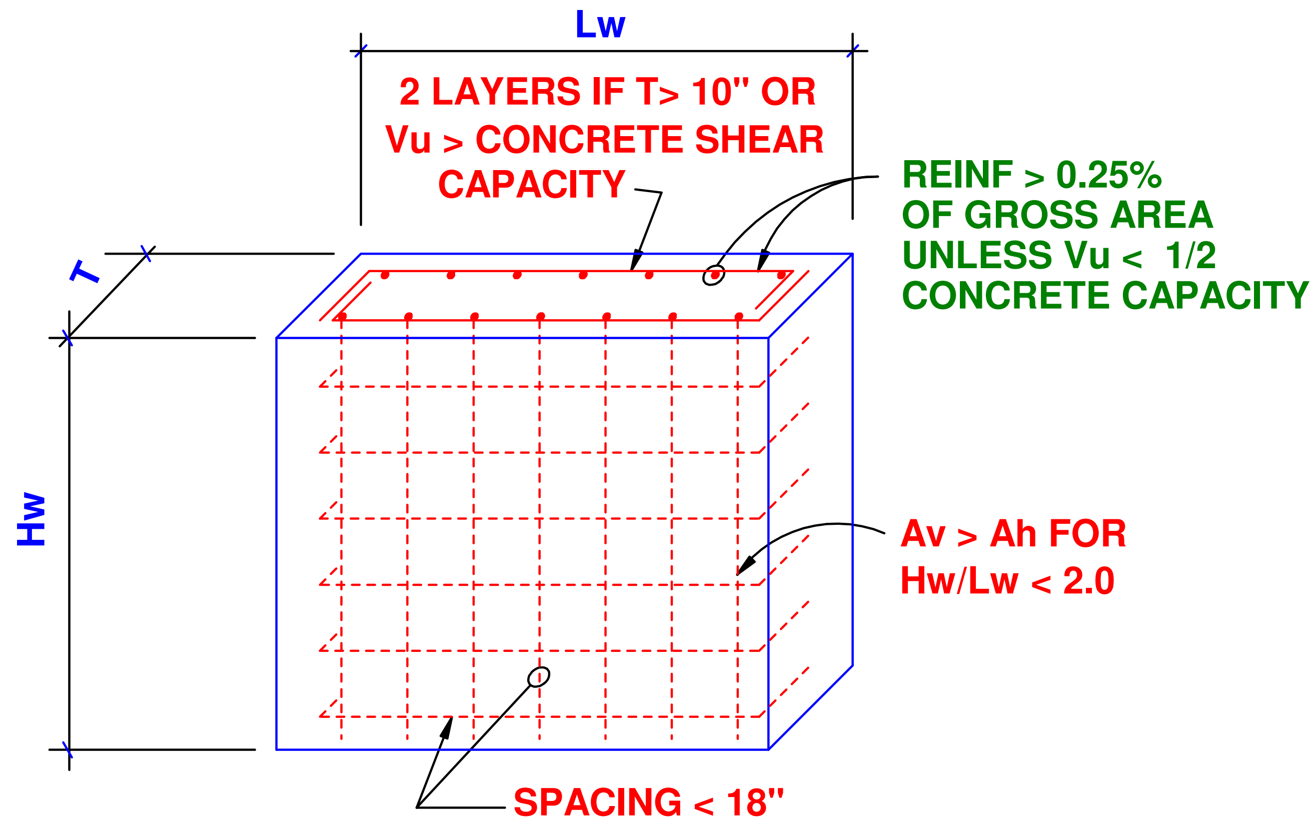
- CANTILEVER ACTION FOR SLENDER WALLS WHERE THE BENDING DEFORMATION IS DOMINANT
- TRUSS ACTION FOR SQUAT/SHORT WALLS WHERE THE SHEAR DEFORMATION IS DOMINANT



WALL REINFORCEMENT

- **MINIMUM TWO CURTAINS OF WALL REINFORCEMENT SHALL BE PROVIDED IF**

  $Vu > 2\ Acv(f'c)^{1/2}$ [$0.166\ Acv(f'c)^{1/2}$] OR THICKNESS > 10 INCHES [25 cm]



WALL REINFORCEMENT

- WALL MINIMUM REINFORCEMENT RATIO (ρ_v or ρ_h) 0.0025

- EXCEPTION FOR $Vu < Acv(f'c)^{1/2}$ [$0.083\ Acv(f'c)^{1/2}$]

  a. MINIMUM VERTICAL REINFORCEMENT RATIO

  ρ_v = 0.0012 FOR BARS NOT LARGER THAN #5 [≤ 16 mm]

  = 0.0015 FOR OTHER DEFORMED BARS

  = 0.0012 FOR WELDED WIRE FABRIC NOT LARGER THAN W31 OR D31[≤ 16 mm]

  b. MINIMUM HORIZONTAL REINFORCEMENT RATIO

  ρ_h = 0.0020 FOR BARS NOT LARGER THAN #5 [≤ 16 mm]

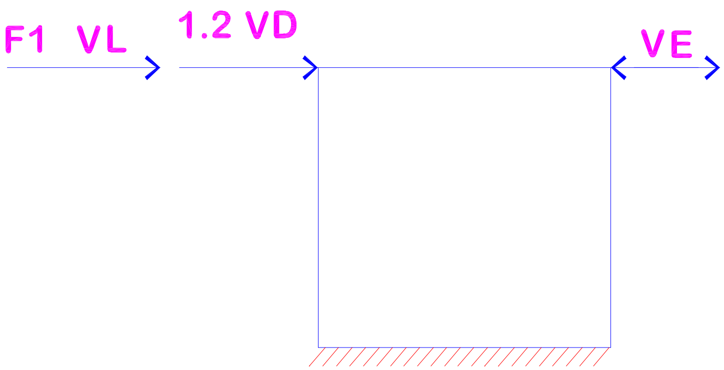
  = 0.0025 FOR OTHER DEFORMED BARS

  = 0.0020 FOR WELDED WIRE FABRIC NOT LARGER THAN W31 OR D31 [≤ 16 mm]

SHEAR DESIGN

☠ Vn > Vu

A. SHEAR DEMAND



- **FACTORED SHEAR FORCE / SHEAR DEMAND**

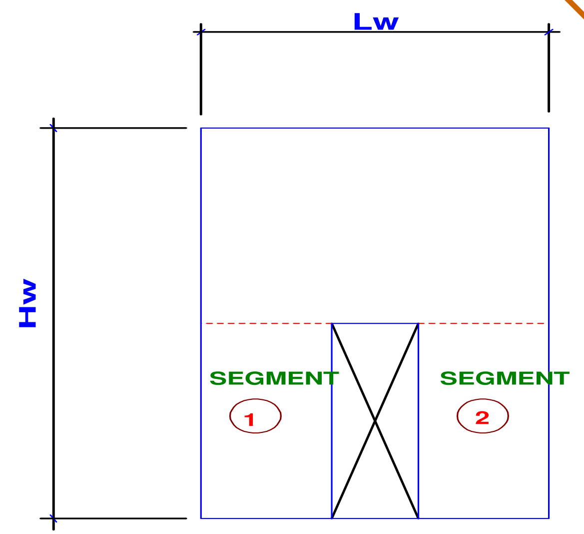
$$Vu = 1.2\ V_D + f1\ V_L \pm V_E$$
$$= 0.9\ V_D \pm V_E$$

f1= 1.0 FOR 100 PSF [500 KG/M2] LIVE LOAD AND GREATER

f1= 0.5 OTHERWISE.

SHEAR DESIGN

B. SHEAR STRENGTH



- **NOMINAL SHEAR STRENGTH**

$$Vn = Acv\ [2(f'c)^{1/2} + \rho_n fy]$$

$$Acv\ [0.166(f'c)^{1/2} + \rho_n fy]$$

- **FOR SQUAT WALLS WITH Hw/Lw < 2.0**

$$Vn = Acv\ [\alpha_c (f'c)^{1/2} + \rho_n fy]$$

$$Acv\ [0.083\alpha_c (f'c)^{1/2} + \rho_n fy]$$

WHERE α_c VARIES LINEARLY FROM 2.0 FOR Hw/Lw =2.0 TO 3.0 FOR Hw/Lw =1.5

- **Hw/Lw SHALL BE TAKEN AS THE LARGEST RATIO FOR ENTIRE WALL OR SEGMENT OF WALL**

SHEAR DESIGN

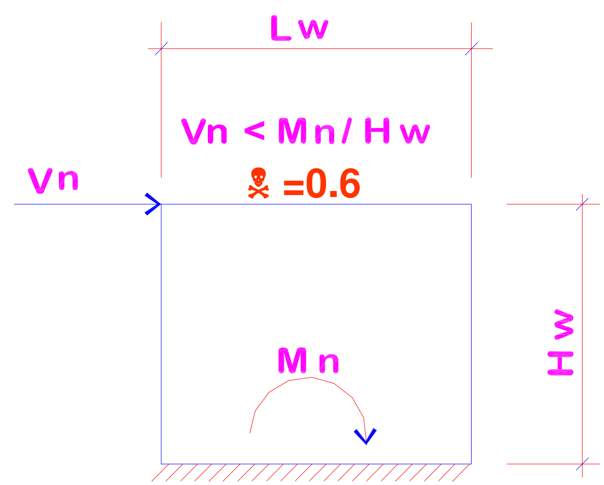
- **MAXIMUM NOMINAL SHEAR STRENGTH**

MAX Vn = Acv [10(f'c)$^{1/2}$]

Acv [0.83(f'c)$^{1/2}$]

- **STRENGTH REDUCTION FACTOR FOR WALLS THAT WILL FAIL IN SHEAR INSTEAD OF BENDING**

☠ =0.6



- **OTHERWISE**

☠ =0.85

FLEXURAL AND AXIAL LOAD DESIGN

A. GENERAL

- **NO NEED TO APPLY MOMENT MAGNIFICATION DUE TO SLENDERNESS**
- **NON-LINEAR STRAIN REQUIREMENT FOR DEEP BEAM DOESN'T APPLY**

- **STRENGTH REDUCTION FACTORS** **0.70**

EXCEPTION FOR WALLS WITH LOW COMPRESSIVE LOAD

☠ = 0.70

FOR

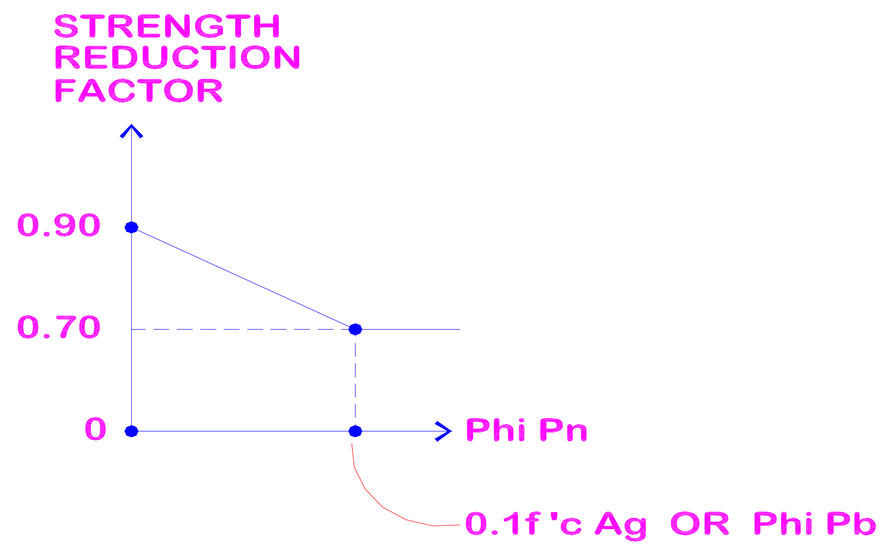
☠Pn = 0.1f'cAg OR ☠Pb

TO

☠ = 0.90

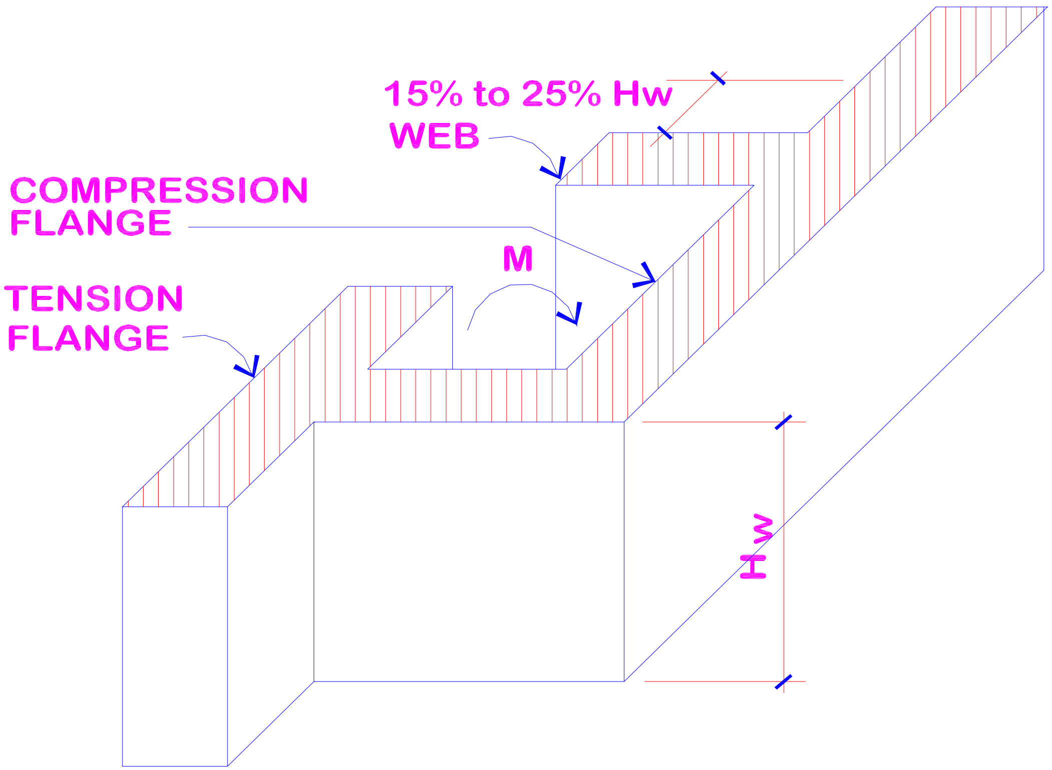
FOR

☠Pn = ZERO OR TENSIOI



FLEXURAL AND AXIAL LOAD DESIGN

- THE EFFECTIVE FLANGE WIDTH FOR I, L , C, OR T SHAPED WALLS
  - a. 1/2 X DISTANCE TO ADJACENT SHEAR WALL WEB
  - b. 15 % OF TOTAL WALL HEIGHT FOR COMP. FLANGE (25 % PER ACI)
  - c. 30 % OF TOTAL WALL HEIGHT FOR TENSION FLANGE (25 % PER ACI)



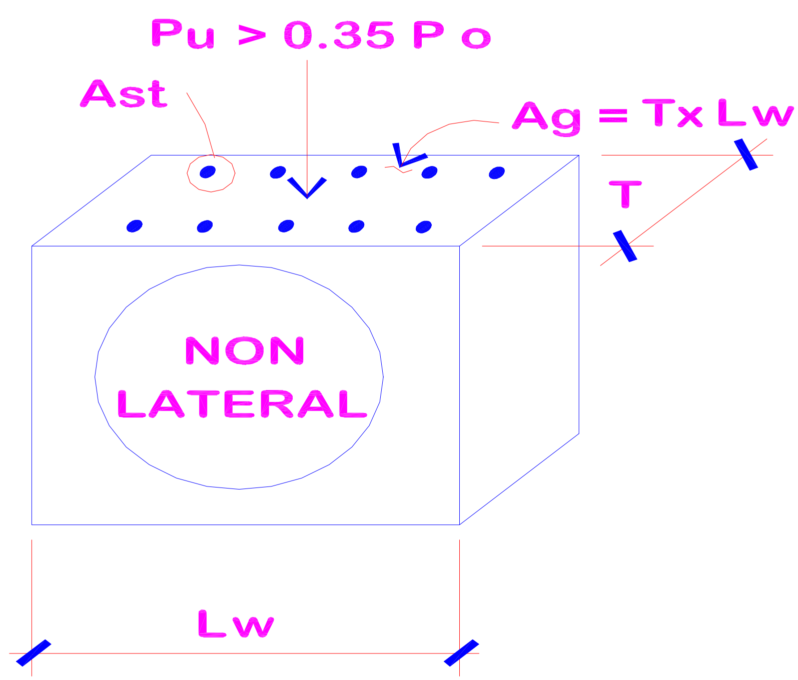
FLEXURAL AND AXIAL LOAD DESIGN

- **WALLS WITH HIGH AXIAL LOAD SHALL NOT BE USED AS LATERAL RESISTING ELEMENTS FOR EARTHQUAKE FORCE IF**

$P_u > 0.35\ P_o$

WHERE

$P_o = 0.8$☠$[0.85 f_c'(A_g - A_{st}) + f_y A_{st}]$



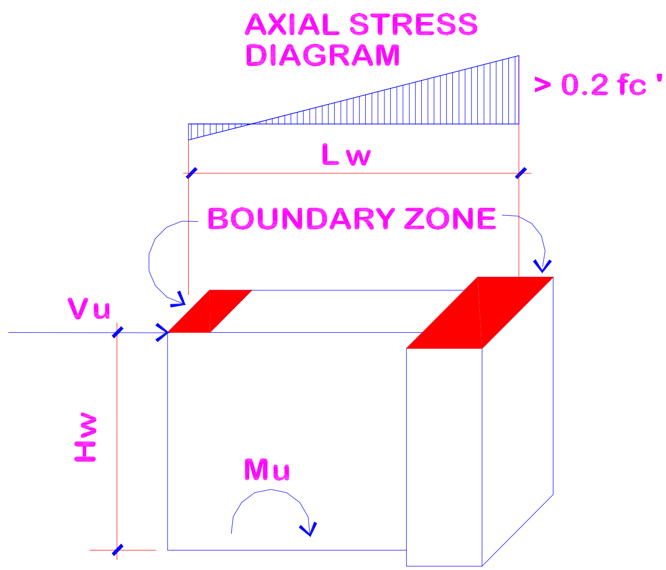
B.1 BOUNDARY ZONE DETERMINATION - SIMPLIFIED APPROACH

BOUNDARY ZONE DETAILING IS NOT REQUIRED IF

- **PER UBC :**

  a. Pu <= 0.10Agf'c FOR SYMMETRICAL WALL

  Pu <= 0.05Agf'c FOR UNSYMMETRICAL WALL



AND EITHER

b. Mu/(VuLw) < = 1.0 (SHORT/SQUAT WALL OR Hw/Lw < 1.0 FOR ONE STORY WALL)

OR

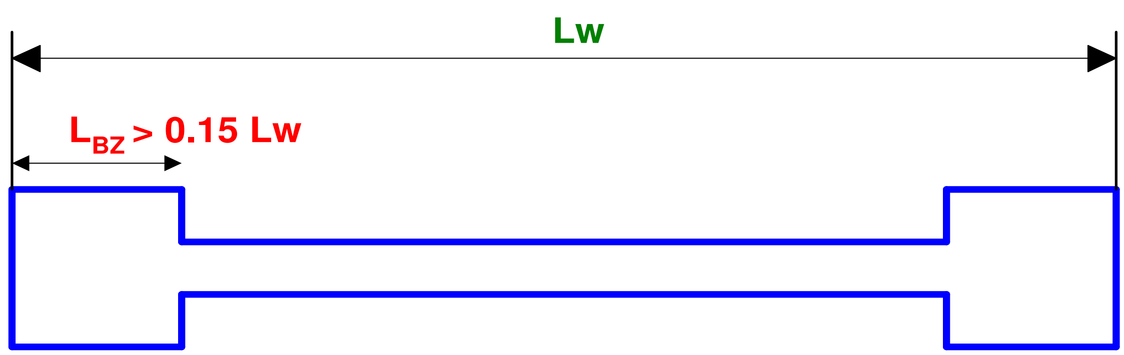
c. Vu <= 3 Acv $(f'c)^{1/2}$ [0.25 Acv $(f'c)^{1/2}$] AND Mu/(VuLw) < = 3.0

- **PER ACI :**

THE FACTORED AXIAL STRESS ON LINEAR ELASTIC GROSS SECTION < 0.2 f'c

B.1 BOUNDARY ZONE DETERMINATION - SIMPLIFIED APPROACH

- **IF REQUIRED, BOUNDARY ZONES AT EACH END OF THE WALL SHALL BE PROVIDED ALONG**
  - **0.25Lw FOR Pu = 0.35 Po**
  - **0.15Lw FOR Pu = 0.15 Po**
- **WITH LINEAR INTERPOLATION FOR Pu BETWEEN 0.15 Po AND 0.35 Po**
- **MINIMUM BOUNDARY ZONE LENGTH : 0.15Lw**

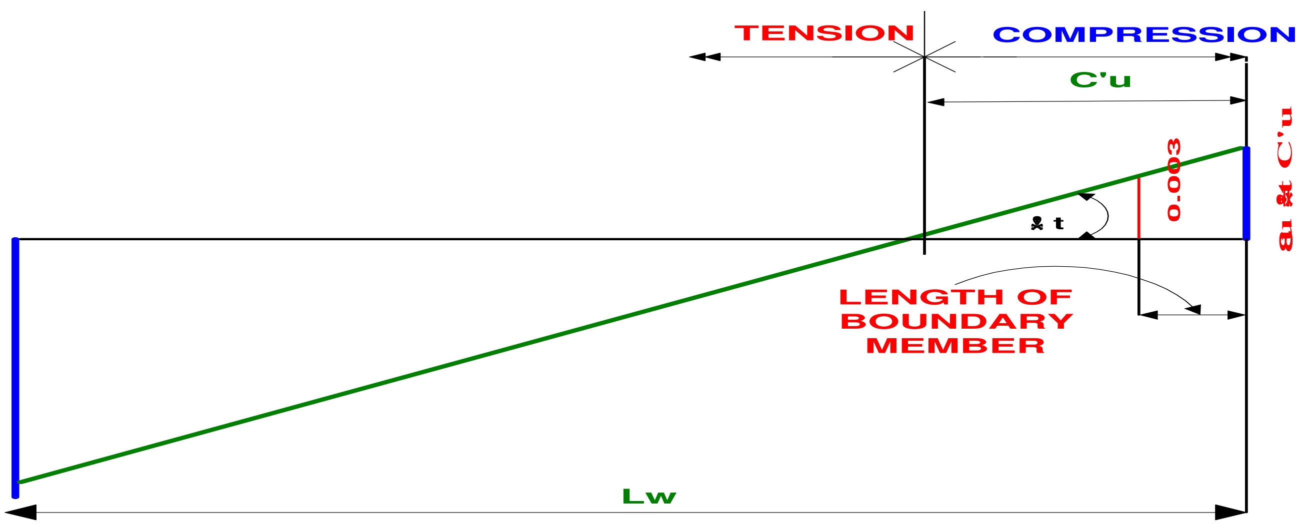


B.2 BOUNDARY ZONE DETERMINATION – RIGOROUS APPROACH

- **BOUNDARY ZONE DETAILING IS NOT REQUIRED IF MAX. COMPRESSIVE STRAIN AT WALL EDGES:**

$$\varepsilon_{max} < 0.003$$

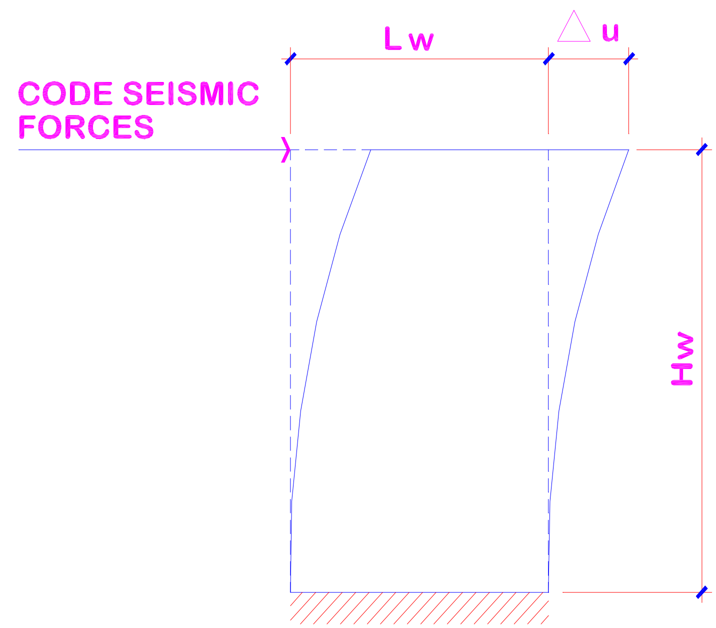
- **THE DISPLACEMENT AND THE STRAIN SHALL BE BASED ON CRACKED SECTION PROPERTIES, UNREDUCED EARTHQUAKE GROUND MOTION AND NON-LINEAR BEHAVIOR OF THE BUILDING.**
- **BOUNDARY ZONE DETAIL SHALL BE PROVIDED OVER THE PORTION OF WALL WITH COMPRESSIVE STRAIN > 0.003.**



B.2 BOUNDARY ZONE DETERMINATION – RIGOROUS APPROACH

◆ THE MAXIMUM ALLOWABLE COMPRESSIVE STRAIN

$$\varepsilon_{max} = 0.015$$



- PER ACI, BOUNDARY ZONE DETAILING IS NOT REQUIRED IF THE LENGTH OF COMP. BLOCK

$$C < Lw/[600*(\Delta_u/Hw)]$$

$$(\Delta_u/Hw) \text{ SHALL NOT BE TAKEN } < 0.007$$

- IF REQUIRED, THE BOUNDARY ZONE LENGTH SHALL BE TAKEN AS

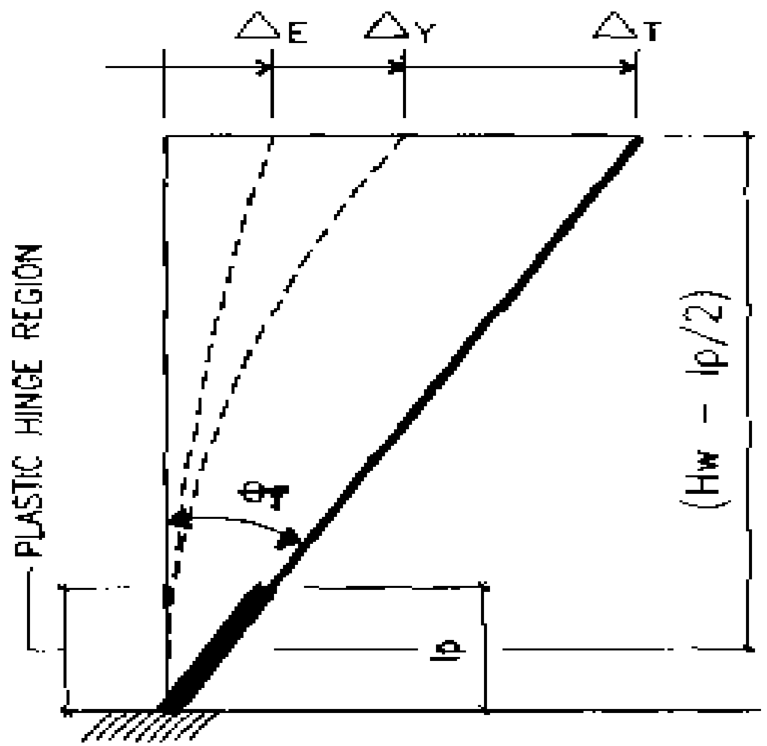
$$Lbz > C - 0.1\ Lw$$

AND

$$> C/2$$

C. APPROXIMATE COMPRESSIVE STRAIN FOR PRISMATIC WALLS YIELDING AT THE BASE

- **DETERMINE Δe : ELASTIC DESIGN DISPLACEMENT AT THE TOP OF WALL DUE TO CODE SEISMIC FORCES BASED ON GROSS SECTION PROPERTIES**

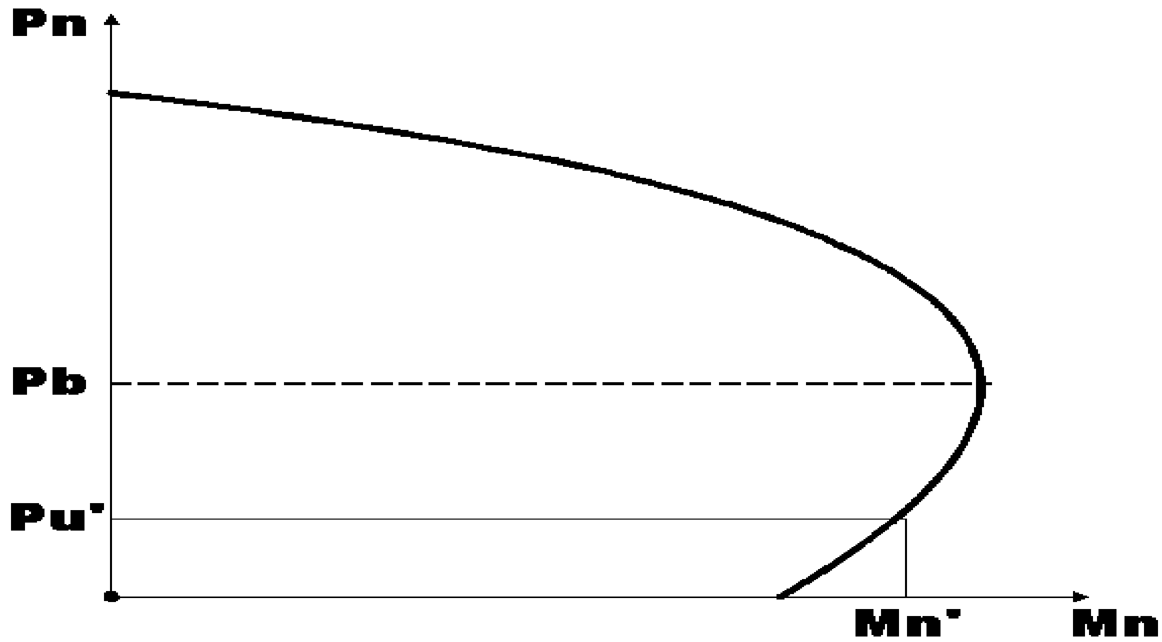


C. APPROXIMATE COMPRESSIVE STRAIN

- **CALCULATE YIELD DEFLECTION AT THE TOP OF WALL CORRESPONDING TO A COMPRESSIVE STRAIN OF 0.003**

$$\Delta y = (Mn'/Me)\Delta e$$

- **Me IS MOMENT DUE TO CODE SEISMIC FORCES**



C. APPROXIMATE COMPRESSIVE STRAIN

- **Mn' IS NOMINAL FLEXURAL STRENGTH AT**

$$Pu = 1.2P_D + 0.5P_L + P_E$$

- **DETERMINE TOTAL DEFLECTION AT THE TOP OF WALL**

  $\Delta t = \Delta m = 0.7\ R\ (2\Delta_E)$ BASED ON GROSS SECTION

  OR

  $\Delta t = \Delta m = 0.7\ R\ \Delta_S$ BASED ON CRACKED SECTION

  WHERE R IS DUCTILITY COEFFICIENT RANGES FROM 4.5 TO 8.5 PER UBC TABLE 16 N.

- **INELASTIC WALL DEFLECTION**

$$\Delta i = \Delta t - \Delta y$$

- **ROTATION AT THE PLASTIC HINGE**

Θ_i = ☠$_i$ Lp = Δi/(Hw - Lp/2)

C. APPROXIMATE COMPRESSIVE STRAIN

- **DETERMINE TOTAL CURVATURE DEMAND AT THE PLASTIC HINGE**

$$\phi_t = \phi_i + \phi_y$$

$$\phi_t = \Delta i/[Lp(Hw - Lp/2)] + \phi_y$$

- **WALL CURVATURE AT YIELD OR AT Mn' CAN BE TAKEN AS**

$$\phi_y = 0.003/Lw$$

- **THE PLASTIC HINGE LENGTH**

$$Lp = Lw/2$$

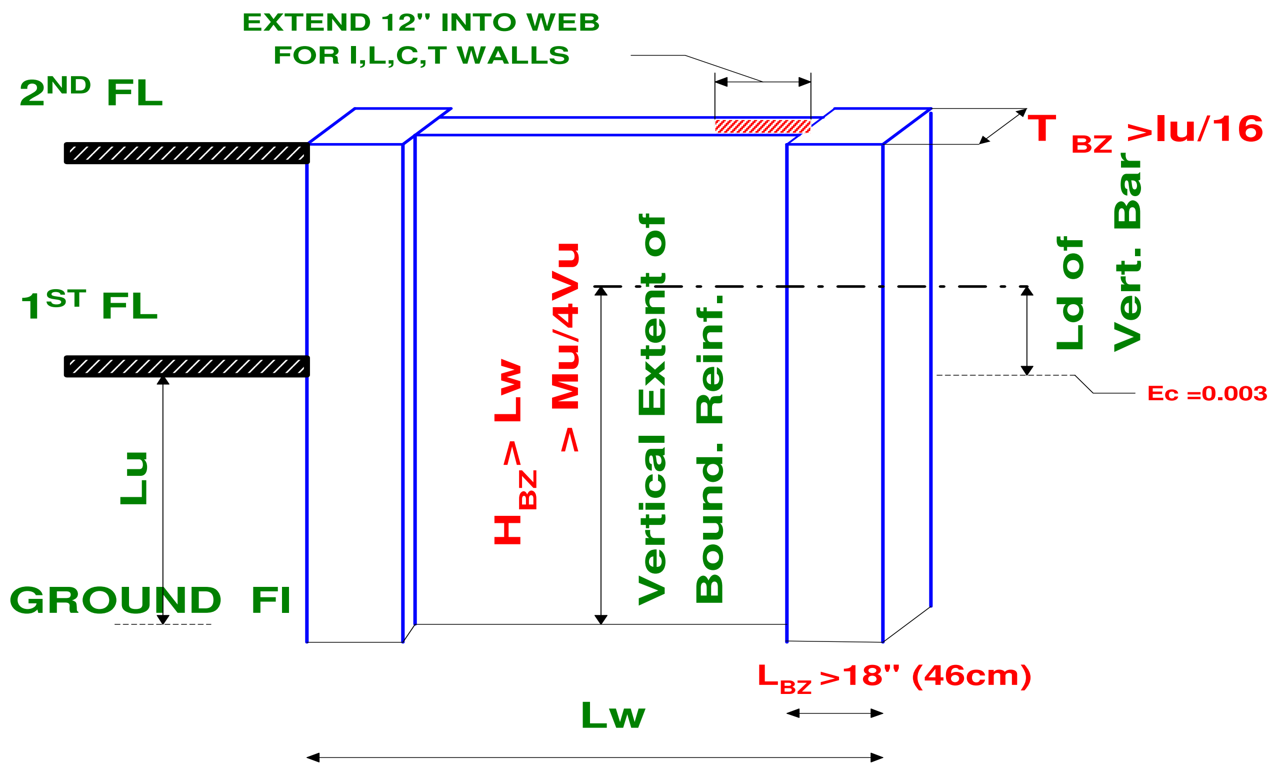
- **THE COMPRESSIVE STRAIN ALONG COMPRESSIVE BLOCK IN THE WALL MAY BE ASSUMED VARY LINEARLY OVER THE DEPTH Cu' WITH A MAXIMUM VALUE EQUAL TO**

$$\varepsilon_{cmax} = (Cu' \times \phi_t)$$

- **THE COMPRESSIVE BLOCK LENGTH Cu' CAN BE DETERMINED USING STRAIN COMPATIBILITY AND REINFORCED CONCRETE SECTION ANALYSIS.**

D. BOUNDARY ZONE DETAILS

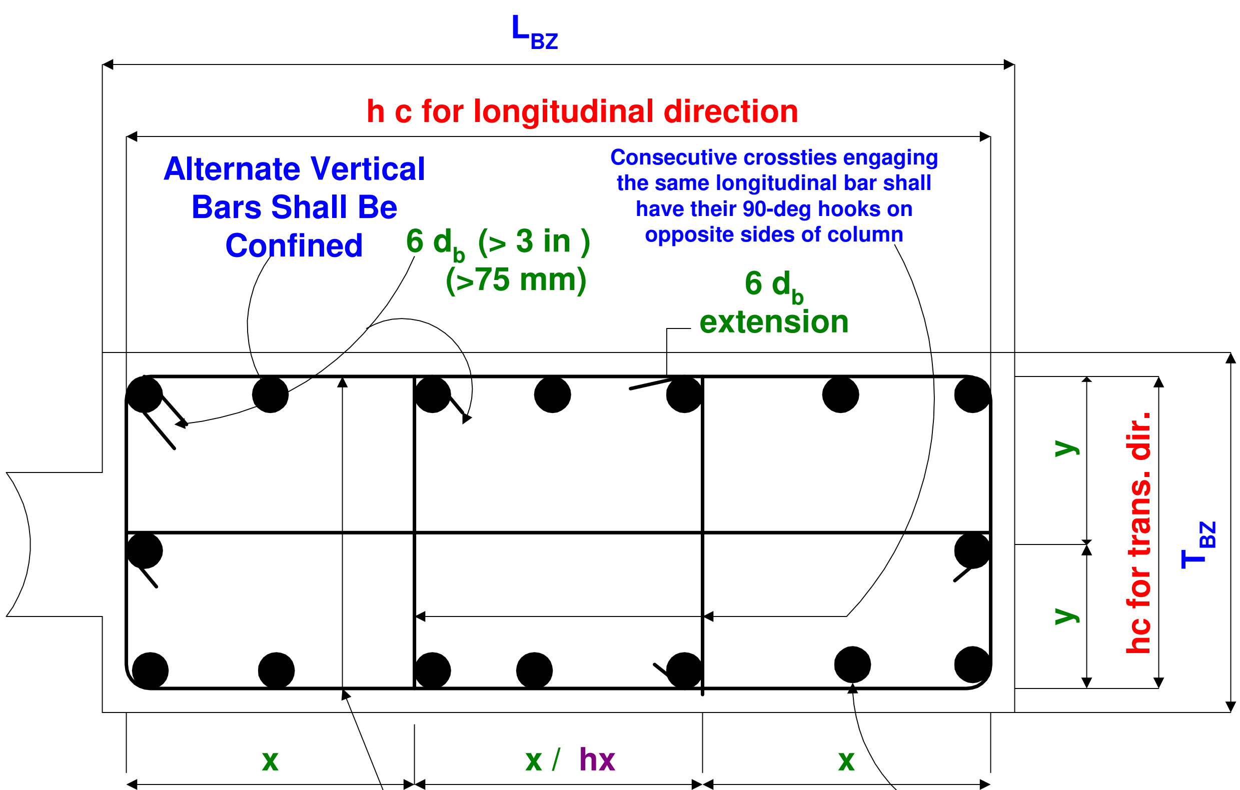
- **DIMENSIONAL REQUIREMENTS**



FOR L, C, I, OR T SHAPED WALL, THE BOUNDARY ZONE SHALL INCLUDE THE EFFECTIVE FLANGE AND SHALL EXTEND AT LEAST 12 INCHES [30 CM] INTO THE WEB

D. BOUNDARY ZONE DETAILS

- **CONFINEMENT REINFORCEMENT**



Minimum Hoops/Ties Area : Ash = 0.09 s hc fc'/fyh with vertical spacing Sv < 6"(15 cm) or 6xDIA of vertical bars

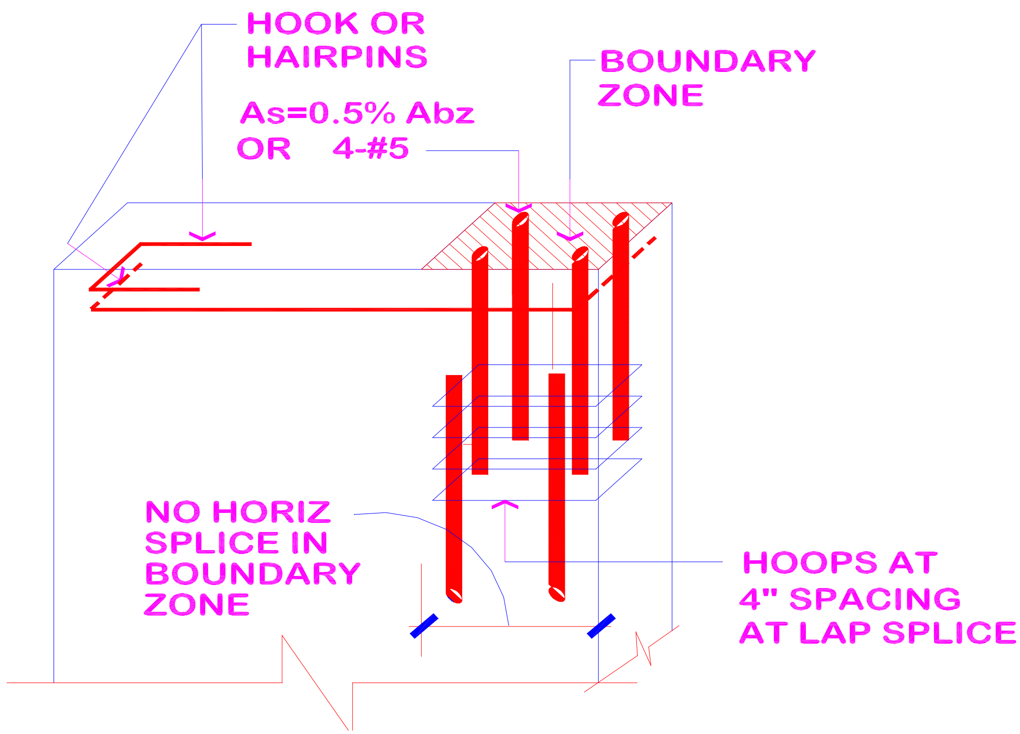
As > 0.005 L_{BZ} T_{BZ} with minimum 4 -# 5(DIA 16 mm)

Notes:

1. Per UBC:
   'x' or 'y' < 12 inches (30 cm)
   Per - ACI
   ' hx' < 14 inches (35 cm)
2. Hoop dimensional ratio
   (3x/2y) or (2y/3x) <3
3. Adjacent hoops shall be overlapping
4. Per ACI:
   Sv < Tbz / 4
   Sv < 4 +[(14-hx)/3]
   in inches
   < 10 + [(35-hx)/3]
   in cm

D. BOUNDARY ZONE DETAILS

- REINFORCEMENT INSIDE BOUNDARY ZONE



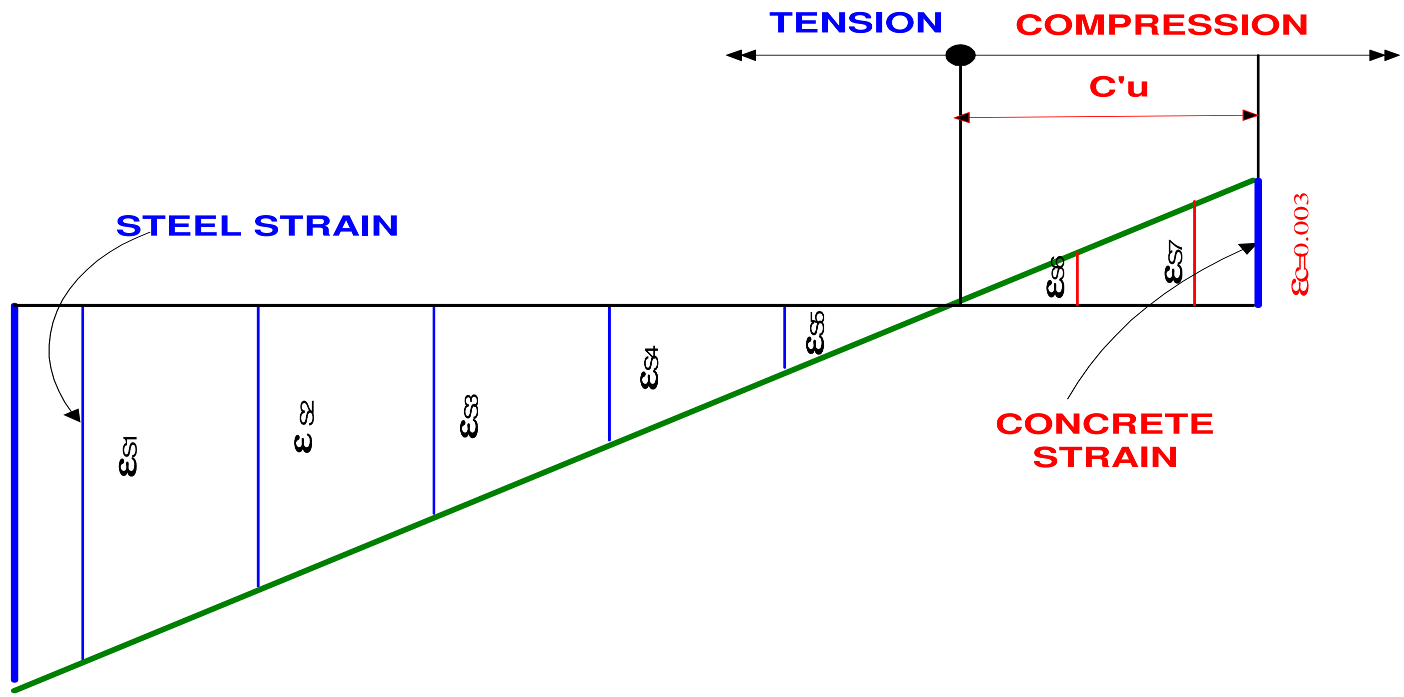
- NO WELDED SPLICE WITHIN THE PLASTIC HINGE REGION
- MECHANICAL CONNECTOR STRENGTH > 160 % OF BAR YIELD STRENGTH OR 95% Fu

STRAIN COMPATIBILITY ANALYSIS FOR ESTIMATING M'n and C'u

- **STRAIN DISTRIBUTION AT ♑$_{cy}$ = 0.003**

♑$_{si}$ > ♑$_{y}$: Tsi = As fy

♑$_{si}$ < ♑$_{y}$: Tsi = As fs WHERE fs = Es ♑$_{s}$



STRAIN COMPATIBILITY ANALYSIS

- **FORCE EQUILIBRIUM**

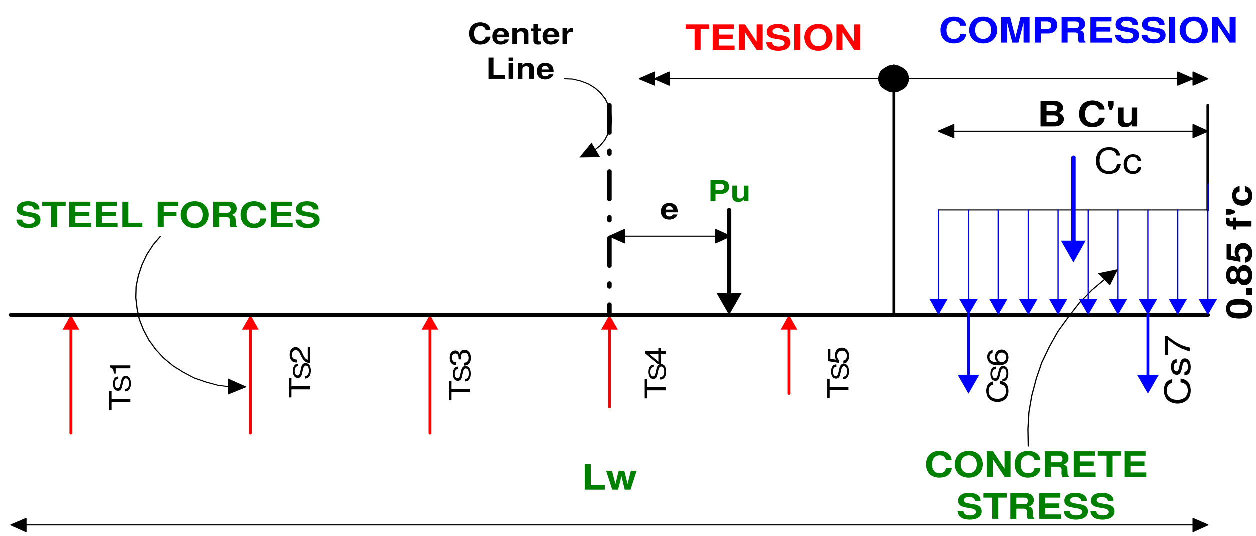
Pu + ☜ Tsi + ☜ Csi + Cc = 0

WHERE Pu = 1.2 D + 0.5 L + E AND Cc= 0.85 f'c B C'u

- **MOMENT EQUILIBRIUM**

M'n = ☜ Tsi X e_{si} + ☜ Csi X e_{si} + Cc e_c

- **SOLVE FOR Cu' THAT SATISFIES THE ABOVE EQUILIBRIUM.**



INTERNAL AND EXTERNAL FORCES ACTING ON WALL SECTION

SUMMARY

- TWO APPROACHES TO DETERMINE THE BOUNDARY ZONE
- THE SIMPLIFIED APPROACH IS BASED ON THE AXIAL FORCE, BENDING AND SHEAR OR FACTORED AXIAL STRESSES IN THE WALL
- THE RIGOROUS APPROACH INVOLVES DISPLACEMENT AND STRAIN CALCULATIONS
- ACI/IBC EQUATIONS ARE SIMPLER THAN UBC EQUATIONS
- COMPUTER AIDED CALCULATIONS ARE REQUIRED FOR THE RIGOROUS APPROACH
- SHEAR WALL DESIGN SPREADSHEET

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