The main factors affecting column strengthening using linear analysis in high seismic regions

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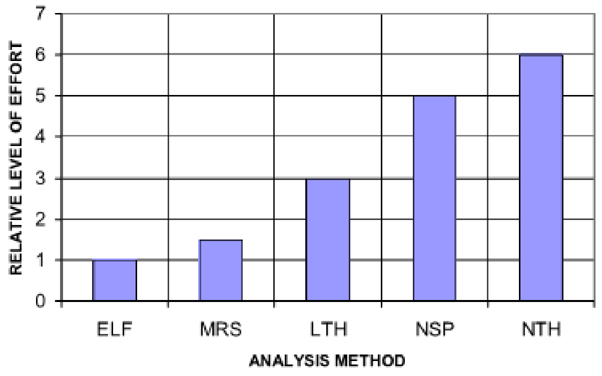
Fundamentals of Seismic Analysis & Design

- Seismic Design (and Analysis) is as much an art as it is a science.

Structural Analysis

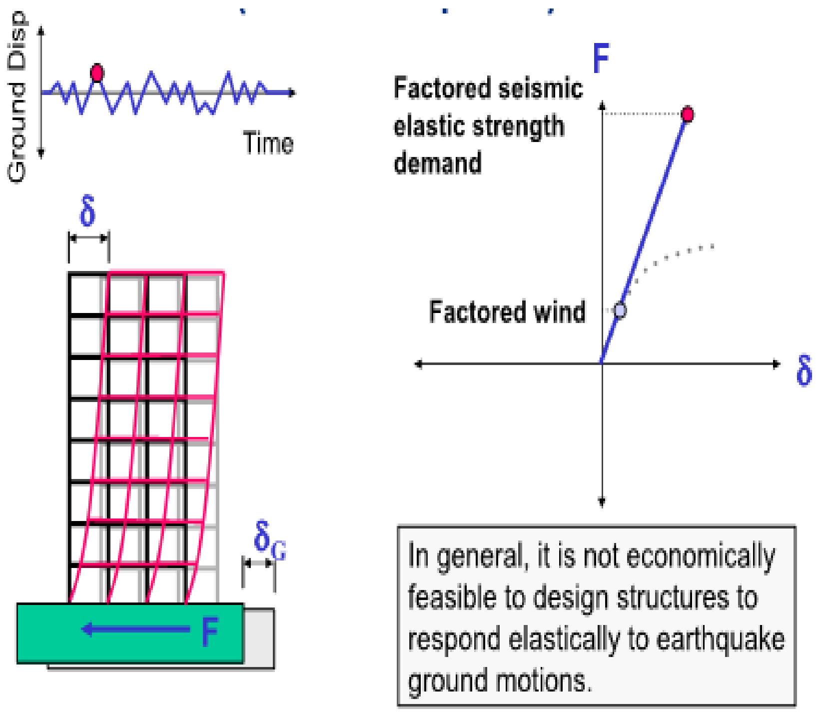
- The forces required to proportion members
- Global deformations
- Equivalent lateral force (ELF) analysis
- Modal response spectrum (MRS) analysis (Good enough for design)
- Linear time history (LTH) analysis
- Nonlinear static pushover (NSP) analysis
- Nonlinear dynamic time history (NTH) analysis

Structural Analysis: Relative Level of Effort



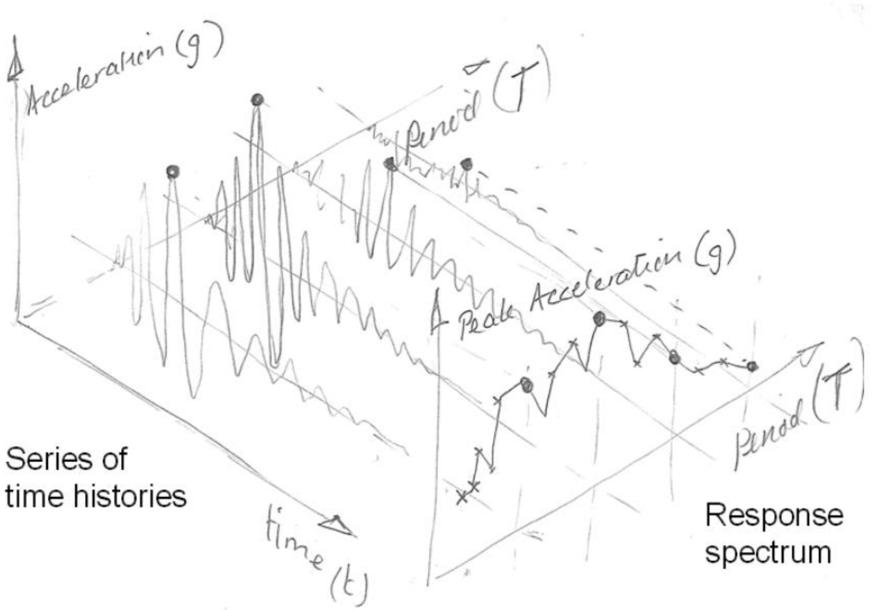
Earthquake

- Loading and response are truly dynamic
- Structural system deforms as a result of inertia forces
- Excitation is an applied displacement at the base
- Deformations are fully reversed
- Structure is designed to respond inelastically under factored loads
- Controlling life safety limit state is deformability
- Enough strength is provided to ensure that inelastic deformation demands do not exceed deformation capacity



Factors affecting columns strengthening

- Seismic demand and load combinations (BSE1E, BSE2E)
- Material properties
- Column Geometry and slenderness (P-Δ amplification)
- Strengthening Technique (Concrete/steel jacketing, FRP)
- Stiffness and Load redistribution (increase demand on adjacent members)
- Overturning moments
- P-Δ Effects
- Foundation capacity
- Interstory drift and deflection limits
- Member connectivity and joint strength
- Drift ratio of individual column based on simplified M-ϕ curve (ϕH/2)
- Linear analysis limitation (Irregularities, Non ductile detailing, Post-yield behavior)



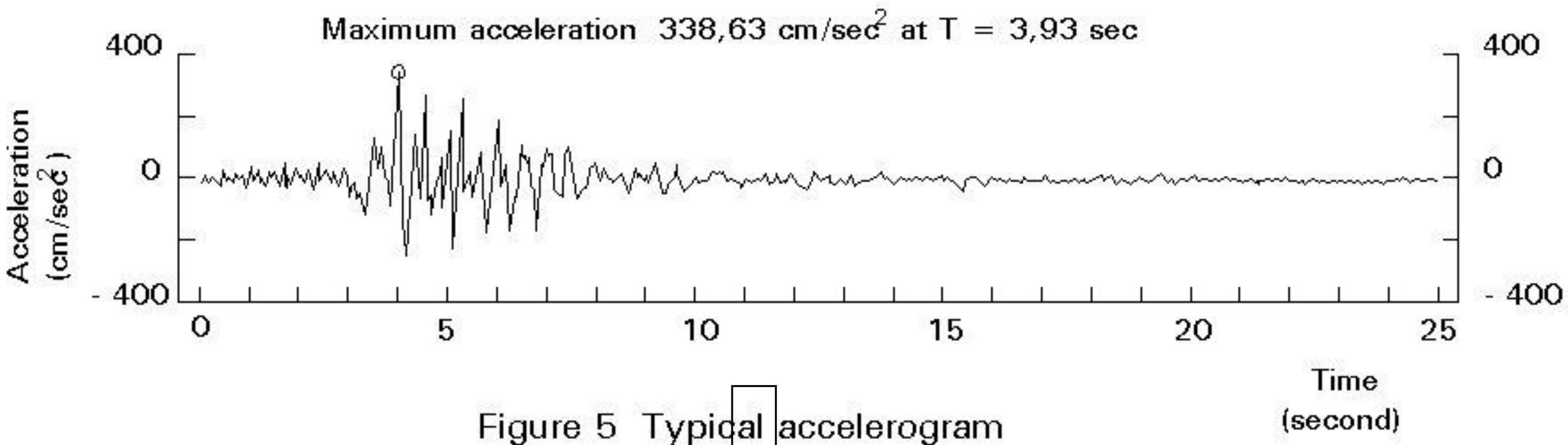


Figure 5 Typical accelerogram

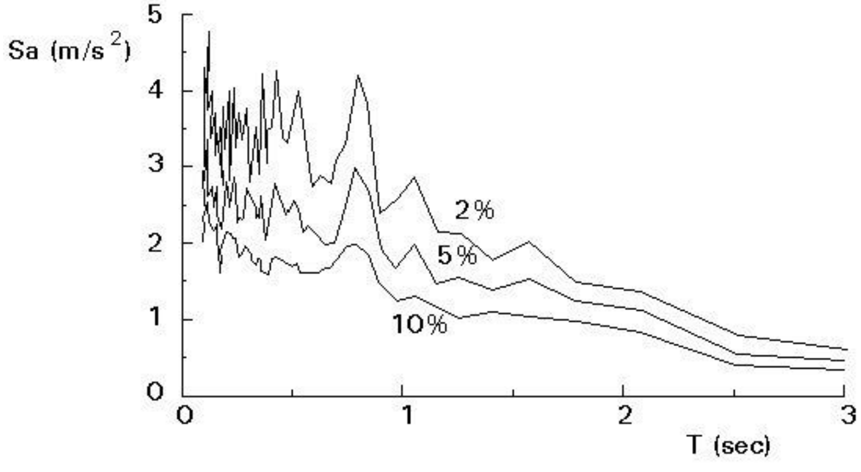
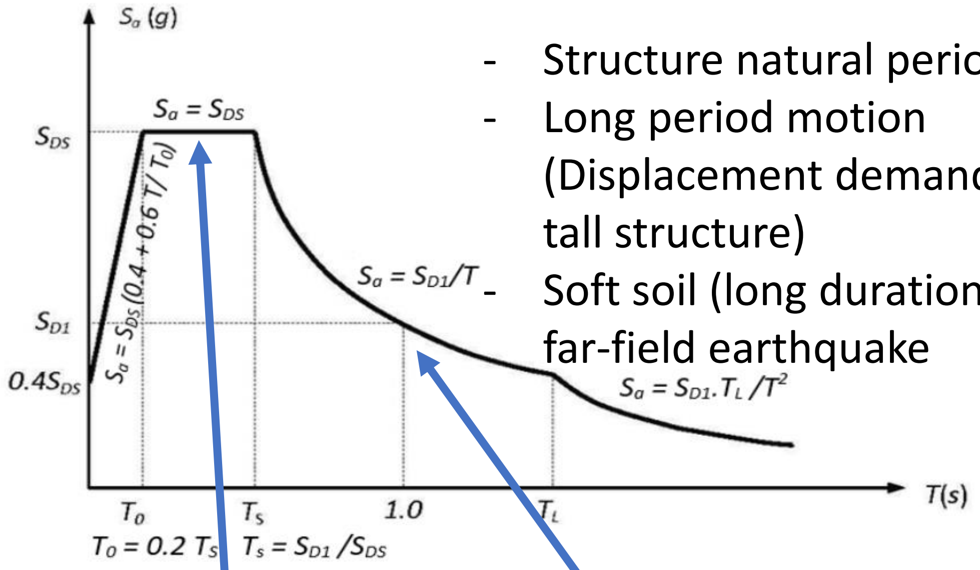


Figure 7 Typical acceleration response spectrum



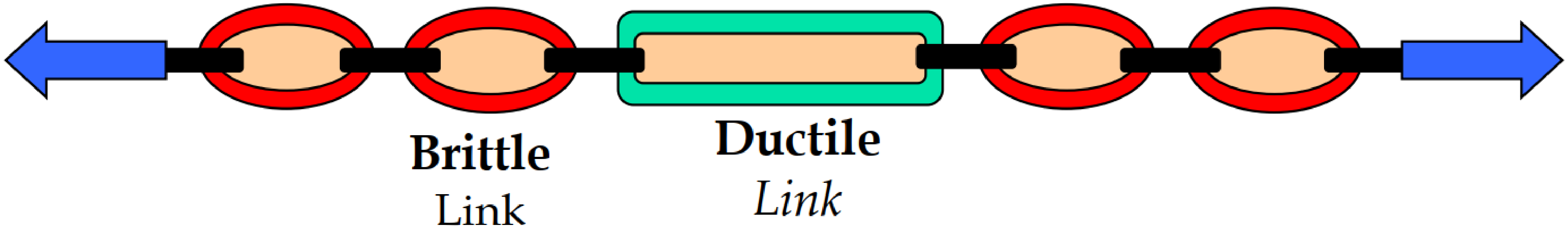
- Structure natural period
- Long period motion (Displacement demand in tall structure)
- Soft soil (long duration and far-field earthquake

Resonance lead to high forces

Resonance lead to high displacement

At resonance, natural period of building matches dominant frequency of ground shaking. The building vibrates in sync with the ground. Amplified motion and very high internal forces.

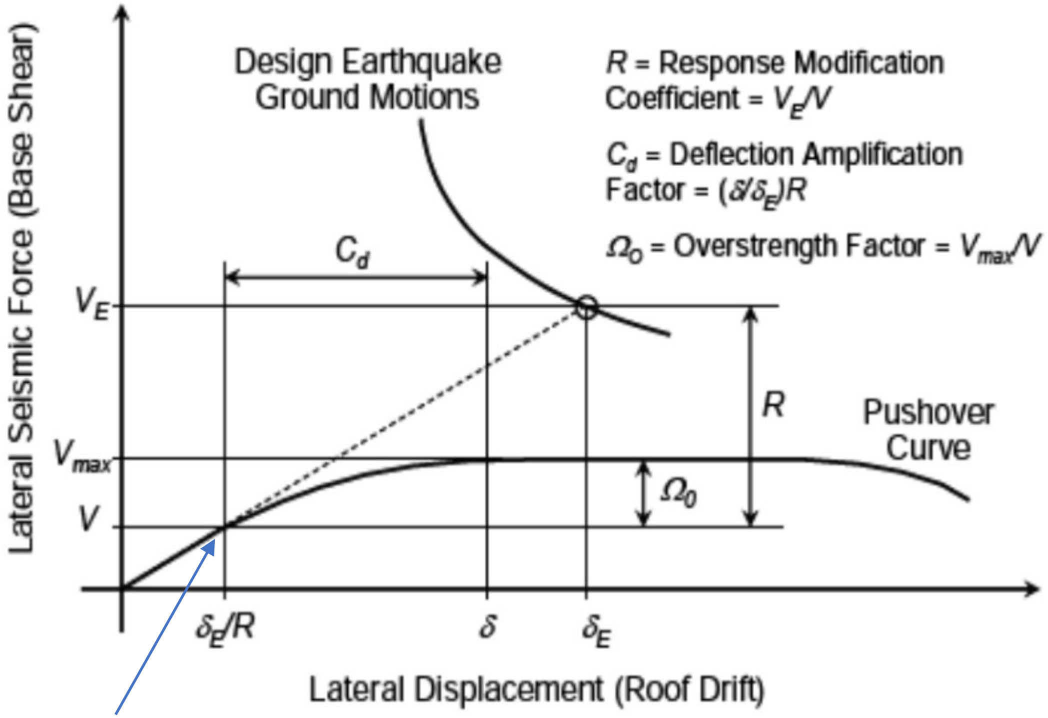
Capacity Design Concept



The chain has both ductile and brittle elements.

To ensure ductile failure, we must ensure that the ductile link yields before any of the brittle links fails.

Engineer designs where and how nonlinear response will occur. ↔ Capacity design is a pre-requisite to nonlinear analysis.

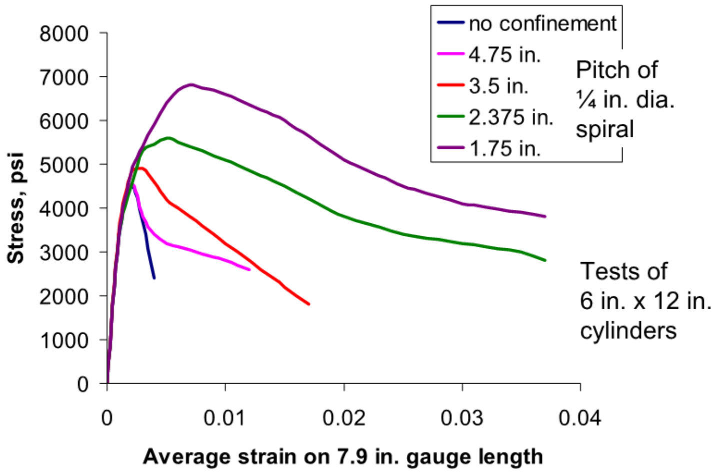


First plastic hinge in beam

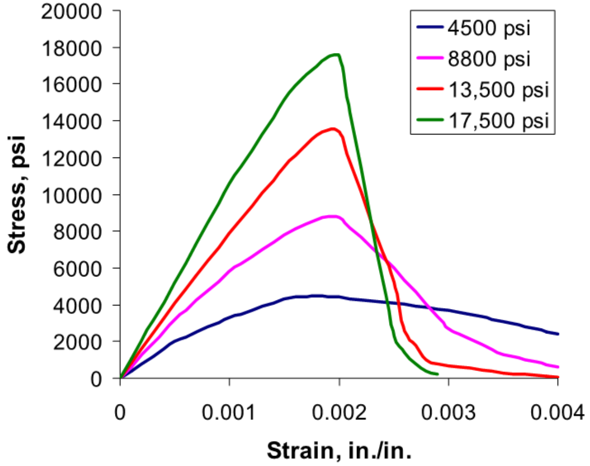
R = Reduces elastic seismic forces to account for ductility
Ωo= Increase force for brittle/non-yielding elements (collectors, anchorage, diaphragms, etc.,) that must remain elastic when other yield
Cd= Amplifies elastic displacements for drift checks
ρ= Increases force demand for non-redundant systems

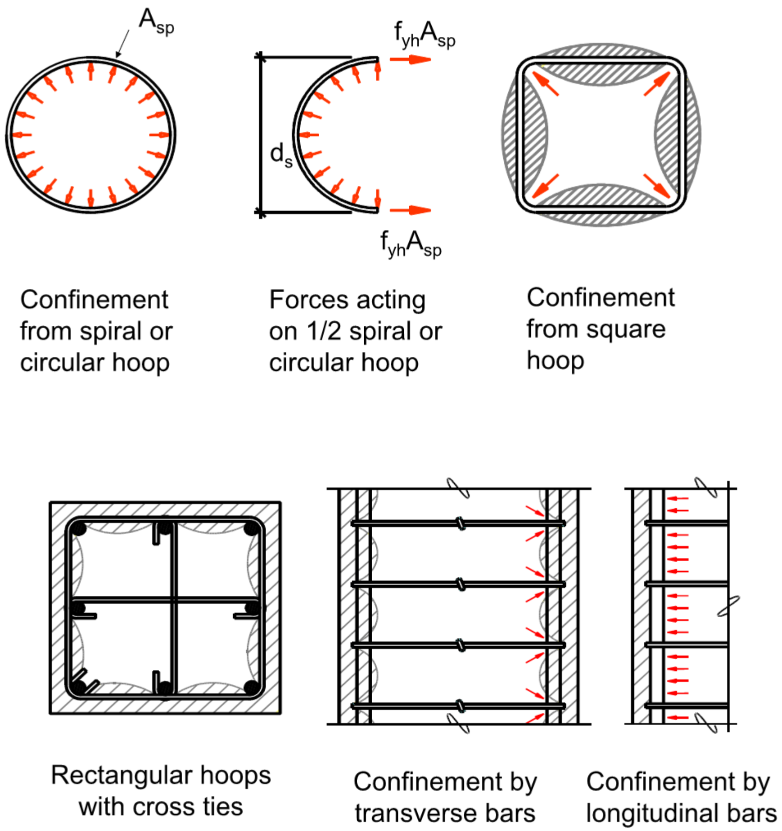
- Overstrength factor
  - Material overstrength
  - Structural redundant and redistribution
  - Geometric confinement
  - Reserve capacity beyond design loads

Confined Concrete Stress-Strain Behavior

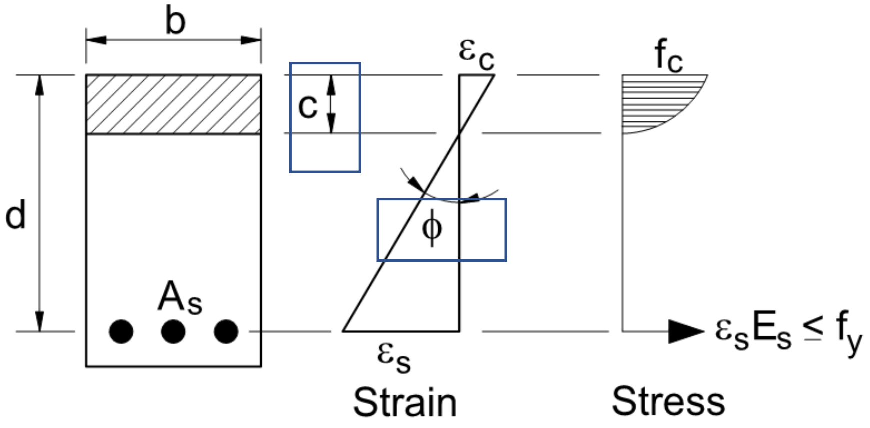


Unconfined Concrete Stress-Strain Behavior

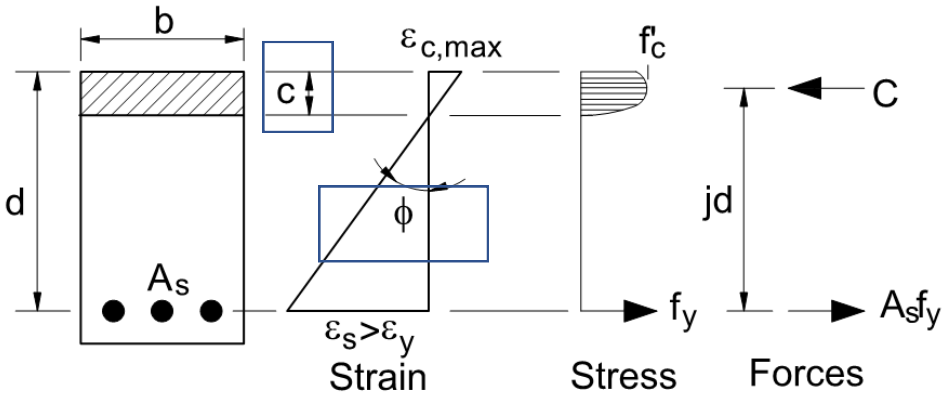




Behavior Up to First Yield of Steel

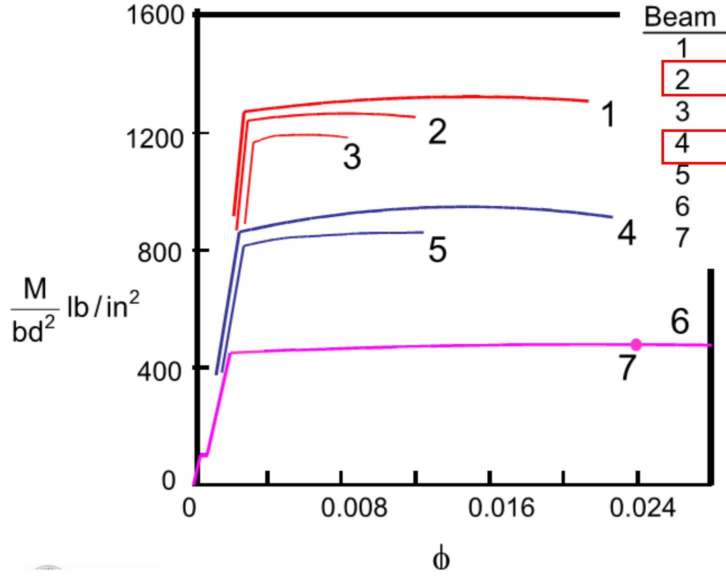


Behavior at Concrete Crushing



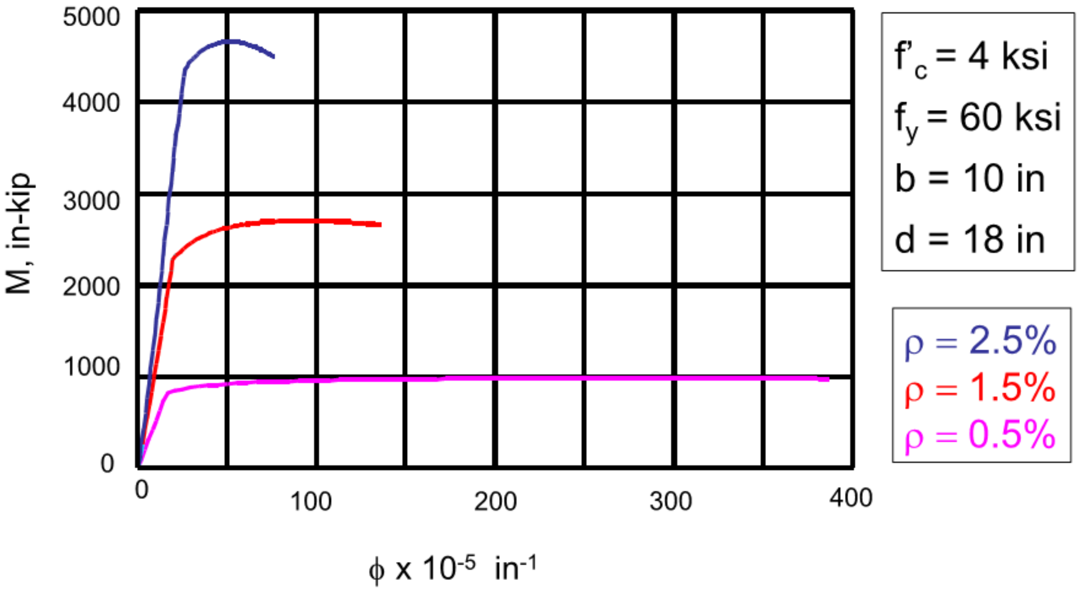
$$M_n = A_s f_y jd$$

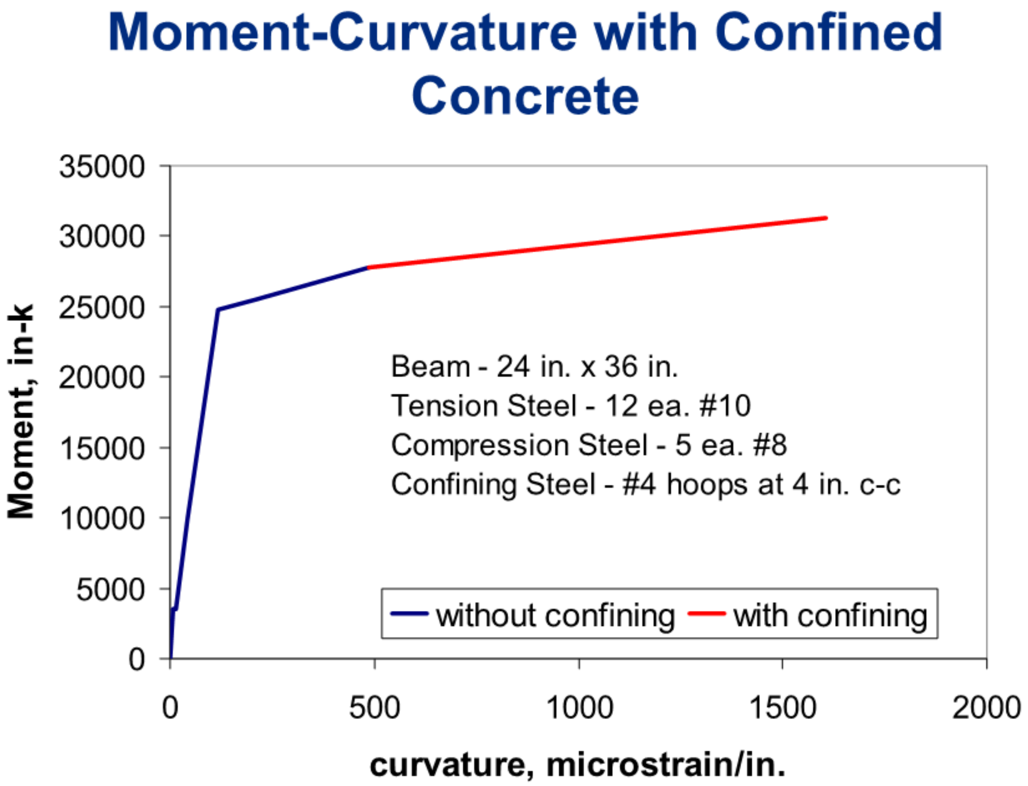
Influence of Compression Reinforcement



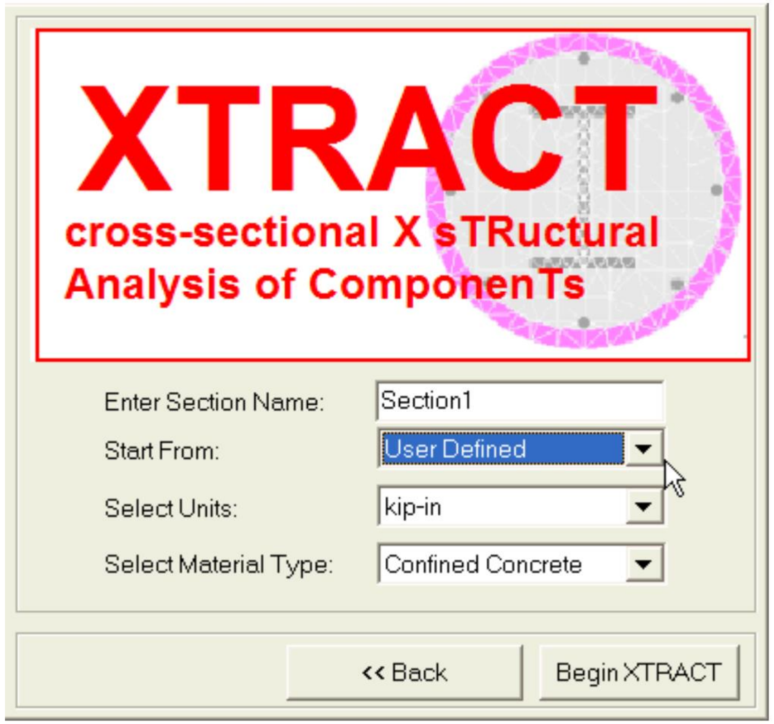
Beam	ρ	ρ'	
1	0.0375	0.0250	
2	0.0375	0.0125	IMRF
3	0.0375	0	
4	0.0250	0.0125	SMRF
5	0.0250	0	
6	0.0125	0.0125	
7	0.0125	0	

Influence of Reinforcement Ratio





Moment-Curvature with Confined Concrete
35000
30000
25000
20000
15000
10000
5000
0
Moment, in-k
0
500
1000
1500
2000
curvature, microstrain/in.
Beam - 24 in. x 36 in.
Tension Steel - 12 ea. #10
Compression Steel - 5 ea. #8
Confining Steel - #4 hoops at 4 in. c-c
without confining
with confining



XTRACT
cross-sectional X sTRuctural
Analysis of ComponenTs
Enter Section Name:
Section1
Start From:
User Defined
Select Units:
kip-in
Select Material Type:
Confined Concrete
<< Back
Begin XTRACT

Strategies to Improve Ductility

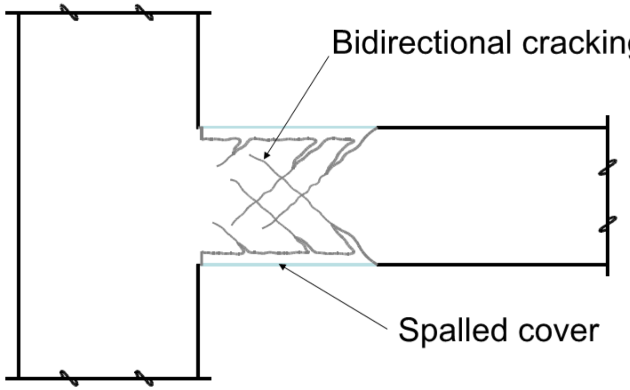
- Use low flexural reinforcement ratio
- Add compression reinforcement
- Add confining reinforcement

Performance Objectives

- **Strong column**
  - Avoid story mechanism
- **Hinge development**
  - Confined concrete core
  - Prevent rebar buckling
  - Prevent shear failure
- **Member shear strength**
- **Joint shear strength**

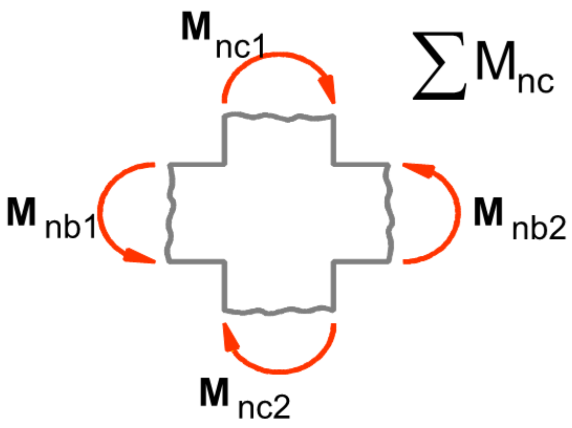
Hinge Development

- **Tightly Spaced Hoops**
  - Provide confinement to increase concrete strength and usable compressive strain
  - Provide lateral support to compression bars to prevent buckling
  - Act as shear reinforcement and preclude shear failures
  - Control splitting cracks from high bar bond stresses



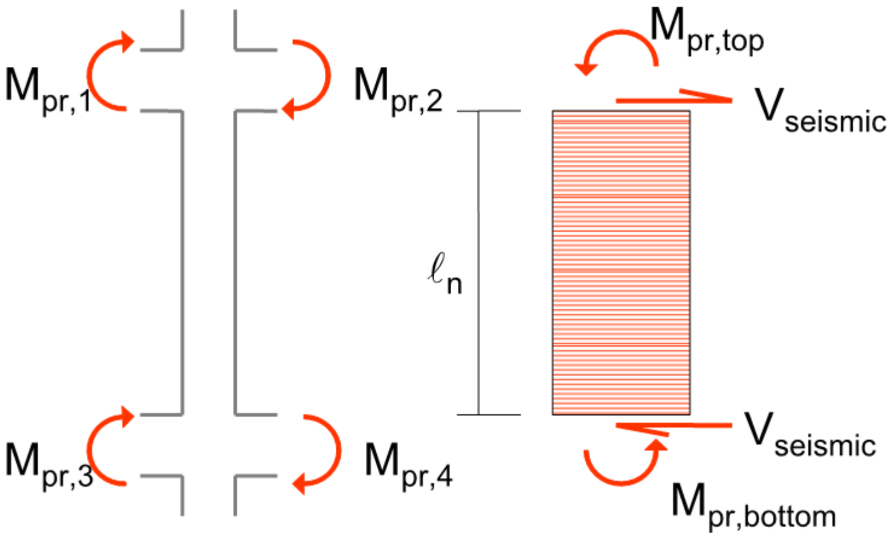
Column Strength

Required Column Strength



$$\sum M_{nc} \geq 1.2 \sum M_{nb}$$

Determine Seismic Shear



Evaluation of member shear strength capacity (Column)

INPUT DATA

Concrete column section properties

fc' =	44.625	Mpa or	6341.48	psi
bw =	300	mm or	12	in
d =	600	mm or	24	in

Shear reinforcement properties

fy = 575 Mpa (shear strength)
n (no of shear legs) = 2
phi (diameter of shear links) = 10 mm
s (spacing of shear reinforcement) = 300 mm

Column axial force (minimum based on various load combination)

N = 500 kN or 110130 Pound

Parameter

lamda =	0.75	for lightweight aggregate concrete
	1	for normal weight concrete

CALCULATION

Vc =	95618.03	Pound or	434.1058	kN
Vs =	301.0693	kN		
V(total) =	735.1751	kN		

Evaluation of member shear strength capacity (Beam)

INPUT DATA

Concrete beam section properties

fc' =	44.625	Mpa
bw =	300	mm
d =	600	mm

Shear reinforcement properties

fy = 575 Mpa (shear strength)
n (no of shear legs) = 2
phi (diameter of shear links) = 10 mm
s (spacing of shear reinforcement) = 300 mm

CALCULATION

Vc =	199.6042	kN
Vs =	180.6416	kN
V(total) =	380.2458	kN

Joint shear demand will obviously be more

- More beams flexural steel
- More rebar strength
- Lower concrete grade

Seismic Demand/Capacity Ratio Checks on Beam-Column Joint

Input

Joint depth (column section depth in direction of framing) =	700	mm	
Joint width =	300	mm	
fc' =	41.65	Mpa	c35
M1 =	500	kNm	
M2 =	400	kNm	
As1 =	1000	mm2	
As2 =	600	mm2	
fy =	552	MPa	460 bar
L1 =	5000	mm	
L1n =	4700	mm	
L2 =	5000	mm	
L2n =	4700	mm	
Lc =	2800	mm	
Lc' =	2800	mm	

Joint shear strength capacity

lamda =	0.75	for lightweight aggregate concrete
	1	for normal weight concrete
gamma =	15	please check ATC-40 report Table 9-5 FEMA 6-10
Aj =	210000	mm2
Vn =	1687.315	kN

Joint shear demand

T =	690	kN
T1=	414	kN
Vcol =	341.9453	kN
Vjh =	762.0547	kN

Joint shear DCR

DCR=	0.451638

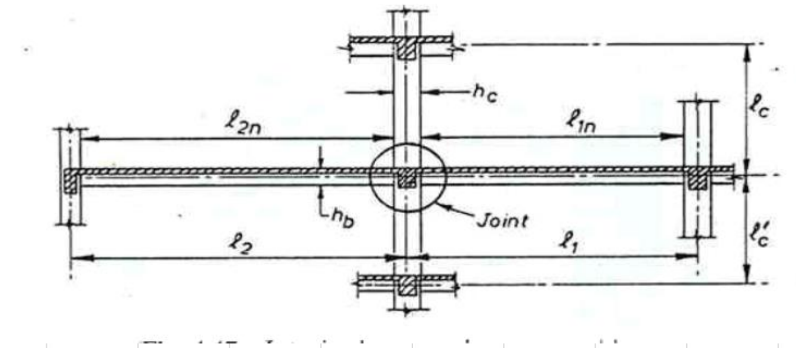


Fig 1. Typical Beam-Column Joint

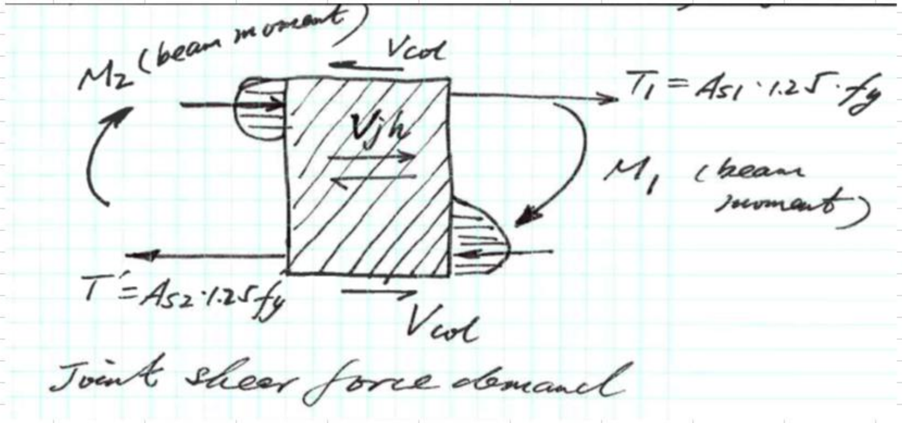


Fig 2. Joint Shear Force Demand Calculation

Thank You