A New Approach
to
Design for Stability

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A New Approach
to
Design for Stability

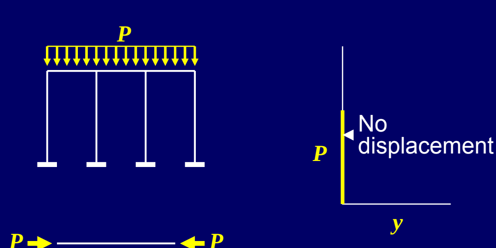
as reflected in the
Stability and Analysis Provisions
of the
2005 AISC Specification

- *What is stability?*
- *How have we been designing for it?*
- *Why do we need to change?*

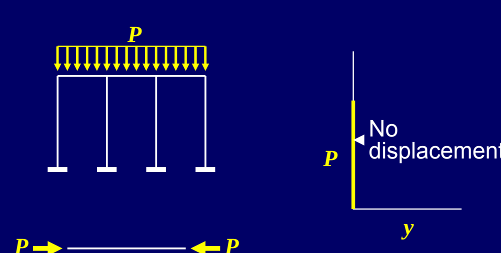
- *The new approach*

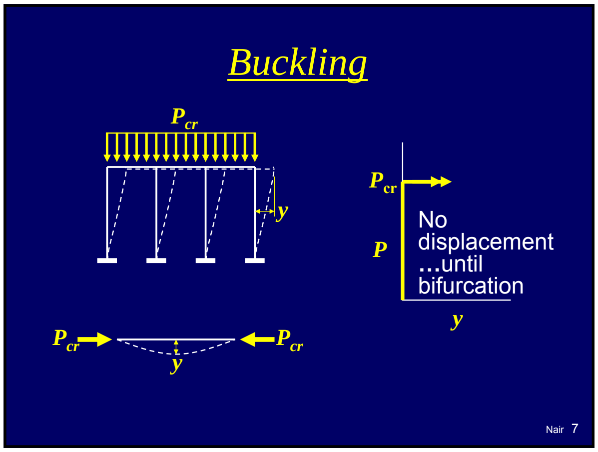
What is stability?

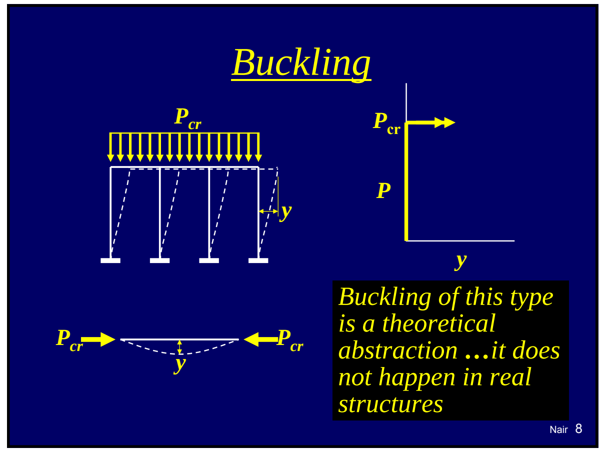
Buckling

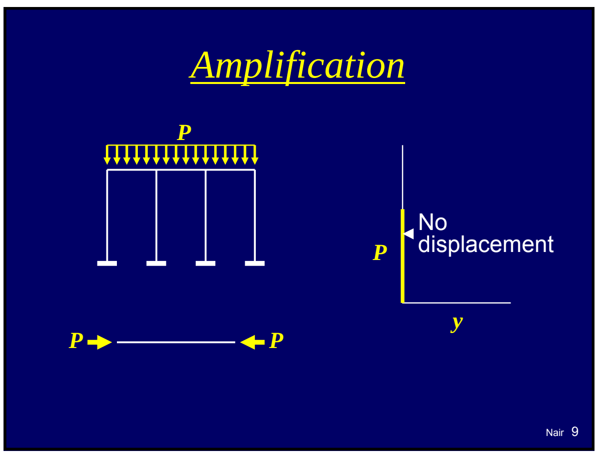


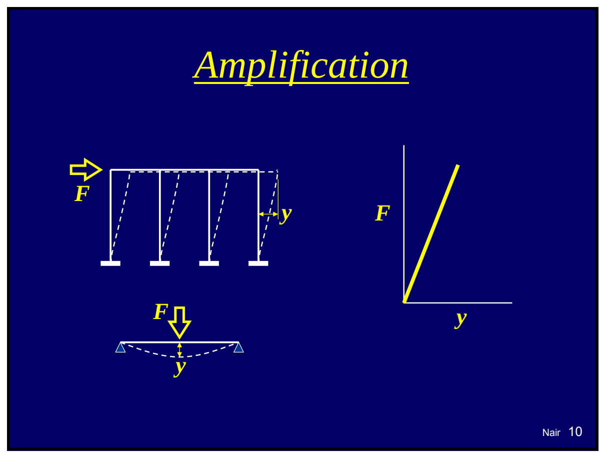
Buckling

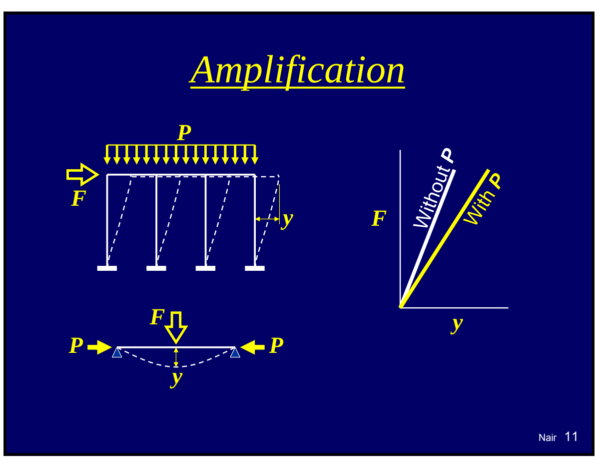


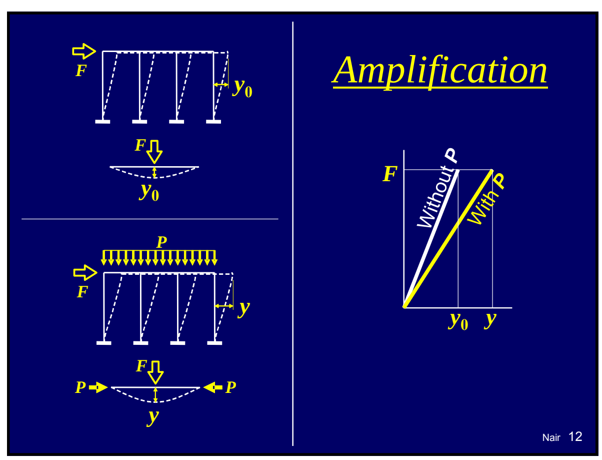

Buckling
Pcr
y
Pcr
P
No displacement …until bifurcation
y
Pcr
Pcr
y
Nair 7

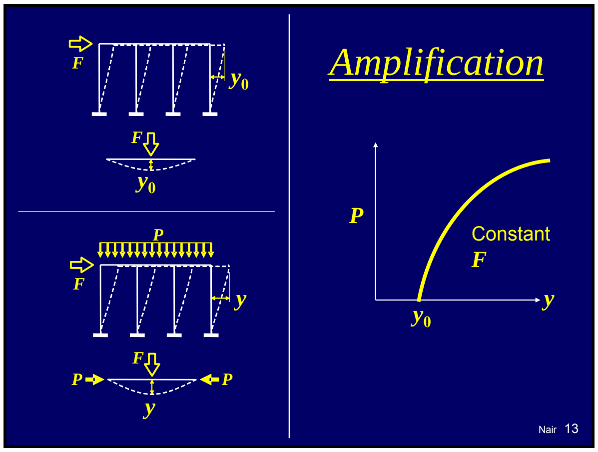

Buckling
Pcr
y
Pcr
P
y
Pcr
Pcr
y
Buckling of this type is a theoretical abstraction …it does not happen in real structures
Nair 8

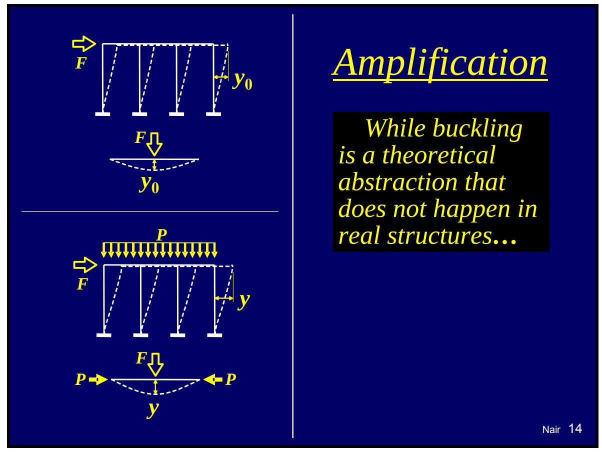

Amplification
P
P
No displacement
y
P
P
Nair 9

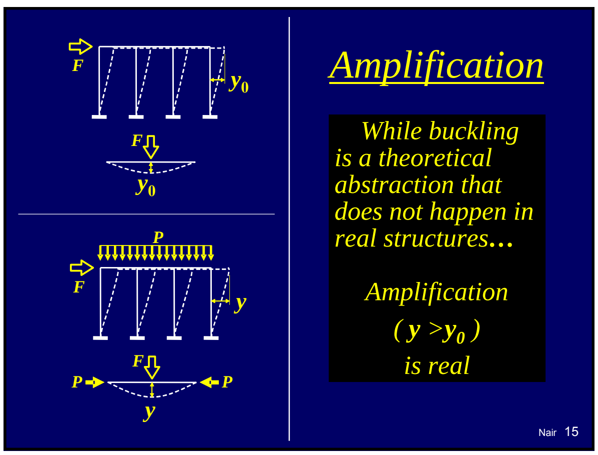

Amplification
F
y
F
y
F
y
Nair 10

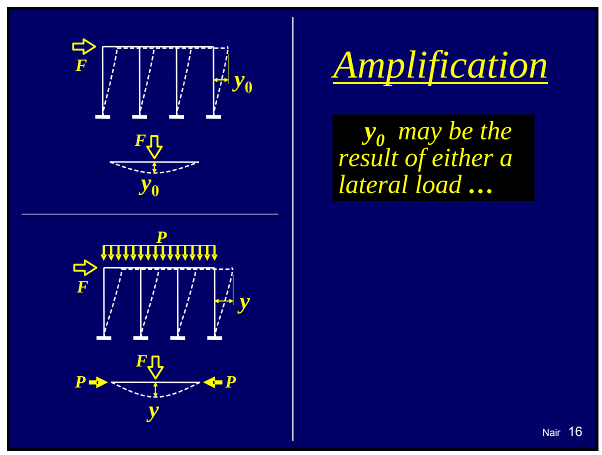

Amplification
P
F
y
F
Without P
With P
y
F
P
P
y
Nair 11

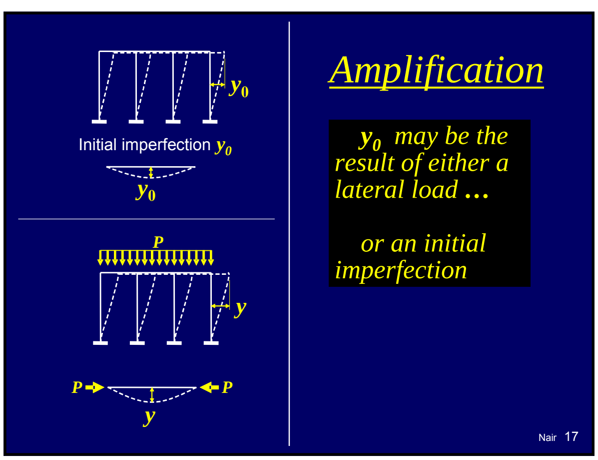

F
y0
F
y0
P
F
y
F
P
P
y
Amplification
F
Without P
With P
y0
y
Nair 12

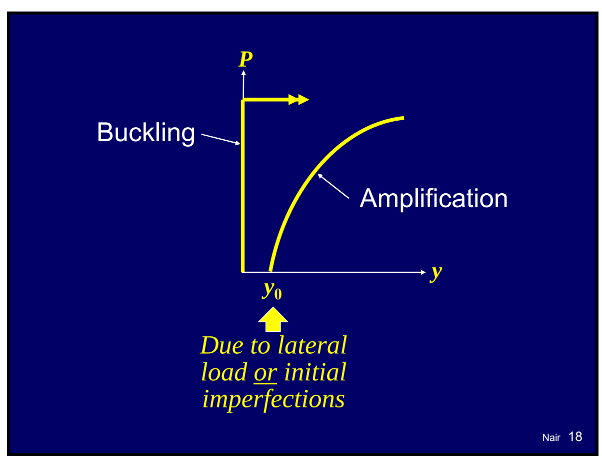

Amplification
F
y_0
F
y_0
P
F
y
F
P
P
y
P
Constant
F
y_0
y
Nair 13

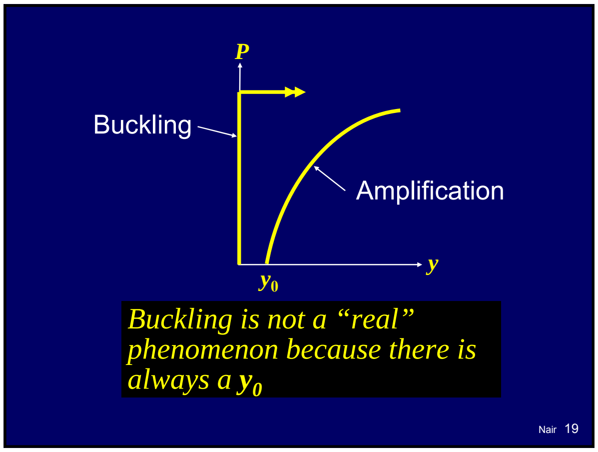

Amplification
While buckling is a theoretical abstraction that does not happen in real structures…
F
y_0
F
y_0
P
F
y
F
P
P
y
Nair 14

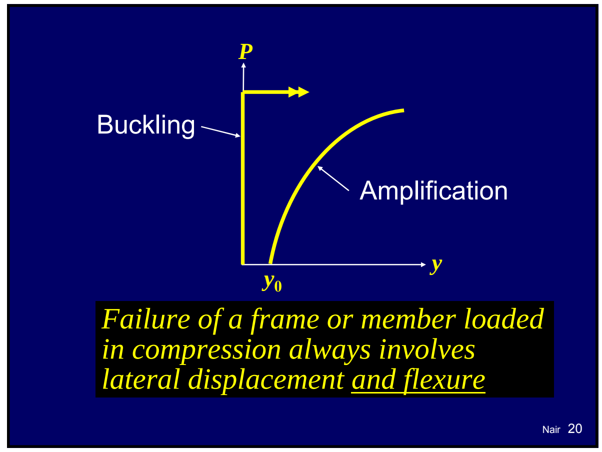

Amplification
While buckling is a theoretical abstraction that does not happen in real structures…
Amplification
$(y > y_0)$
is real
F
y_0
F
y_0
P
F
y
F
P
P
y
Nair 15

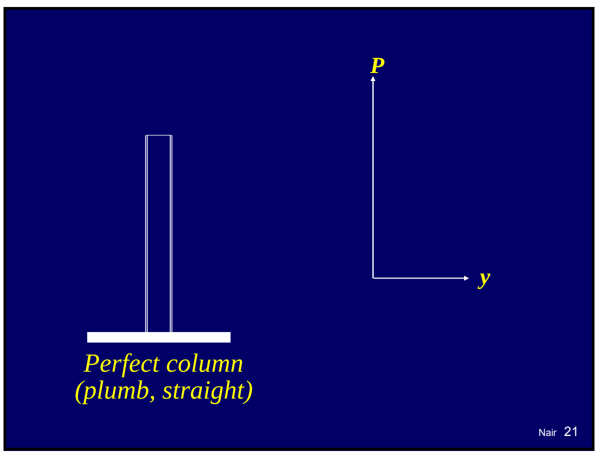

Amplification
y_0 may be the result of either a lateral load …
F
y_0
F
y_0
P
F
y
F
P
P
y
Nair 16

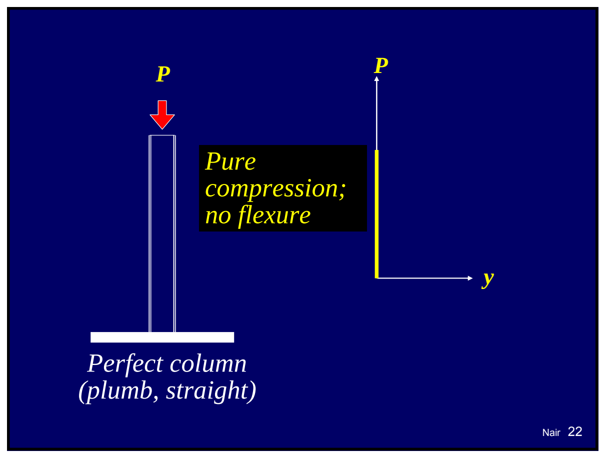

Amplification
y_0 may be the result of either a lateral load …
or an initial imperfection
y_0
Initial imperfection y_0
y_0
P
y
P
P
y
Nair 17

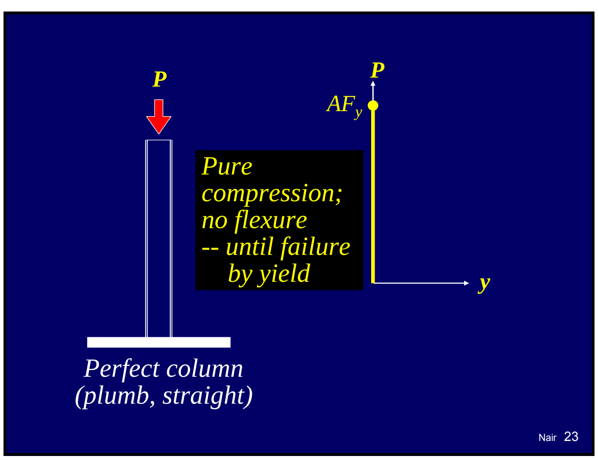

P
Buckling
Amplification
y
y_0
Due to lateral load or initial imperfections
Nair 18

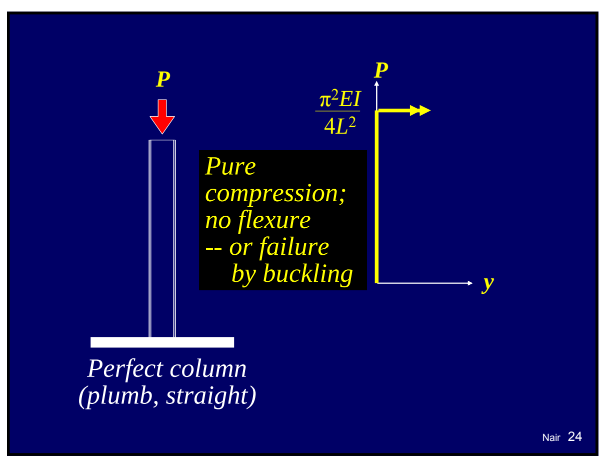

P
Buckling
Amplification
y
y_0
Buckling is not a "real" phenomenon because there is always a y_0
Nair 19

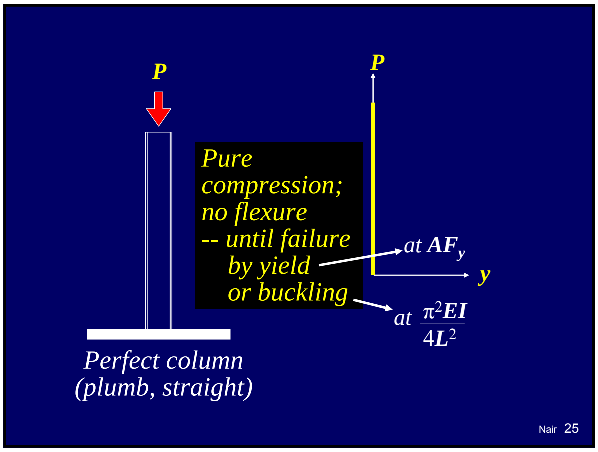

P
Buckling
Amplification
y
y_0
Failure of a frame or member loaded in compression always involves lateral displacement and flexure
Nair 20

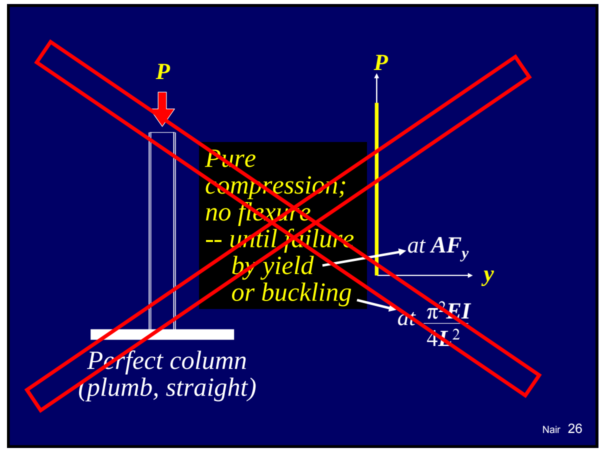

P
y
Perfect column (plumb, straight)
Nair 21

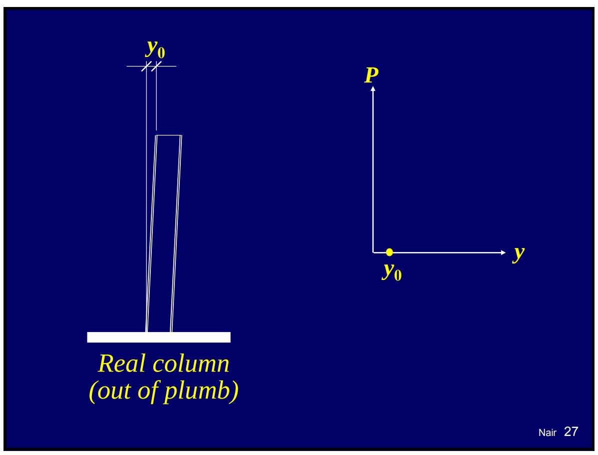

P
P
Pure compression; no flexure
y
Perfect column (plumb, straight)
Nair 22

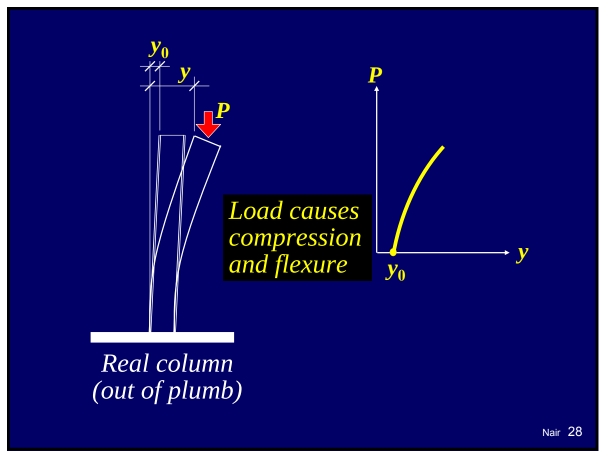

P
P
AF_y
Pure compression; no flexure -- until failure by yield
y
Perfect column (plumb, straight)
Nair 23

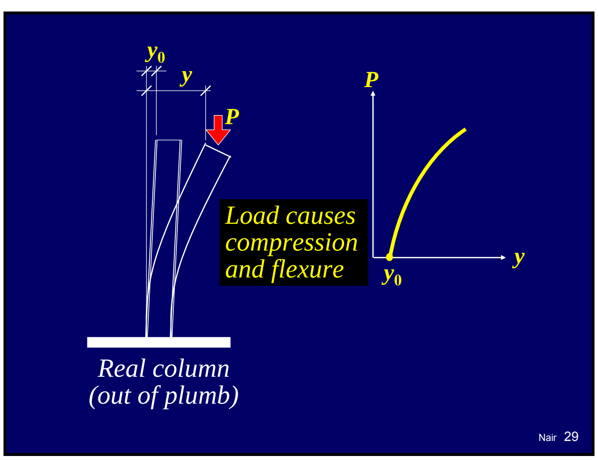

P
P
$\frac{\pi^2 EI}{4L^2}$
Pure compression; no flexure -- or failure by buckling
y
Perfect column (plumb, straight)
Nair 24

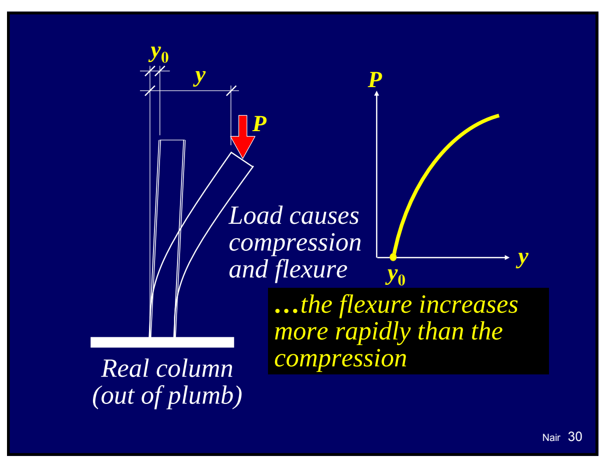

P
P
Pure compression; no flexure -- until failure by yield or buckling
at AF_y
y
at $\frac{\pi^2 EI}{4L^2}$
Perfect column (plumb, straight)
Nair 25

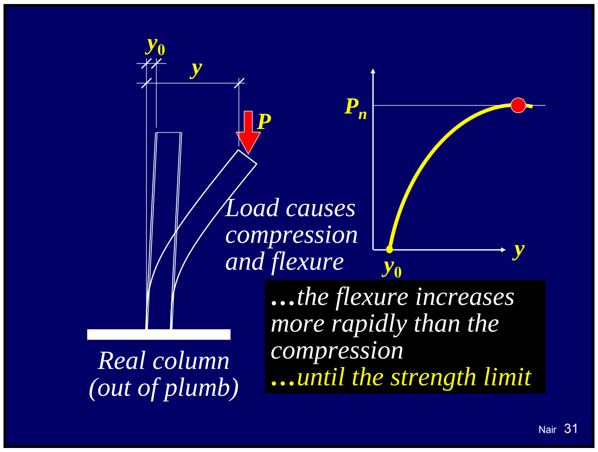

P
P
Pure compression; no flexure -- until failure by yield or buckling
at AF_y
y
at $\frac{\pi^2 EI}{4L^2}$
Perfect column (plumb, straight)
Nair 26


y_0
P
y
y_0
Real column (out of plumb)
Nair 27


y_0
y
P
P
Load causes compression and flexure
y
y_0
Real column (out of plumb)
Nair 28


y_0
y
P
P
Load causes compression and flexure
y
y_0
Real column (out of plumb)
Nair 29


y_0
y
P
P
Load causes compression and flexure
y
y_0
…the flexure increases more rapidly than the compression
Real column (out of plumb)
Nair 30



Failure of a "real" member loaded in "pure" compression is by:

…not crushing in compression ($\boldsymbol{AF_y}$)

Failure of a "real" member loaded in "pure" compression is by:

…not crushing in compression ($\boldsymbol{AF_y}$)

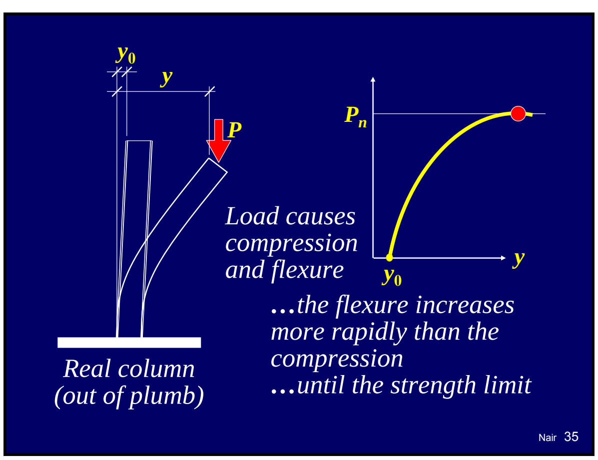
…not buckling ($\pi^2 \boldsymbol{EI}/(\boldsymbol{KL})^2$)

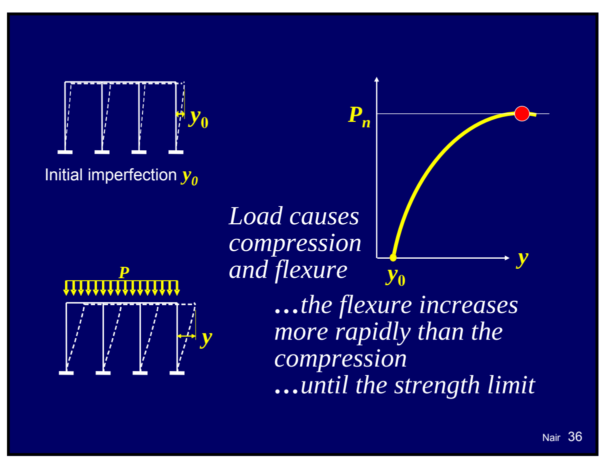
Failure of a "real" member loaded in "pure" compression is by:

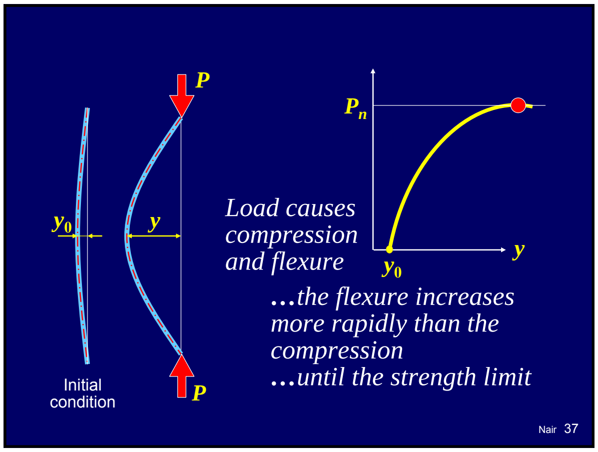
…not crushing in compression ($\boldsymbol{AF_y}$)

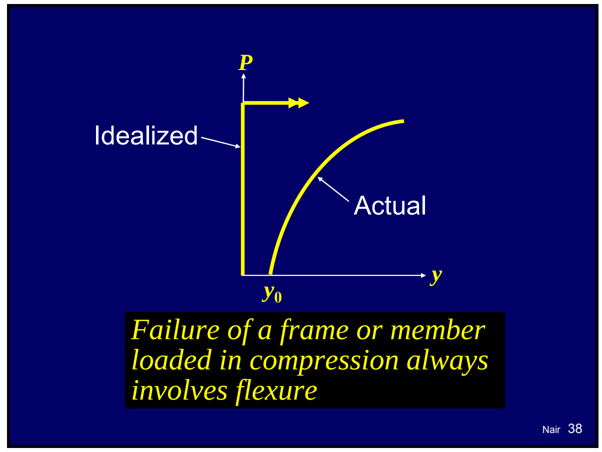
…not buckling ($\pi^2 \boldsymbol{EI}/(\boldsymbol{KL})^2$)

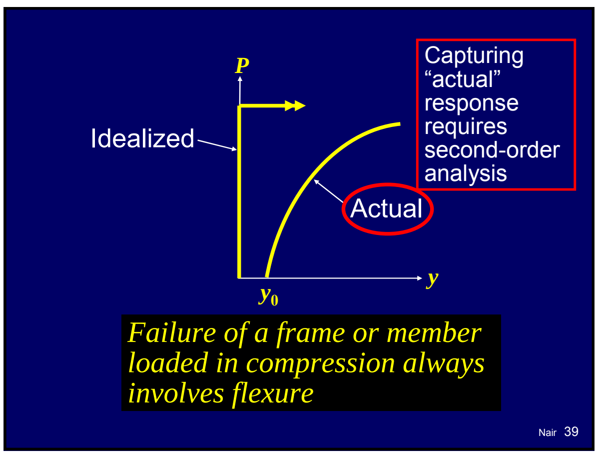
*…but compression & **flexure***

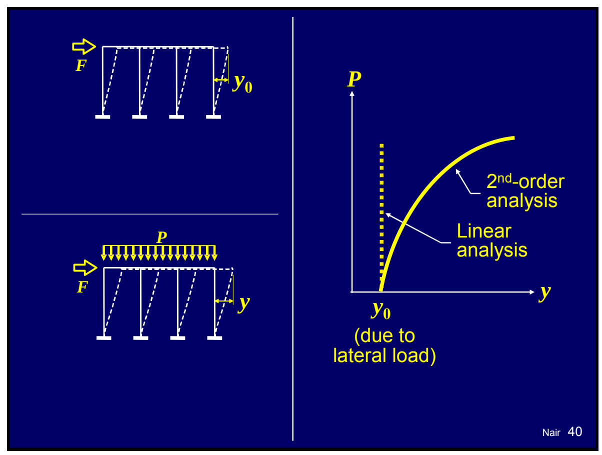


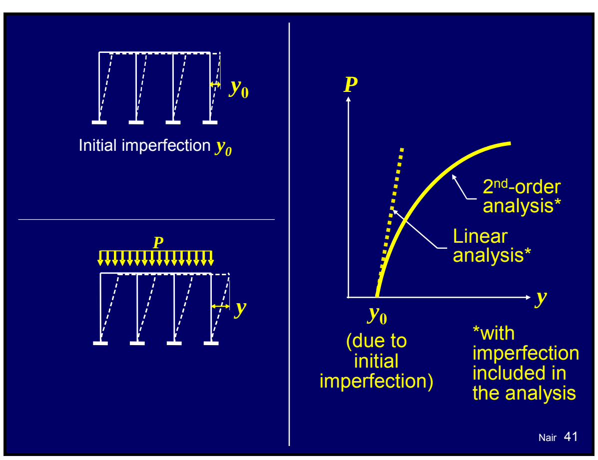


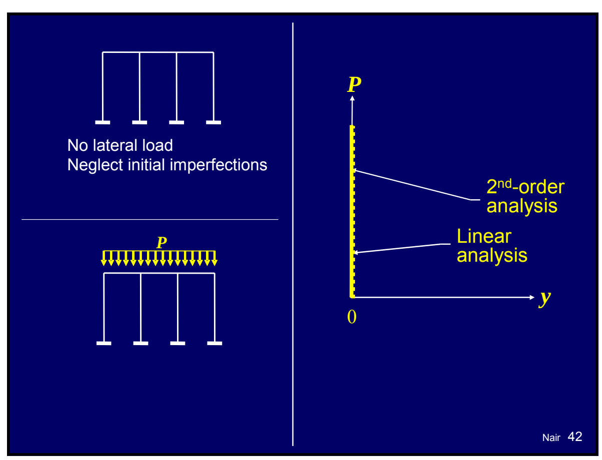

P
P_n
y_0
y
Initial condition
Load causes compression and flexure
y_0
y
…the flexure increases more rapidly than the compression
…until the strength limit
Nair 37

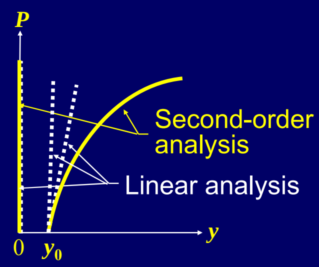

P
Idealized
Actual
y_0
y
Failure of a frame or member loaded in compression always involves flexure
Nair 38


P
Capturing "actual" response requires second-order analysis
Idealized
Actual
y_0
y
Failure of a frame or member loaded in compression always involves flexure
Nair 39

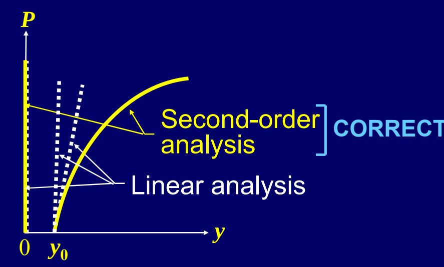

F
y_0
P
F
y
P
2nd-order analysis
Linear analysis
y_0
(due to lateral load)
y
Nair 40


y_0
Initial imperfection y_0
P
y
P
2nd-order analysis*
Linear analysis*
y_0
(due to initial imperfection)
y
*with imperfection included in the analysis
Nair 41

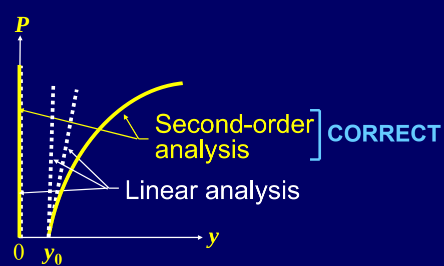

No lateral load
Neglect initial imperfections
P
P
2nd-order analysis
Linear analysis
0
y
Nair 42



Nair 43



Nair 44



Correct prediction of response also requires correct y_0
... including initial imperfections

Nair 45

For correct prediction of response:

- *Second-order analysis*
- *Correct* y_0 *(including imperfections)*

Nair 46

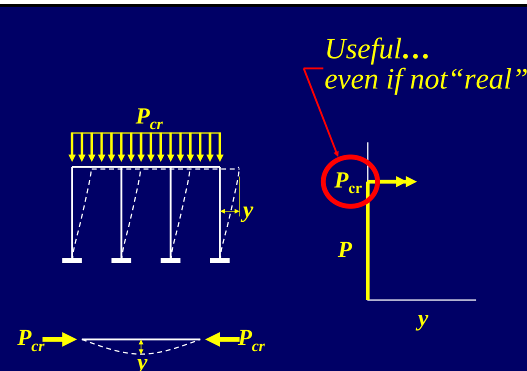
For correct prediction of response:

- *Second-order analysis*
- *Correct* y_0 *(including imperfections)*

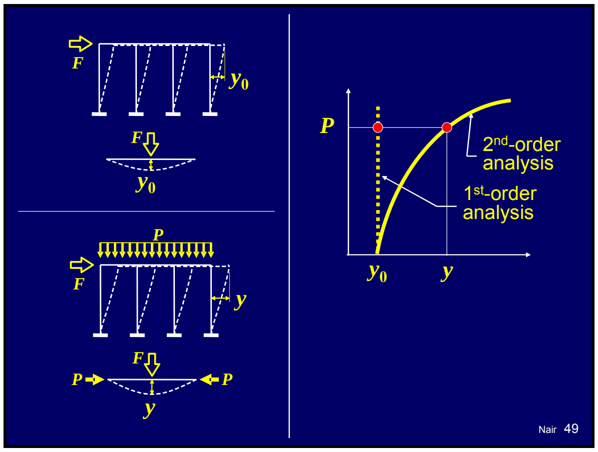
The second-order analysis can be either:

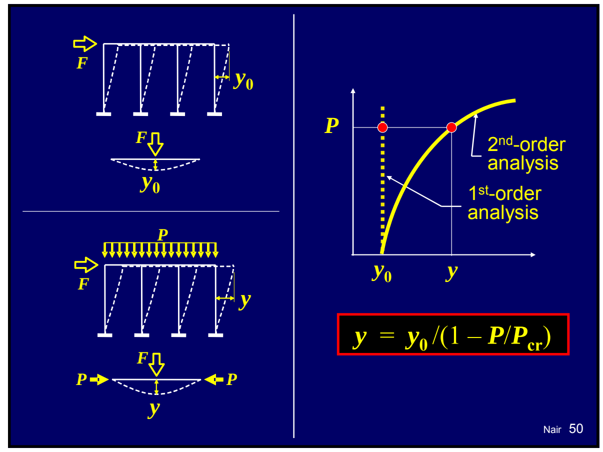
- *Direct second-order analysis or*
- *Amplified first-order analysis*

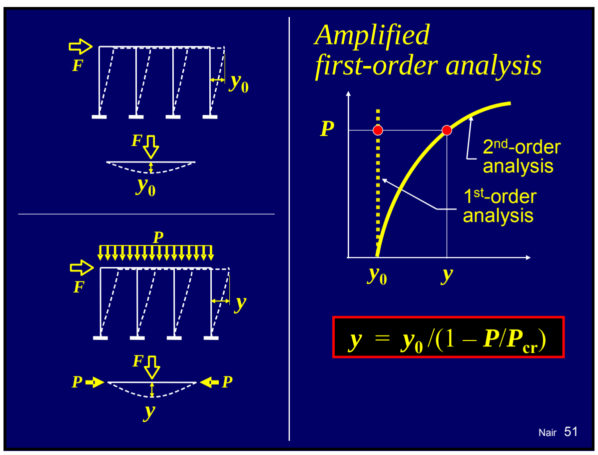
Nair 47

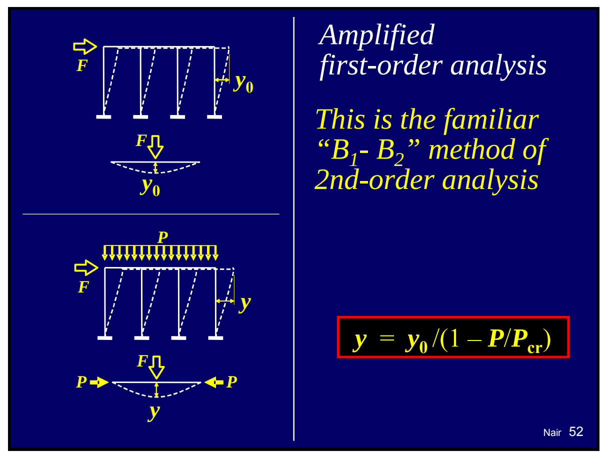


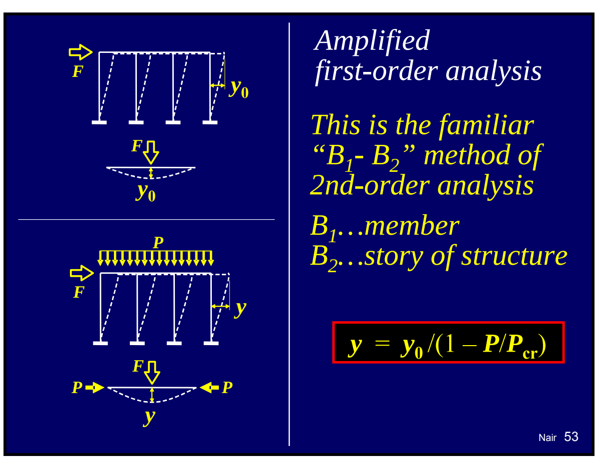
Nair 48

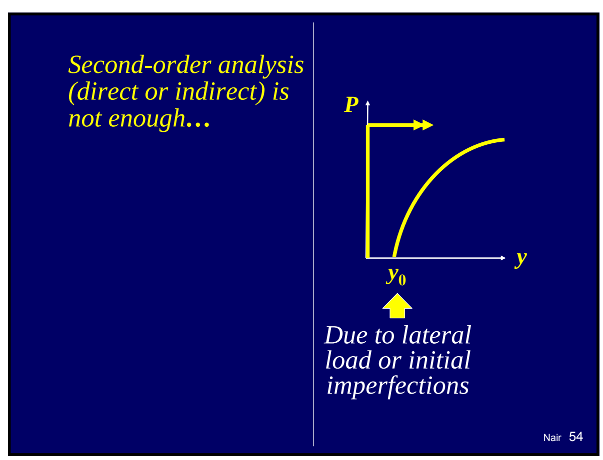

F
y0
F
y0
P
F
y
F
P
P
y
P
2nd-order analysis
1st-order analysis
y0
y
Nair 49


F
y0
F
y0
P
F
y
F
P
P
y
P
2nd-order analysis
1st-order analysis
y0
y
y = y0/(1 – P/Pcr)
Nair 50


Amplified
first-order analysis
F
y0
F
y0
P
F
y
F
P
P
y
P
2nd-order analysis
1st-order analysis
y0
y
y = y0/(1 – P/Pcr)
Nair 51

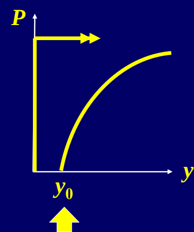

Amplified
first-order analysis
This is the familiar
"B1- B2" method of
2nd-order analysis
F
y0
F
y0
P
F
y
F
P
P
y
y = y0/(1 – P/Pcr)
Nair 52


Amplified
first-order analysis
This is the familiar
"B1- B2" method of
2nd-order analysis
B1…member
B2…story of structure
F
y0
F
y0
P
F
y
F
P
P
y
y = y0/(1 – P/Pcr)
Nair 53


Second-order analysis
(direct or indirect) is
not enough…
P
y
y0
Due to lateral
load or initial
imperfections
Nair 54

Second-order analysis (direct or indirect) is not enough

…must also have correct y_0

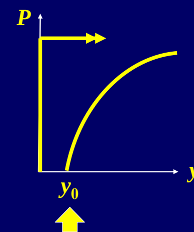


Due to lateral load or initial imperfections

Second-order analysis (direct or indirect) is not enough

…must also have correct y_0

…must also adjust for stiffness reduction due to inelasticity



Due to lateral load or initial imperfections

Second-order analysis (direct or indirect) is not enough

…must also have correct y_0

…must also adjust for stiffness reduction due to inelasticity

Typical residual stress in a rolled section = 0.3 F_y

Second-order analysis (direct or indirect) is not enough

…must also have correct y_0

…must also adjust for stiffness reduction due to inelasticity

Typical residual stress in a rolled section = 0.3 F_y

… part of section yields when stress due axial force & flexure reaches 0.7 F_y

Second-order analysis (direct or indirect) is not enough

…must also have correct y_0

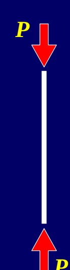
…must also adjust for stiffness reduction due to inelasticity

Typical residual stress in a rolled section = 0.3 F_y

… part of section yields when stress due axial force & flexure reaches 0.7 F_y

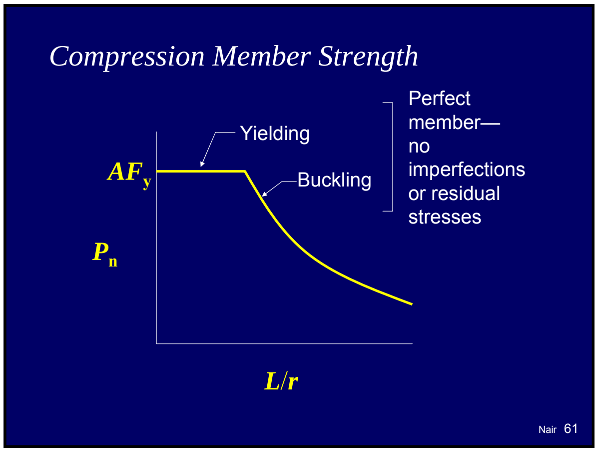
… then stiffness decreases

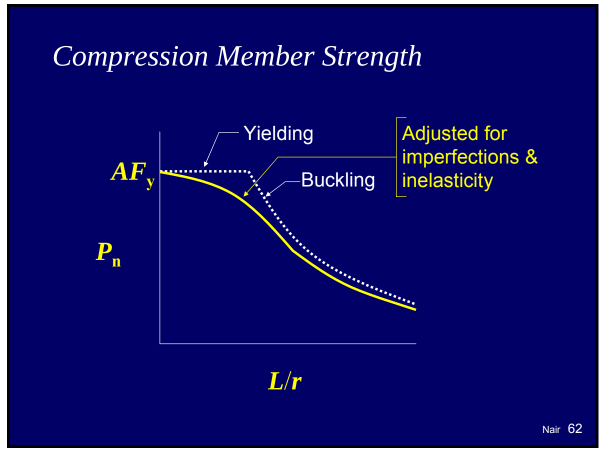
Compression Member Strength

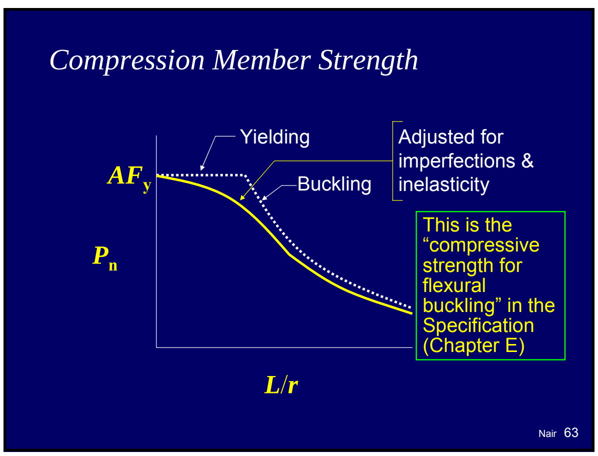


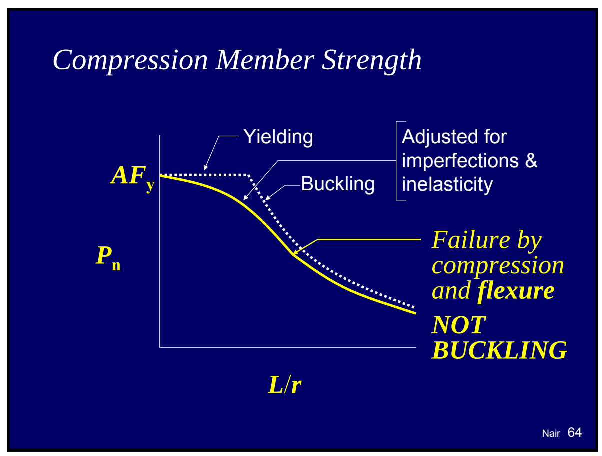
For perfect member (no imperfection, no residual stress):

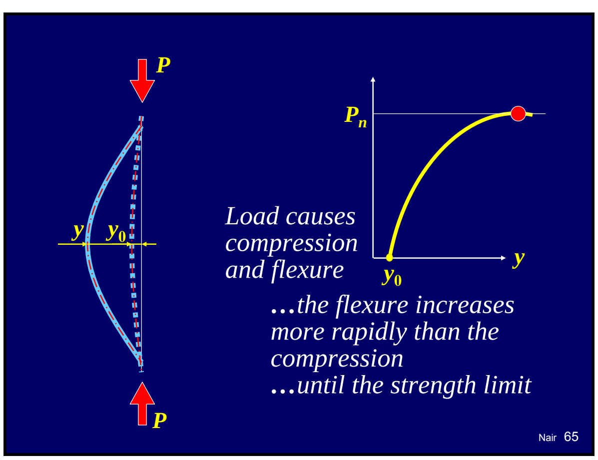
$$P_n = \text{lesser of} \begin{cases} \pi^2 EI/L^2 \\ AF_y \end{cases}$$

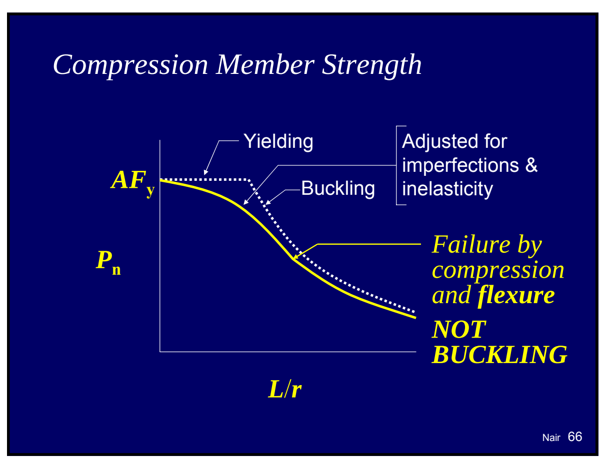

Compression Member Strength
Perfect member—no imperfections or residual stresses
Yielding
Buckling
AFy
Pn
L/r
Nair 61


Compression Member Strength
Yielding
Adjusted for imperfections & inelasticity
Buckling
AFy
Pn
L/r
Nair 62


Compression Member Strength
Yielding
Adjusted for imperfections & inelasticity
Buckling
AFy
Pn
This is the "compressive strength for flexural buckling" in the Specification (Chapter E)
L/r
Nair 63


Compression Member Strength
Yielding
Adjusted for imperfections & inelasticity
Buckling
AFy
Pn
Failure by compression and flexure
NOT BUCKLING
L/r
Nair 64


P
Pn
y
y0
Load causes compression and flexure
y0
y
…the flexure increases more rapidly than the compression
…until the strength limit
P
Nair 65


Compression Member Strength
Yielding
Adjusted for imperfections & inelasticity
Buckling
AFy
Pn
Failure by compression and flexure
NOT BUCKLING
L/r
Nair 66

How have we been designing for stability?

Conventional design approach (pre-2005)

- *Find P & M in members from second-order analysis* neglecting imperfections and inelasticity*

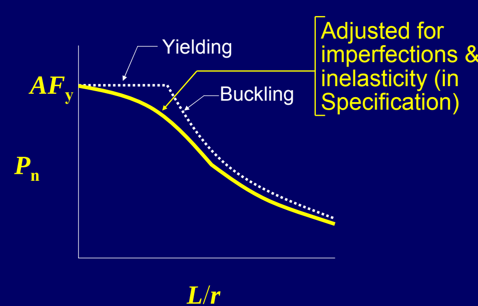
*The 2nd-order analysis may consist of either direct 2nd-order analysis or 1st-order analysis adjusted by B_1 and B_2

Conventional design approach (pre-2005)

- *Find P & M in members from second-order analysis* neglecting imperfections and inelasticity*
- *Check member capacity using column curve (strength equation) that includes effects of imperfections and inelasticity*

*The 2nd-order analysis may consist of either direct 2nd-order analysis or 1st-order analysis adjusted by B_1 and B_2

Compression Member Strength

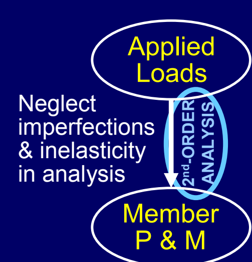


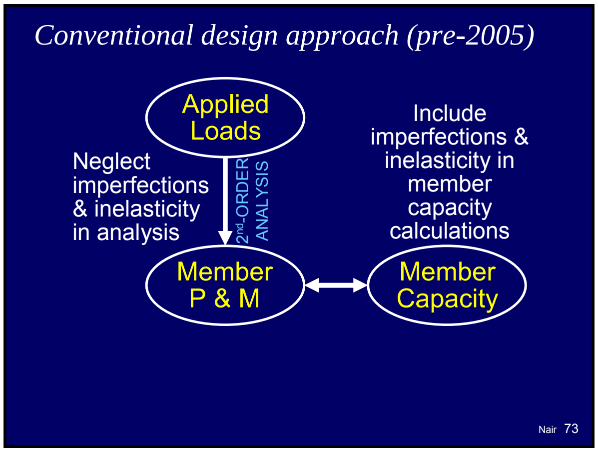
Conventional design approach (pre-2005)

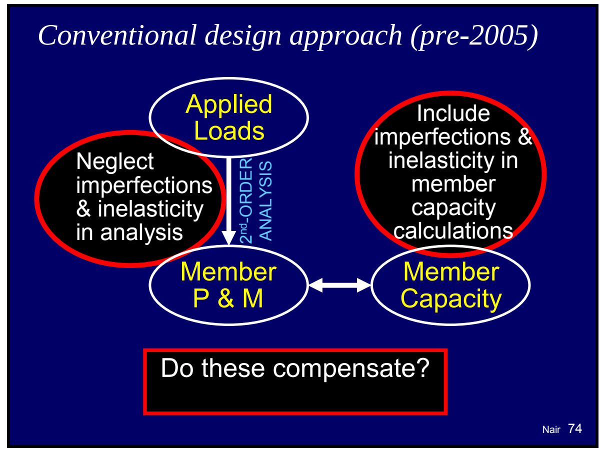
- *Find P & M in members from second-order analysis* neglecting imperfections and inelasticity*
- *Check member capacity using column curve (strength equation) that includes effects of imperfections and inelasticity*

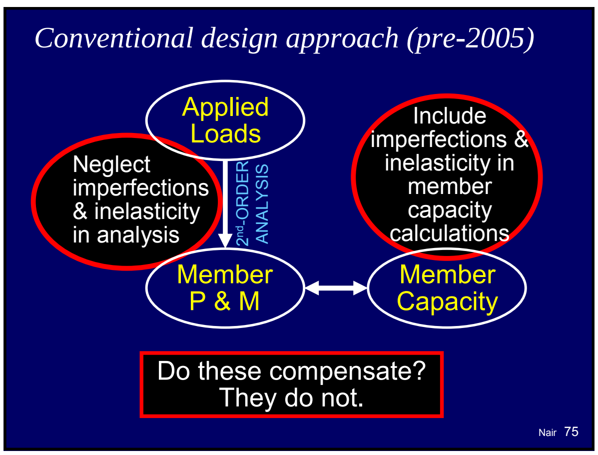
*The 2nd-order analysis may consist of either direct 2nd-order analysis or 1st-order analysis adjusted by B_1 and B_2

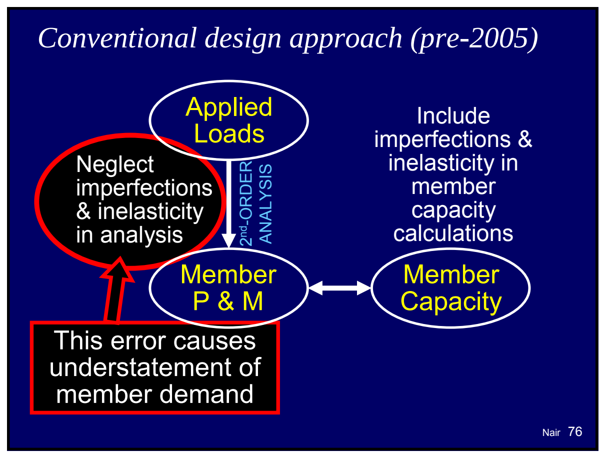
Conventional design approach (pre-2005)

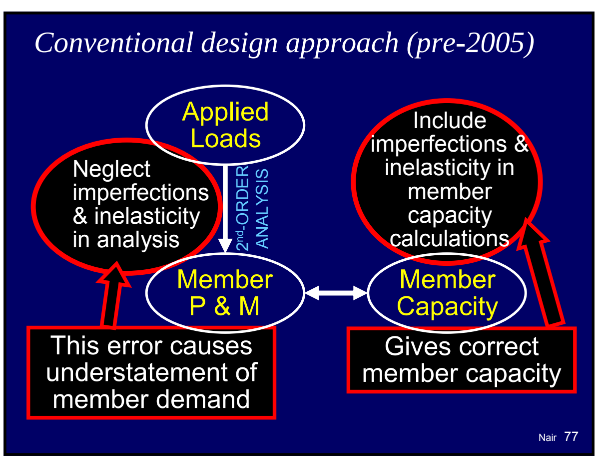


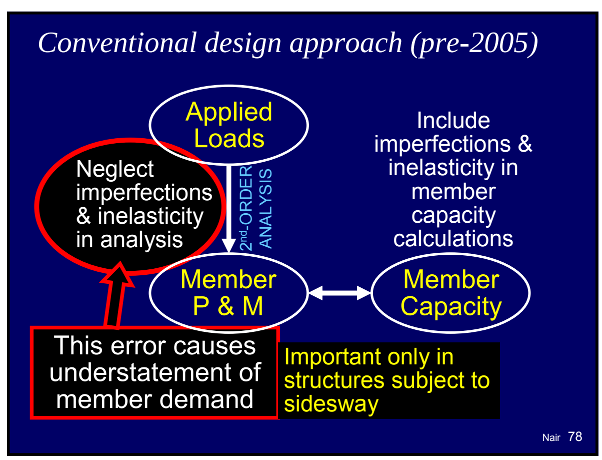

Conventional design approach (pre-2005)
Applied Loads
Neglect imperfections & inelasticity in analysis
2nd-ORDER ANALYSIS
Include imperfections & inelasticity in member capacity calculations
Member P & M
Member Capacity
Nair 73

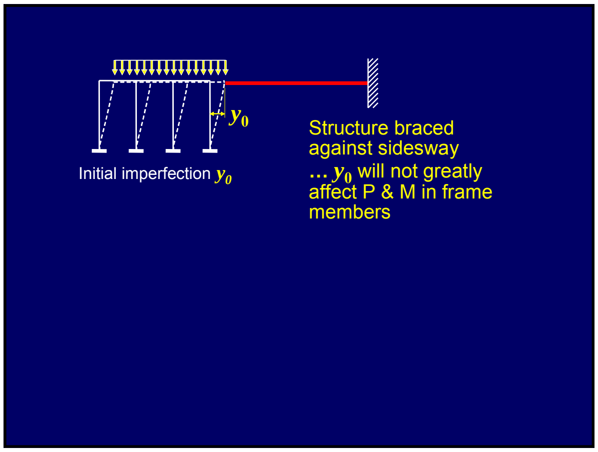

Conventional design approach (pre-2005)
Applied Loads
Neglect imperfections & inelasticity in analysis
2nd-ORDER ANALYSIS
Include imperfections & inelasticity in member capacity calculations
Member P & M
Member Capacity
Do these compensate?
Nair 74


Conventional design approach (pre-2005)
Applied Loads
Neglect imperfections & inelasticity in analysis
2nd-ORDER ANALYSIS
Include imperfections & inelasticity in member capacity calculations
Member P & M
Member Capacity
Do these compensate? They do not.
Nair 75

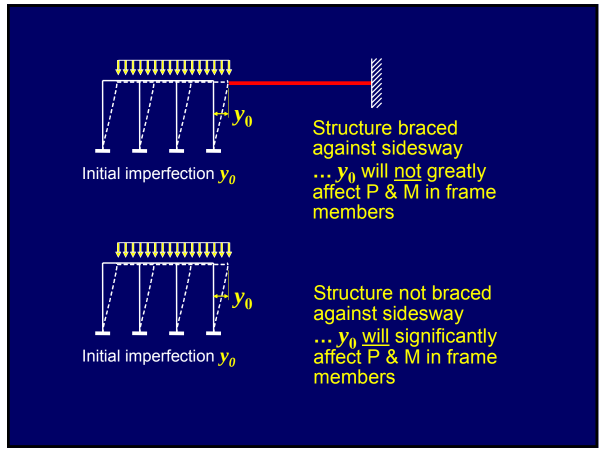

Conventional design approach (pre-2005)
Applied Loads
Neglect imperfections & inelasticity in analysis
2nd-ORDER ANALYSIS
Include imperfections & inelasticity in member capacity calculations
Member P & M
Member Capacity
This error causes understatement of member demand
Nair 76


Conventional design approach (pre-2005)
Applied Loads
Neglect imperfections & inelasticity in analysis
2nd-ORDER ANALYSIS
Include imperfections & inelasticity in member capacity calculations
Member P & M
Member Capacity
This error causes understatement of member demand
Gives correct member capacity
Nair 77

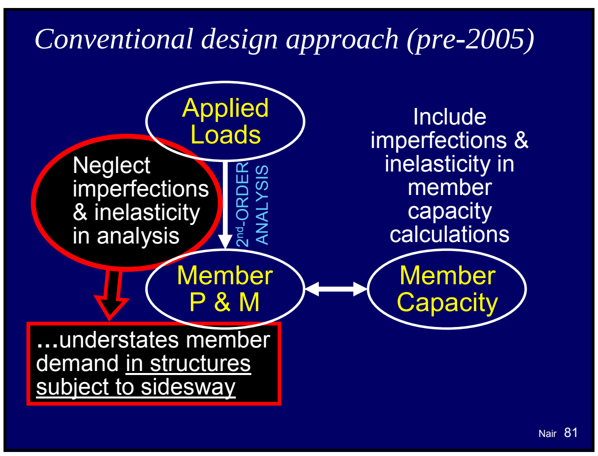

Conventional design approach (pre-2005)
Applied Loads
Neglect imperfections & inelasticity in analysis
2nd-ORDER ANALYSIS
Include imperfections & inelasticity in member capacity calculations
Member P & M
Member Capacity
This error causes understatement of member demand
Important only in structures subject to sideway
Nair 78



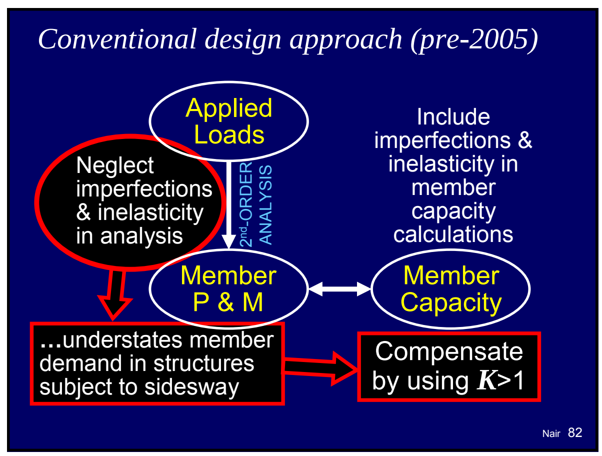
y_0
Initial imperfection y_0
Structure braced against sideway
… y_0 will not greatly affect P & M in frame members



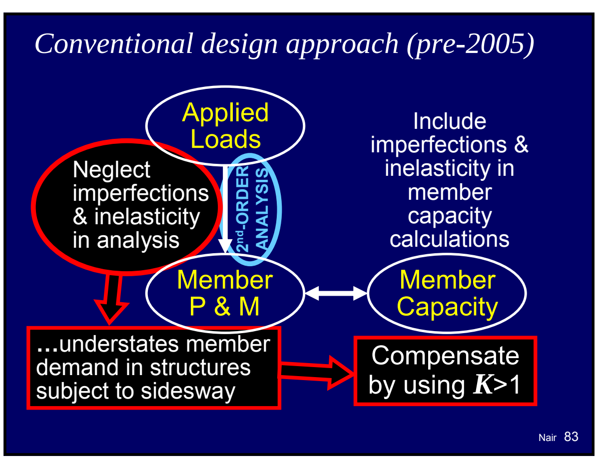
y_0
Initial imperfection y_0
Structure braced against sideway
… y_0 will not greatly affect P & M in frame members
y_0
Initial imperfection y_0
Structure not braced against sidesway
… y_0 will significantly affect P & M in frame members



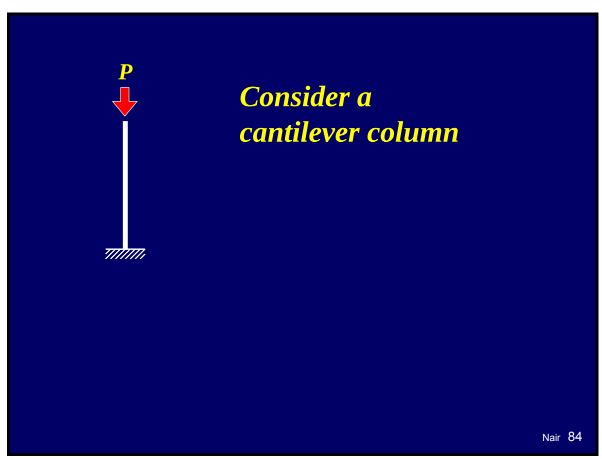
Conventional design approach (pre-2005)
Applied Loads
Neglect imperfections & inelasticity in analysis
2nd-ORDER ANALYSIS
Include imperfections & inelasticity in member capacity calculations
Member P & M
Member Capacity
…understates member demand in structures subject to sidesway
Nair 81



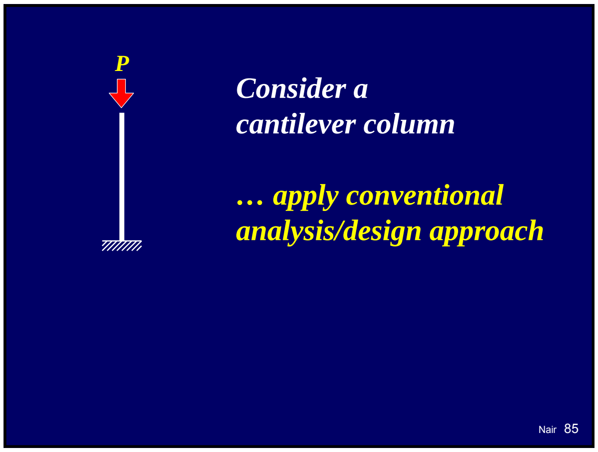
Conventional design approach (pre-2005)
Applied Loads
Neglect imperfections & inelasticity in analysis
2nd-ORDER ANALYSIS
Include imperfections & inelasticity in member capacity calculations
Member P & M
Member Capacity
…understates member demand in structures subject to sidesway
Compensate by using K>1
Nair 82

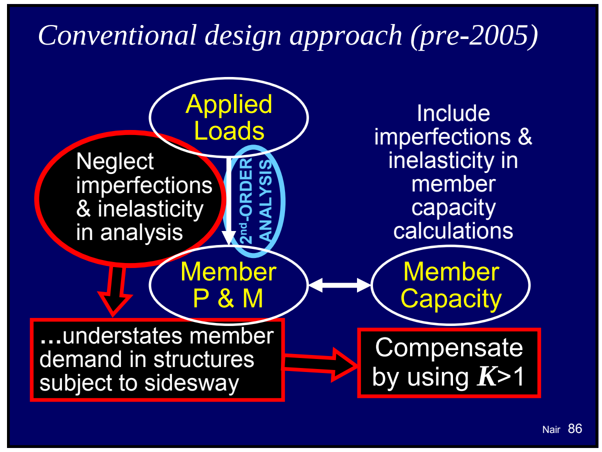


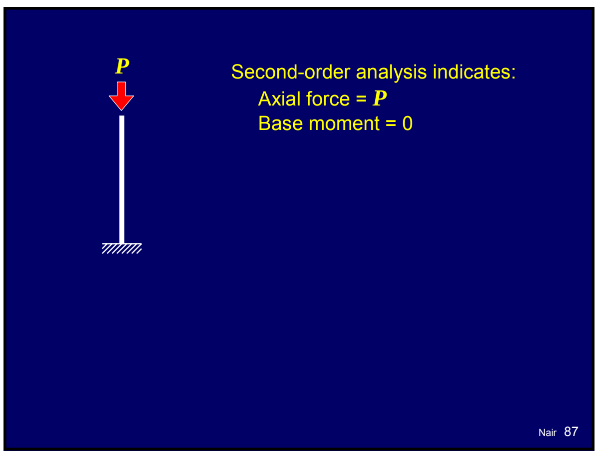
Conventional design approach (pre-2005)
Applied Loads
Neglect imperfections & inelasticity in analysis
2nd-ORDER ANALYSIS
Include imperfections & inelasticity in member capacity calculations
Member P & M
Member Capacity
…understates member demand in structures subject to sidesway
Compensate by using K>1
Nair 83

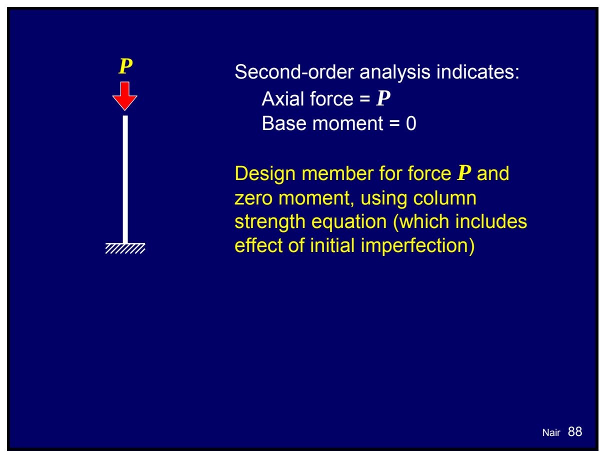


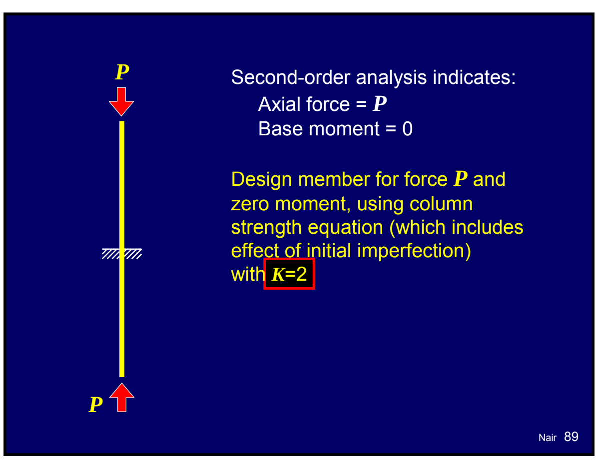
P
Consider a cantilever column
Nair 84

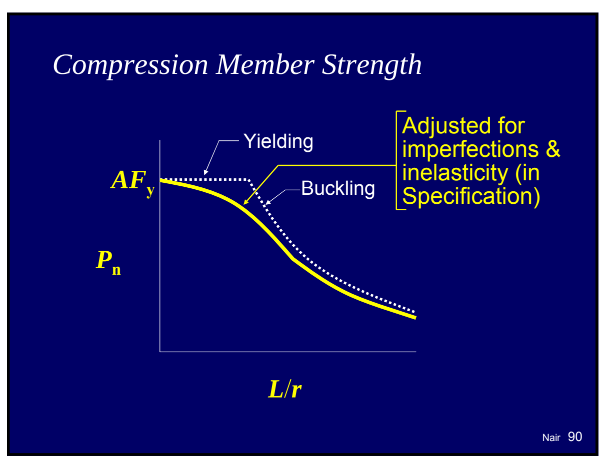

P
Consider a cantilever column
… apply conventional analysis/design approach
Nair 85

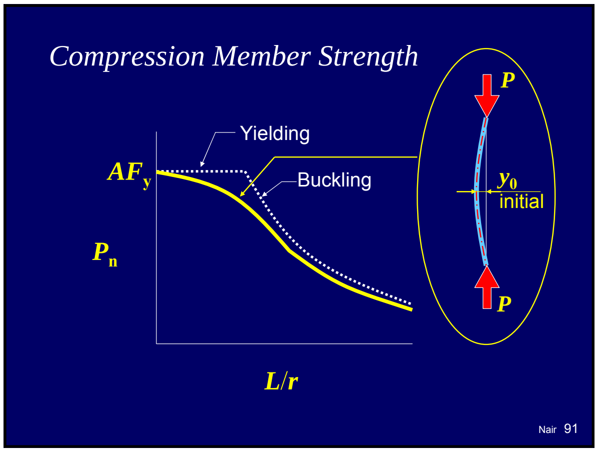

Conventional design approach (pre-2005)
Applied Loads
Neglect imperfections & inelasticity in analysis
2nd-ORDER ANALYSIS
Include imperfections & inelasticity in member capacity calculations
Member P & M
Member Capacity
…understates member demand in structures subject to sidesway
Compensate by using K>1
Nair 86


P
Second-order analysis indicates:
Axial force = P
Base moment = 0
Nair 87

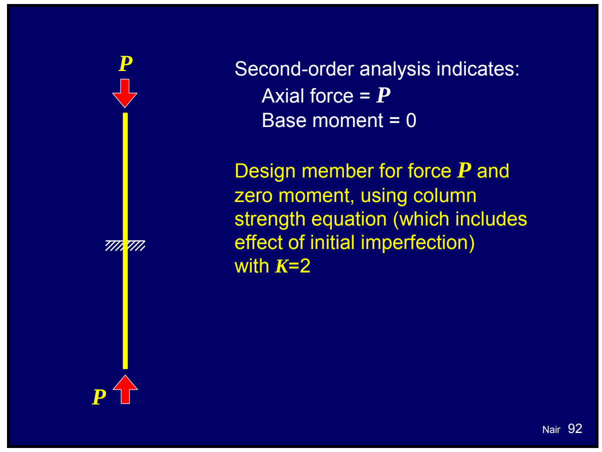

P
Second-order analysis indicates:
Axial force = P
Base moment = 0
Design member for force P and zero moment, using column strength equation (which includes effect of initial imperfection)
Nair 88


P
Second-order analysis indicates:
Axial force = P
Base moment = 0
Design member for force P and zero moment, using column strength equation (which includes effect of initial imperfection) with K=2
P
Nair 89

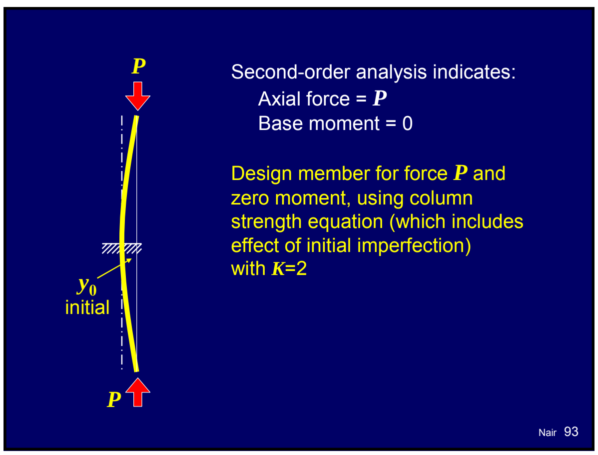

Compression Member Strength
Yielding
Adjusted for imperfections & inelasticity (in Specification)
AFy
Buckling
Pn
L/r
Nair 90



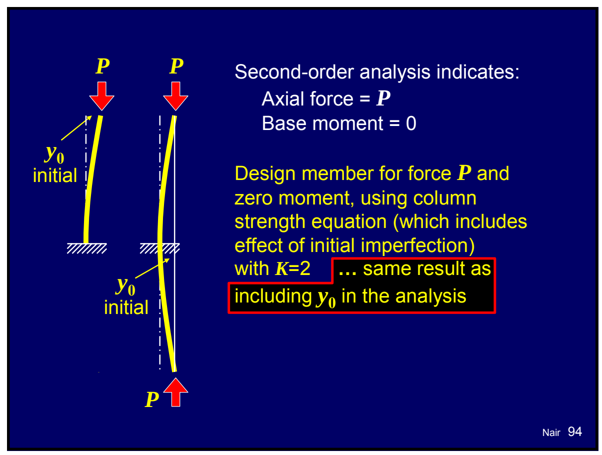
Compression Member Strength
Yielding
Buckling
AF_y
P_n
L/r
P
y_0
initial
P
Nair 91



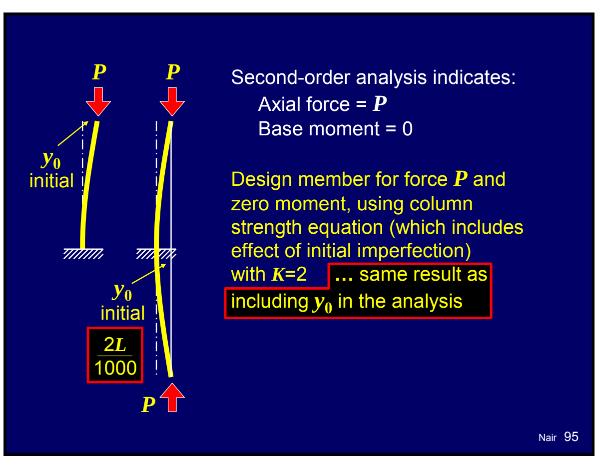
P
P
Second-order analysis indicates:
Axial force = P
Base moment = 0
Design member for force P and zero moment, using column strength equation (which includes effect of initial imperfection) with K=2
Nair 92



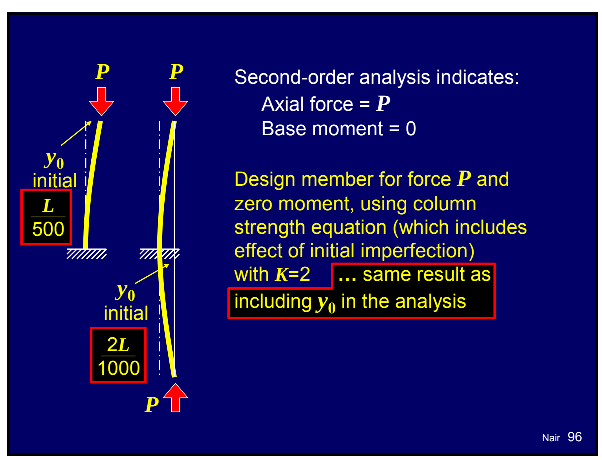
P
y_0
initial
P
Second-order analysis indicates:
Axial force = P
Base moment = 0
Design member for force P and zero moment, using column strength equation (which includes effect of initial imperfection) with K=2
Nair 93



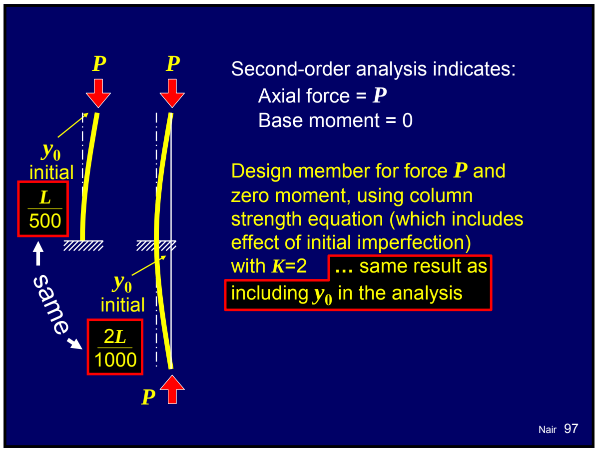
P
P
y_0
initial
y_0
initial
P
Second-order analysis indicates:
Axial force = P
Base moment = 0
Design member for force P and zero moment, using column strength equation (which includes effect of initial imperfection) with K=2
… same result as including y_0 in the analysis
Nair 94

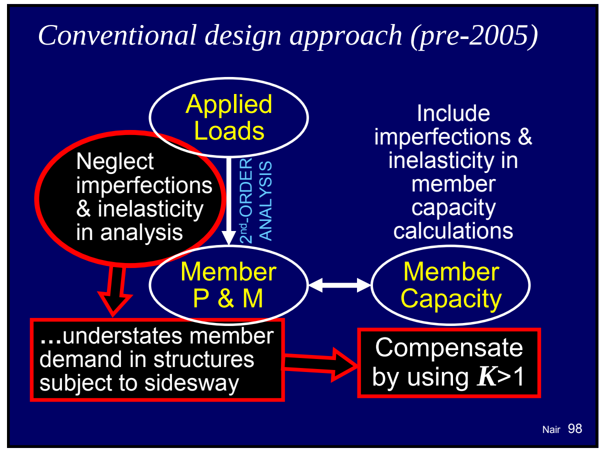


P
P
y_0
initial
y_0
initial
$\frac{2L}{1000}$
P
Second-order analysis indicates:
Axial force = P
Base moment = 0
Design member for force P and zero moment, using column strength equation (which includes effect of initial imperfection) with K=2
… same result as including y_0 in the analysis
Nair 95

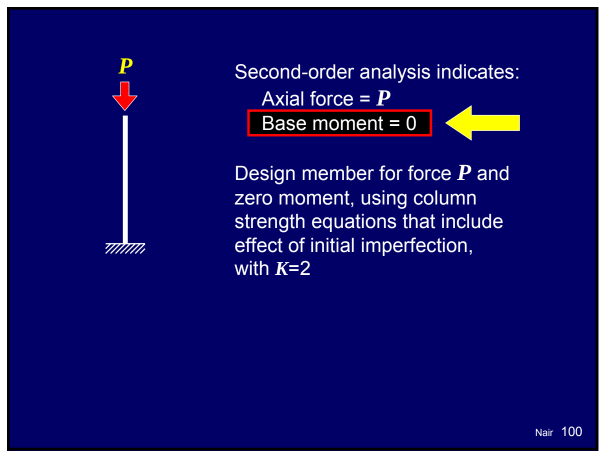


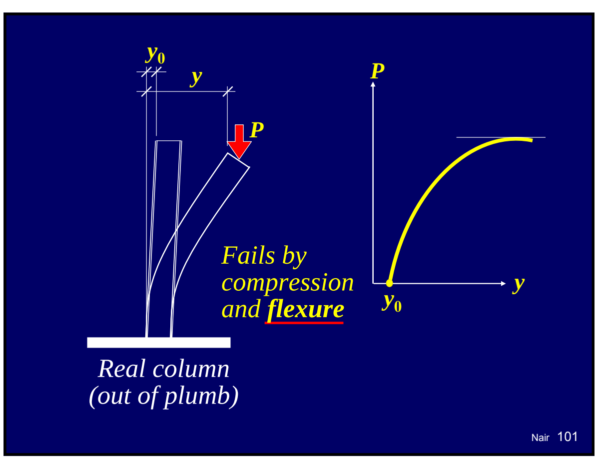
P
P
y_0
initial
$\frac{L}{500}$
y_0
initial
$\frac{2L}{1000}$
P
Second-order analysis indicates:
Axial force = P
Base moment = 0
Design member for force P and zero moment, using column strength equation (which includes effect of initial imperfection) with K=2
… same result as including y_0 in the analysis
Nair 96

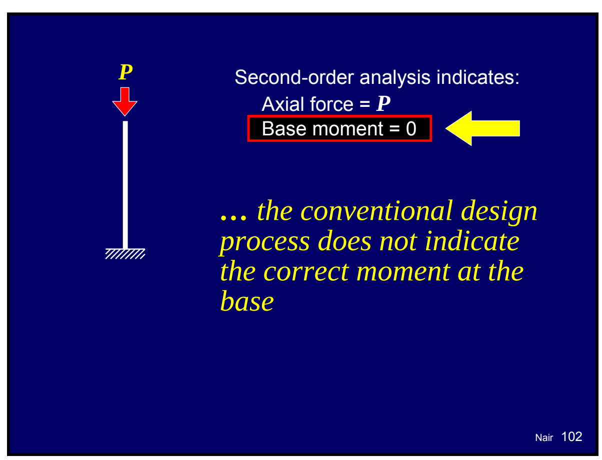

P
P
y_0 initial
$\frac{L}{500}$
same
y_0 initial
$\frac{2L}{1000}$
P
Second-order analysis indicates:
Axial force = P
Base moment = 0
Design member for force P and zero moment, using column strength equation (which includes effect of initial imperfection) with K=2
… same result as including y_0 in the analysis
Nair 97


Conventional design approach (pre-2005)
Applied Loads
Neglect imperfections & inelasticity in analysis
2nd-ORDER ANALYSIS
Include imperfections & inelasticity in member capacity calculations
Member P & M
Member Capacity
…understates member demand in structures subject to sidesway
Compensate by using K>1
Nair 98

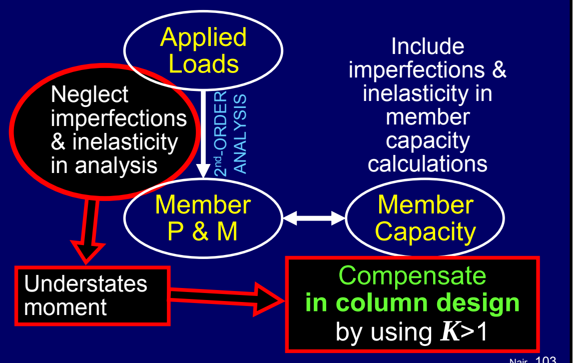

Conventional design approach (pre-2005)
… appears to work, but there are problems
Nair 99


P
Second-order analysis indicates:
Axial force = P
Base moment = 0
Design member for force P and zero moment, using column strength equations that include effect of initial imperfection, with K=2
Nair 100

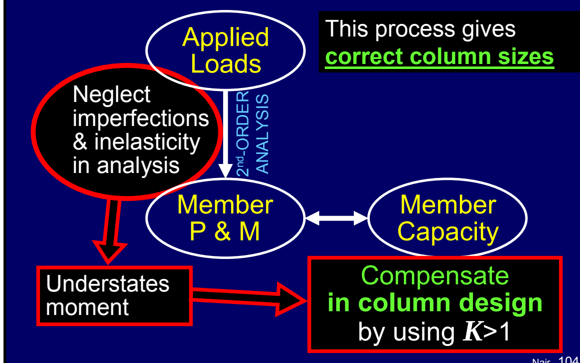

y_0
y
P
Fails by compression and flexure
P
y_0
y
Real column (out of plumb)
Nair 101


P
Second-order analysis indicates:
Axial force = P
Base moment = 0
… the conventional design process does not indicate the correct moment at the base
Nair 102

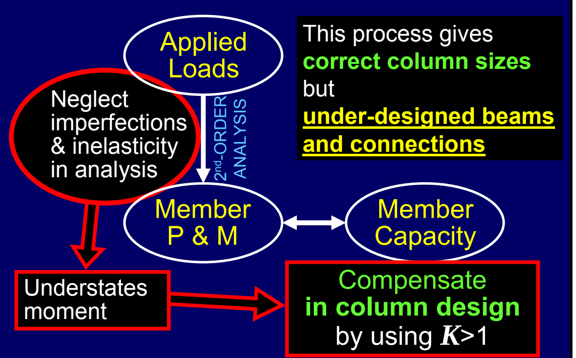
Conventional design approach (pre-2005)



Conventional design approach (pre-2005)



Conventional design approach (pre-2005)



Conventional design approach (pre-2005)

… indicates incorrect design moments

Conventional design approach (pre-2005)

… indicates incorrect design moments

… requires calculation of K--

Conventional design approach (pre-2005)

… indicates incorrect design moments

*… requires calculation of K-- **how??***

"Sidesway uninhibited" alignment chart for column effective length—

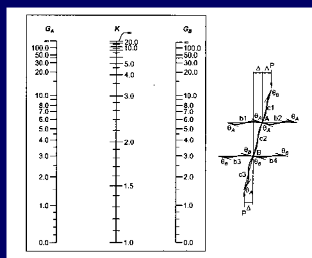


Fig. C-C2.4. Alignment chart—sidesway uninhibited (moment frame).

"Sidesway uninhibited" alignment chart for column effective length—

The Commentary to the AISC Specification lists nine conditions for the applicability of this chart.

"Sidesway uninhibited" alignment chart for column effective length—

The Commentary to the AISC Specification lists nine conditions for the applicability of this chart.

- *8. All columns buckle simultaneously.*

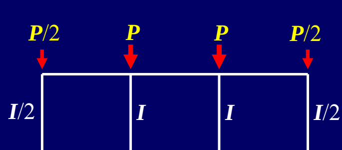
"Sidesway uninhibited" alignment chart for column effective length—

The Commentary to the AISC Specification lists nine conditions for the applicability of this chart.

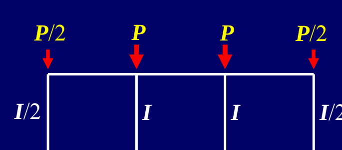
- *8. All columns buckle simultaneously.*

Ratio of column force ***P*** to $\frac{\pi^2 EI}{(KL)^2}$

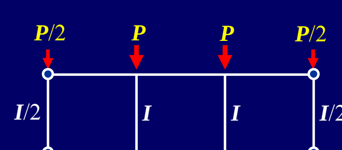
must be same for all columns in a story



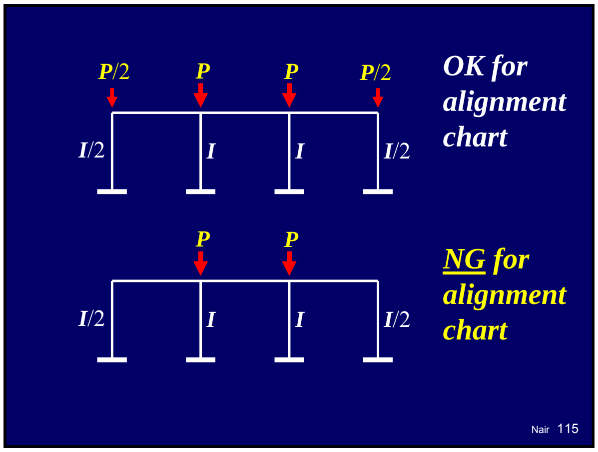
OK for alignment chart

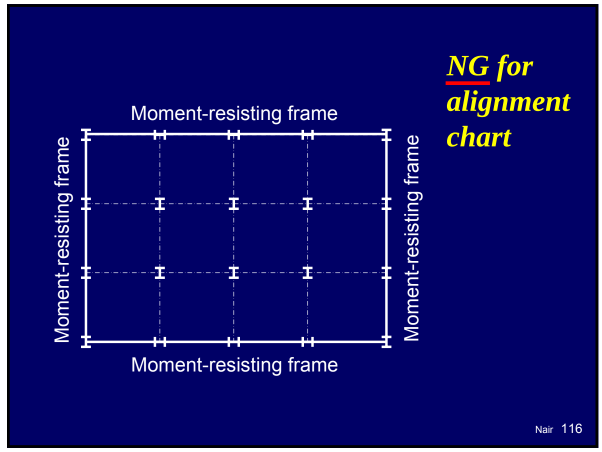


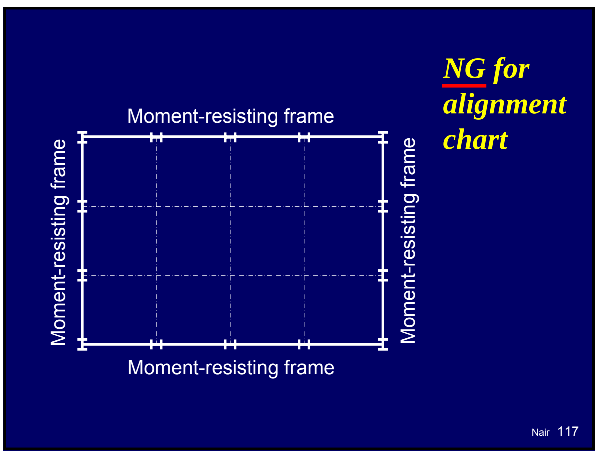
OK for alignment chart

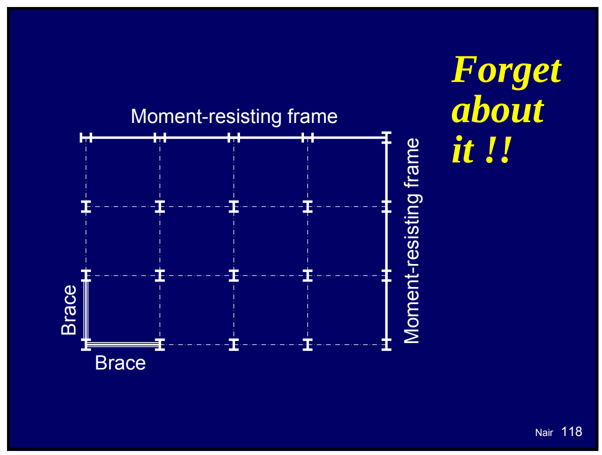


NG for alignment chart







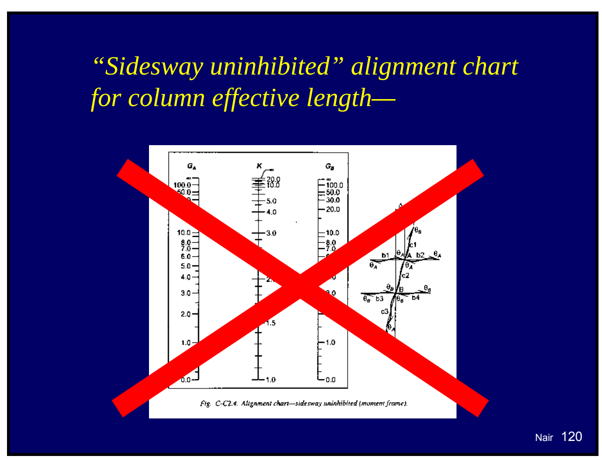


"Sidesway uninhibited" alignment chart for column effective length—

The Commentary to the AISC Specification lists conditions required for the applicability of these charts.

Few real-world buildings meet the conditions for applicability of the alignment chart.

Nair 119



Conventional design approach (pre-2005)

… *indicates incorrect design moments*

… *requires calculation of K-- how ?*

Nair 121

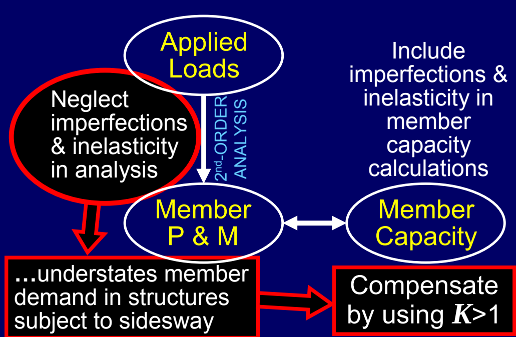
Conventional design approach (pre-2005)

… *indicates incorrect design moments*

… *requires calculation of K-- how indeed?*

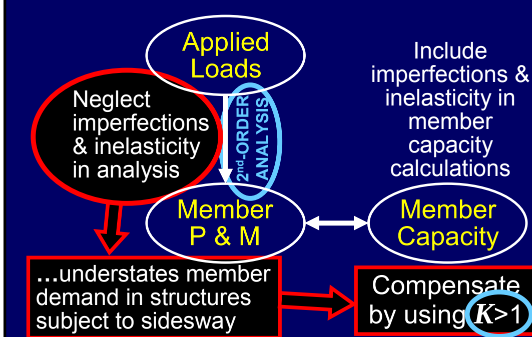
Nair 122

Conventional design approach



Nair 123

Conventional design approach



Nair 124

Conventional design approach (pre-2005)

… *indicates incorrect design moments*

… *requires calculation of K-- how?*

… *sometimes, too conservative*

Nair 125

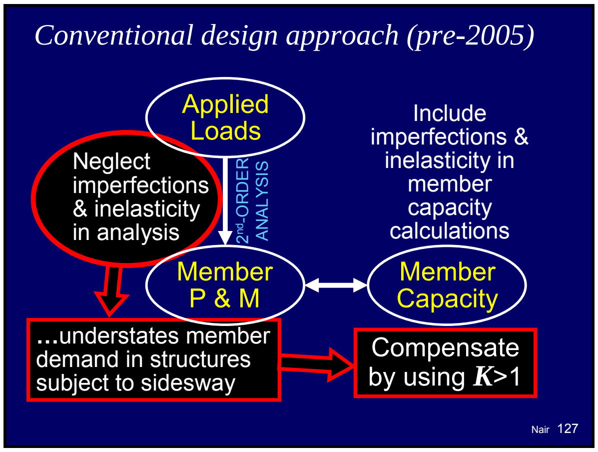
Conventional design approach (pre-2005)

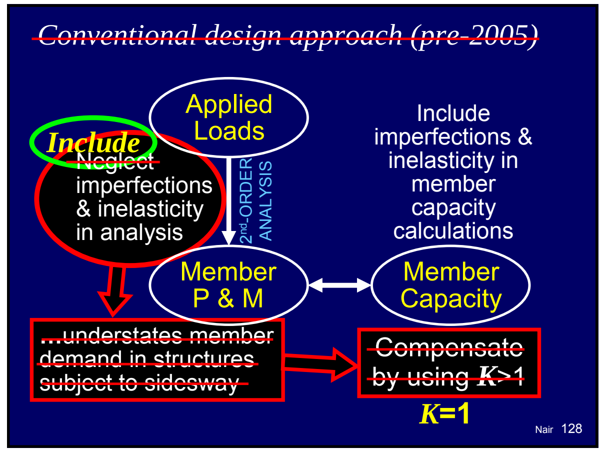
… *indicates incorrect design moments*

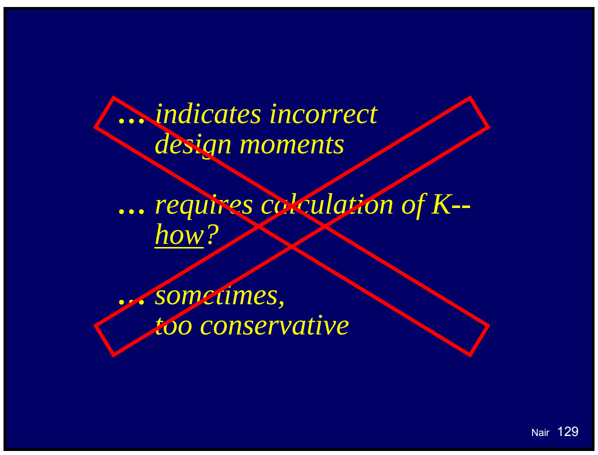
… *requires calculation of K-- how?*

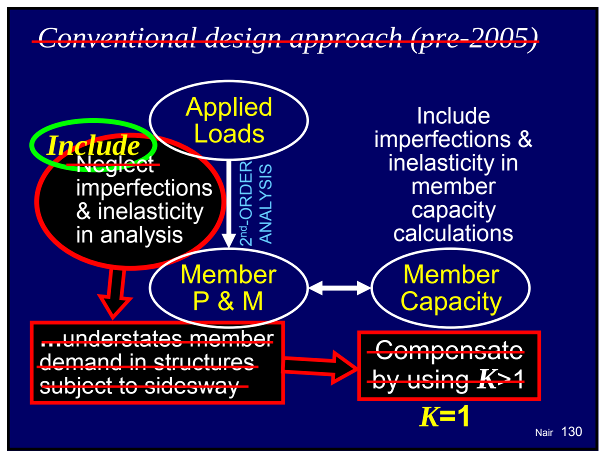
… *sometimes, too conservative*

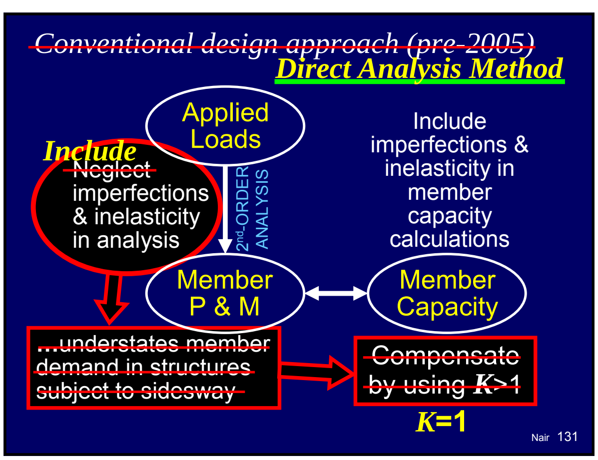
Nair 126

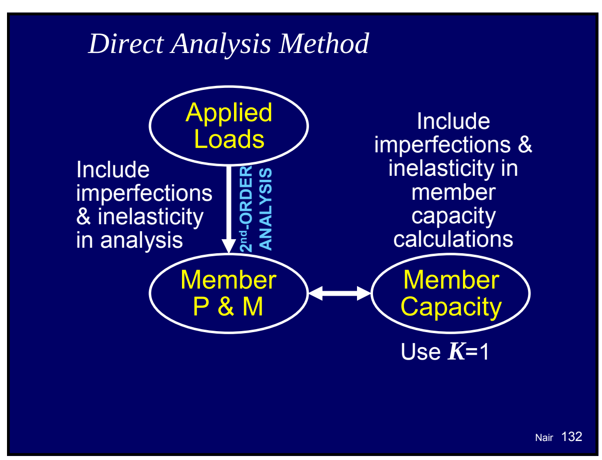

Conventional design approach (pre-2005)
Applied Loads
Neglect imperfections & inelasticity in analysis
2nd-ORDER ANALYSIS
Include imperfections & inelasticity in member capacity calculations
Member P & M
Member Capacity
…understates member demand in structures subject to sidesway
Compensate by using K>1
Nair 127


Conventional design approach (pre-2005)
Applied Loads
Include
Neglect imperfections & inelasticity in analysis
2nd-ORDER ANALYSIS
Include imperfections & inelasticity in member capacity calculations
Member P & M
Member Capacity
…understates member demand in structures subject to sidesway
Compensate by using K>1
K=1
Nair 128


… indicates incorrect design moments
… requires calculation of K-- how?
… sometimes, too conservative
Nair 129


Conventional design approach (pre-2005)
Applied Loads
Include
Neglect imperfections & inelasticity in analysis
2nd-ORDER ANALYSIS
Include imperfections & inelasticity in member capacity calculations
Member P & M
Member Capacity
…understates member demand in structures subject to sidesway
Compensate by using K>1
K=1
Nair 130


Conventional design approach (pre-2005)
Direct Analysis Method
Applied Loads
Include
Neglect imperfections & inelasticity in analysis
2nd-ORDER ANALYSIS
Include imperfections & inelasticity in member capacity calculations
Member P & M
Member Capacity
…understates member demand in structures subject to sidesway
Compensate by using K>1
K=1
Nair 131


Direct Analysis Method
Applied Loads
Include imperfections & inelasticity in analysis
2nd-ORDER ANALYSIS
Include imperfections & inelasticity in member capacity calculations
Member P & M
Member Capacity
Use K=1
Nair 132

Stability and Analysis Provisions

of the

2005 AISC Specification
for Steel Buildings

Nair 133

CHAPTER B

DESIGN REQUIREMENTS

B1. GENERAL PROVISIONS

"The design of members and connections shall be consistent with the intended behavior and the assumptions made in the structural analysis."

Nair 134

CHAPTER C

STABILITY ANALYSIS AND DESIGN

Nair 135

CHAPTER C

STABILITY ANALYSIS AND DESIGN

…specifies that the design of the structure for stability must consider various effects.

Nair 136

Effects to be considered:

- Flexural, shear and axial deformations of members

Nair 137

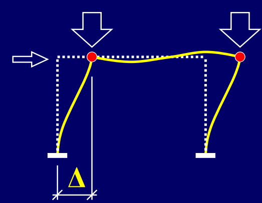
Effects to be considered:

- Member deformations
- All component and connection deformations that contribute to lateral displacement

Nair 138

Effects to be considered:

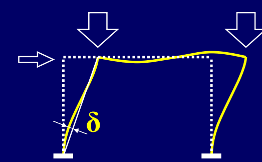
- Member deformations
- Other deformations
- P- Δ effects



Nair 139

Effects to be considered:

- Member deformations
- Other deformations
- P- Δ effects
- P- δ effects



Nair 140

Effects to be considered:

- Member deformations
- Other deformations
- P- Δ effects
- P- δ effects
- Geometric imperfections
  ...member shape imperfections (out-of-straightness)
  ...node position imperfections (out-of-plumbness)

Nair 141

Effects to be considered:

- Member deformations
- Other deformations
- P- Δ effects
- P- δ effects
- Geometric imperfections
- Stiffness reductions due to residual stresses

Nair 142

Effects to be considered:

- Member deformations
- Other deformations
- P- Δ effects
- P- δ effects
- Geometric imperfections
- Residual stresses

When the analysis has considered all these effects, members can be designed using the provisions for individual members (Chapters D, E, F, G, H, I)

Nair 143

Effects to be considered:

- Member deformations
- Other deformations
- P- Δ effects
- P- δ effects
- Geometric imperfections
- Residual stresses

Any method of analysis and design that considers all these effects is permissible

When the analysis has considered all these effects, members can be designed using the provisions for individual members (Chapters D, E, F, G, H, I)

Nair 144

Effects to be considered:

- Member deformations
- Other deformations

General analysis requirements

- P- Δ effects
- P- δ effects
- Geometric imperfections
- Residual stresses

When the analysis has considered all these effects, members can be designed using the provisions for individual members (Chapters D, E, F, G, H, I)

Nair 145

Effects to be considered:

- Member deformations
- Other deformations
- P- Δ effects
- P- δ effects
- Geometric imperfections
- Residual stresses

Spec presents approaches that consider these effects

When the analysis has considered all these effects, members can be designed using the provisions for individual members (Chapters D, E, F, G, H, I)

Nair 146

APPENDIX 7

DIRECT ANALYSIS METHOD

Nair 147

APPENDIX 7

DIRECT ANALYSIS METHOD

Applicable to all types of structures

Does not distinguish between

…Braced frames
…Moment frames
…Shear wall systems
…Combinations

Nair 148

DIRECT ANALYSIS METHOD

- P- Δ effects
- P- δ effects
- Geometric imperfections
- Residual stresses

Nair 149

DIRECT ANALYSIS METHOD

- **P- Δ effects**
- **P- δ effects**
- Geometric imperfections
- Residual stresses

Use second-order elastic analysis that considers both P-Δ and P-δ effects.

Nair 150

DIRECT ANALYSIS METHOD

- **P- Δ effects**
- **P- δ effects**
- Geometric imperfections
- Residual stresses

Use second-order elastic analysis that considers both P-Δ and P-δ effects. Options:

… any general second-order analysis method

DIRECT ANALYSIS METHOD

- **P- Δ effects**
- **P- δ effects**
- Geometric imperfections
- Residual stresses

Use second-order elastic analysis that considers both P-Δ and P-δ effects. Options:

… any general second-order analysis method

… amplified first-order analysis (B_1 & B_2)

First-order analysis amplified by B_1 and B_2

is

Second-order analysis

DIRECT ANALYSIS METHOD

- **P- Δ effects**
- **P- δ effects**
- Geometric imperfections
- Residual stresses

Use second-order elastic analysis that considers both P-Δ and P-δ effects. Options:

…any general second-order analysis method

…amplified first-order analysis (B_1 & B_2)

DIRECT ANALYSIS METHOD

- **P- Δ effects**
- **P- δ effects**
- Geometric imperfections
- Residual stresses

Use second-order elastic analysis that considers both P-Δ and P-δ effects. Options:

…any general second-order analysis method

…amplified first-order analysis (B_1 & B_2)

Exception: P-δ effects can be neglected when member axial loads are below a specified level.

DIRECT ANALYSIS METHOD

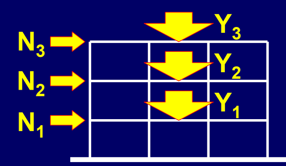
- P- Δ effects
- P- δ effects
- **Geometric imperfections**
- Residual stresses

DIRECT ANALYSIS METHOD

- P- Δ effects
- P- δ effects
- **Geometric imperfections**
- Residual stresses

Apply “notional loads”:

$$N_i = 0.002\ Y_i$$



$$N_i = 0.002\ Y_i$$

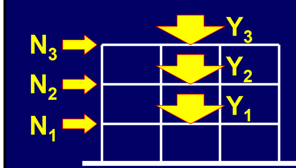
DIRECT ANALYSIS METHOD

- P- Δ effects
- P- δ effects
- **Geometric imperfections**
- Residual stresses

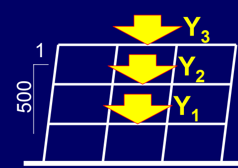
Apply “notional loads”:

$$N_i = 0.002\ Y_i$$

The $0.002Y_i$ notional load is equivalent to an initial out-of-plumbness of 1/500



$$N_i = 0.002\ Y_i$$



Equivalent structure

DIRECT ANALYSIS METHOD

- P- Δ effects
- P- δ effects
- **Geometric imperfections**
- Residual stresses

Apply “notional loads”:

$$N_i = 0.002\ Y_i$$

The 0.002 coefficient corresponds to an initial out-of-plumbness of 1/500

… lower value can be used if justified by the actual anticipated out-of-plumbness

DIRECT ANALYSIS METHOD

- P- Δ effects
- P- δ effects
- **Geometric imperfections**
- Residual stresses

Apply “notional loads”

Logically, these notional loads should be additive to other lateral loads in all cases.

DIRECT ANALYSIS METHOD

- P- Δ effects
- P- δ effects
- **Geometric imperfections**
- Residual stresses

Apply “notional loads”

Logically, these notional loads should be additive to other lateral loads in all cases.

But in a concession to past practice, the notional loads can be treated as a minimum lateral load when $\Delta/\Delta_0 < 1.5$

DIRECT ANALYSIS METHOD

- P- Δ effects
- P- δ effects
- **Geometric imperfections**
- Residual stresses

Alternative: Instead of applying notional loads to account for geometric imperfections…

the designer may model imperfections directly in the analysis.

DIRECT ANALYSIS METHOD

- P- Δ effects
- P- δ effects
- Geometric imperfections
- **Residual stresses**

DIRECT ANALYSIS METHOD

- P- Δ effects
- P- δ effects
- Geometric imperfections
- **Residual stresses**

Use reduced flexural and axial stiffnesses EI* and EA* in the analysis

DIRECT ANALYSIS METHOD

- P- Δ effects
- P- δ effects
- Geometric imperfections
- **Residual stresses**

Use reduced flexural and axial stiffnesses EI* and EA* in the analysis

$EI^* = 0.8\ \tau_b\ EI$

$EA^* = 0.8\ EA$

DIRECT ANALYSIS METHOD

- P- Δ effects
- P- δ effects
- Geometric imperfections
- **Residual stresses**

Use reduced flexural and axial stiffnesses EI* and EA* in the analysis

$EI^* = 0.8\ \tau_b\ EI$

$EA^* = 0.8\ EA$

τ_b depends on level of axial stress in member;
$\tau_b = 1$ when $P < 0.5\ P_y$

DIRECT ANALYSIS METHOD

- P- Δ effects
- P- δ effects
- Geometric imperfections
- **Residual stresses**

Use reduced flexural and axial stiffnesses EI* and EA* in the analysis

$EI^* = 0.8\,\tau_b\,EI$

$EA^* = 0.8\,EA$

τ_b can be taken as 1 in all cases if additional notional load of $0.001Y_i$ is applied.

Nair 169

DIRECT ANALYSIS METHOD

- P- Δ effects
- P- δ effects
- Geometric imperfections
- Residual stresses

The EI and EA adjustments also account for the effects of member out-of-straightness on the response of the overall structure

Nair 170

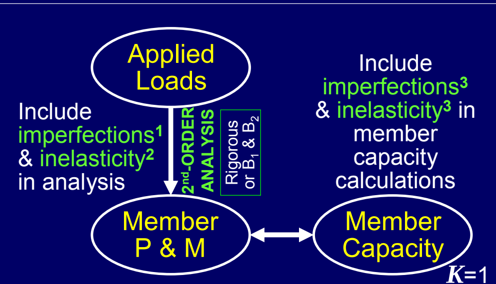
DIRECT ANALYSIS METHOD

- P- Δ effects
- P- δ effects
- Geometric imperfections
- Residual stresses

Design members using the provisions for individual members (Chapters D, E, F, G, H, I), with K=1 for computing compression strengths

Nair 171

DIRECT ANALYSIS METHOD



[1]Notional loads or direct modeling
[2]Reduced EI & EA

[3]The usual column strength formulas

Nair 172

APPENDIX 7

DIRECT ANALYSIS METHOD

Applicable to all types of structures

Does not distinguish between
…Braced frames
…Moment frames
…Shear wall systems
…Combinations

Nair 173

APPENDIX 7

DIRECT ANALYSIS METHOD

MAY be used in all cases

MUST be used when $\Delta/\Delta_0 > 1.5$

Nair 174

APPENDIX 7

DIRECT ANALYSIS METHOD

MAY be used in all cases

MUST be used when $\Delta/\Delta_0 > 1.5$

When $\Delta/\Delta_0 < 1.5$
there are other options…

Nair 175

CHAPTER C

STABILITY ANALYSIS AND DESIGN

C2. **CACULATION OF REQUIRED STRENGTHS**

2. Design Requirements
   Can use Appendix 7 in all cases
   Can use C2.2a or C2.2b if $\Delta/\Delta_0 < 1.5$

DIRECT ANALYSIS METHOD

2a. Design by Second-Order Analysis

EFFECTIVE LENGTH METHOD

2b. Design by First-Order Analysis

FIRST-ORDER ANALYSIS METHOD

Nair 176

EFFECTIVE LENGTH METHOD

Generally similar to the method in the 1999 Specification

Nair 177

EFFECTIVE LENGTH METHOD

Perform second-order elastic analysis
- use nominal geometry
- use nominal stiffness

Nair 178

EFFECTIVE LENGTH METHOD

First-order analysis
amplified by B_1 and B_2

is

Second-order analysis

Nair 179

EFFECTIVE LENGTH METHOD

Perform second-order elastic analysis
- use nominal geometry
- use nominal stiffness

Nair 180

EFFECTIVE LENGTH METHOD

Perform second-order elastic analysis
- use nominal geometry
- use nominal stiffness

Apply notional loads, $N_i = 0.002\ Y_i$
- as a minimum lateral load

Nair 181

EFFECTIVE LENGTH METHOD

Perform second-order elastic analysis
- use nominal geometry
- use nominal stiffness

Apply notional loads, $N_i = 0.002\ Y_i$
- as a minimum lateral load **…(NEW)**

Nair 182

EFFECTIVE LENGTH METHOD

Perform second-order elastic analysis
- use nominal geometry
- use nominal stiffness

Apply notional loads, $N_i = 0.002\ Y_i$
- as a minimum lateral load

Determine K factors for columns in moment frames by sidesway buckling analysis

Nair 183

EFFECTIVE LENGTH METHOD

Perform second-order elastic analysis
- use nominal geometry
- use nominal stiffness

Apply notional loads, $N_i = 0.002\ Y_i$
- as a minimum lateral load

Determine K factors for columns in moment frames by sidesway buckling analysis. (Exception: Use K=1 if $\Delta/\Delta_0 < 1.1$)

Nair 184

EFFECTIVE LENGTH METHOD

Perform second-order elastic analysis
- use nominal geometry
- use nominal stiffness

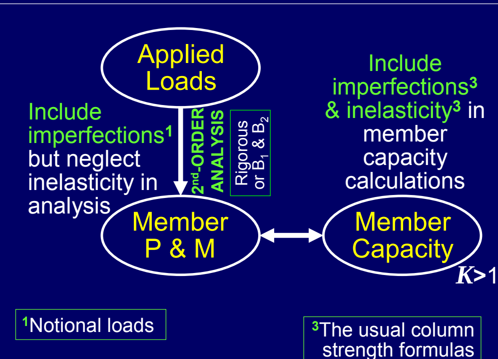
Apply notional loads, $N_i = 0.002\ Y_i$
- as a minimum lateral load

Determine K factors for columns in moment frames by sidesway buckling analysis

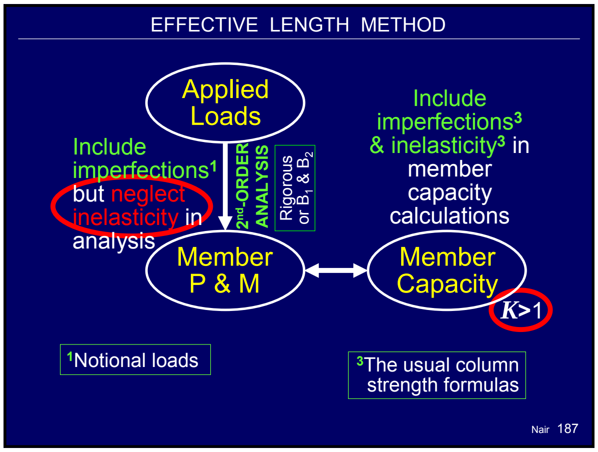
Design individual members using K from step 3 for computing compression strengths

Nair 185

EFFECTIVE LENGTH METHOD



Nair 186



CHAPTER C

STABILITY ANALYSIS AND DESIGN

C2. CACULATION OF REQUIRED STRENGTHS

2. Design Requirements — **DIRECT ANALYSIS METHOD**
   Can use Appendix 7 in all cases
   Can use C2.2a or C2.2b if $\Delta/\Delta_0 < 1.5$

2a. Design by Second-Order Analysis — **EFFECTIVE LENGTH METHOD**

2b. Design by First-Order Analysis — **FIRST-ORDER ANALYSIS METHOD**

FIRST-ORDER ANALYSIS METHOD

Can be used only when $P < 0.5 P_y$ in all columns whose flexural stiffness contributes to the lateral stability of the structure

FIRST-ORDER ANALYSIS METHOD

Perform first-order elastic analysis
- use nominal geometry
- use nominal stiffness

FIRST-ORDER ANALYSIS METHOD

Perform first-order elastic analysis
- use nominal geometry
- use nominal stiffness

Apply additional lateral loads:
$N_i = 2.1(\Delta/L)\,Y_i > 0.0042\,Y_i$

FIRST-ORDER ANALYSIS METHOD

Perform first-order elastic analysis
- use nominal geometry
- use nominal stiffness

Apply additional lateral loads:
$N_i = 2.1(\Delta/L)\,Y_i > 0.0042\,Y_i$

Apply B_1 multiplier to full moment in all beam-columns

FIRST-ORDER ANALYSIS METHOD

Perform first-order elastic analysis
- use nominal geometry
- use nominal stiffness

Apply additional lateral loads:
$N_i = 2.1(\Delta/L)\,Y_i > 0.0042\,Y_i$

Apply B_1 multiplier to full moment in all beam-columns

Design individual members using K=1 for computing compression strengths

FIRST-ORDER ANALYSIS METHOD

… is the Direct Analysis Method by the back door

… uses mathematical manipulation to get roughly the same results as the DAM for typical structures

CHAPTER C

STABILITY ANALYSIS AND DESIGN

C2. CACULATION OF REQUIRED STRENGTHS

2. Design Requirements
   Can use Appendix 7 in all cases — **DIRECT ANALYSIS METHOD**
   Can use C2.2a or C2.2b if $\Delta/\Delta_0 < 1.5$

2a. Design by Second-Order Analysis — **EFFECTIVE LENGTH METHOD**

2b. Design by First-Order Analysis — **FIRST-ORDER ANALYSIS METHOD**

	DIRECT ANALYSIS	EFFECTIVE LENGTH	FIRST ORDER
Limitations	---	$\Delta/\Delta_0 < 1.5$	$\Delta/\Delta_0 < 1.5$ $P/P_y < 0.5$

	DIRECT ANALYSIS	EFFECTIVE LENGTH	FIRST ORDER
Limitations	---	$\Delta/\Delta_0 < 1.5$	$\Delta/\Delta_0 < 1.5$ $P/P_y < 0.5$
Analysis	Second-Order	Second-Order	First-Order

	DIRECT ANALYSIS	EFFECTIVE LENGTH	FIRST ORDER
Limitations	---	$\Delta/\Delta_0 < 1.5$	$\Delta/\Delta_0 < 1.5$ $P/P_y < 0.5$
Analysis	Second-Order	Second-Order	First-Order (but apply B_1 to moment in beam-columns)

	DIRECT ANALYSIS	EFFECTIVE LENGTH	FIRST ORDER
Limitations	---	$\Delta/\Delta_0 < 1.5$	$\Delta/\Delta_0 < 1.5$ $P/P_y < 0.5$
Analysis	Second-Order	Second-Order	First-Order
Geometry	Nominal	Nominal	Nominal

	DIRECT ANALYSIS	EFFECTIVE LENGTH	FIRST ORDER
Limitations	---	$\Delta/\Delta_0 < 1.5$	$\Delta/\Delta_0 < 1.5$ $P/P_y < 0.5$
Analysis	Second-Order	Second-Order	First-Order
Geometry	Nominal	Nominal	Nominal
EI & EA	Reduced	Nominal	Nominal

	DIRECT ANALYSIS	EFFECTIVE LENGTH	FIRST ORDER
Limitations	---	$\Delta/\Delta_0 < 1.5$	$\Delta/\Delta_0 < 1.5$ $P/P_y < 0.5$
Analysis	Second-Order	Second-Order	First-Order
Geometry	Nominal	Nominal	Nominal
EI & EA	Reduced	Nominal	Nominal
Notional Load	0.002 Y_i minimum*	0.002 Y_i minimum	>0.0042Y_i additive

*additive when $\Delta/\Delta_0 > 1.5$

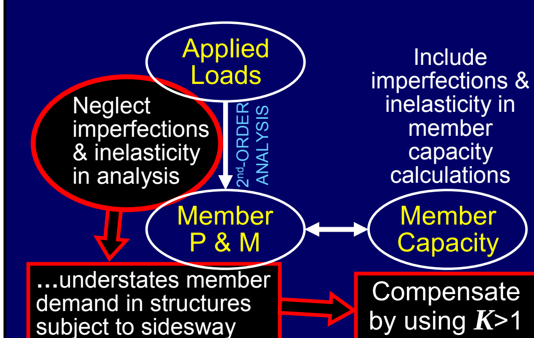
	DIRECT ANALYSIS	EFFECTIVE LENGTH	FIRST ORDER
Limitations	---	$\Delta/\Delta_0 < 1.5$	$\Delta/\Delta_0 < 1.5$ $P/P_y < 0.5$
Analysis	Second-Order	Second-Order	First-Order
Geometry	Nominal	Nominal	Nominal
EI & EA	Reduced	Nominal	Nominal
Notional Load	0.002 Y_i minimum*	0.002 Y_i minimum	>0.0042Y_i additive
K for member P_n	K = 1	Sidesway buckling analysis	K = 1

*additive when $\Delta/\Delta_0 > 1.5$

	DIRECT ANALYSIS	EFFECTIVE LENGTH	FIRST ORDER
Limitations	---	$\Delta/\Delta_0 < 1.5$	$\Delta/\Delta_0 < 1.5$ $P/P_y < 0.5$
Analysis	Second-Order	Second-Order	First-Order
Geometry	Nominal	Nominal	Nominal
EI & EA	Reduced	Nominal	Nominal
Notional Load	0.002 Y_i minimum*	0.002 Y_i minimum	>0.0042Y_i additive
K for member P_n	K = 1	Sidesway buckling analysis	K = 1

*additive when $\Delta/\Delta_0 > 1.5$

Conventional design approach (pre-2005)

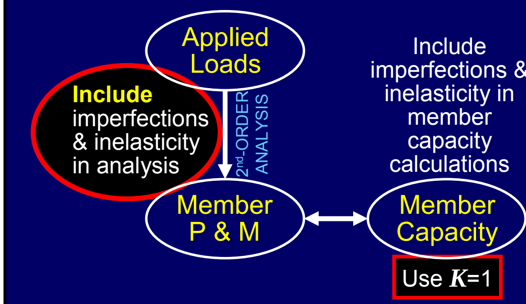


Conventional design approach (pre-2005)

- *… indicates incorrect design moments (unconservative error)*
- *… requires calculation of K-- how?*
- *… sometimes, too conservative*

Nair 205

Direct Analysis Method



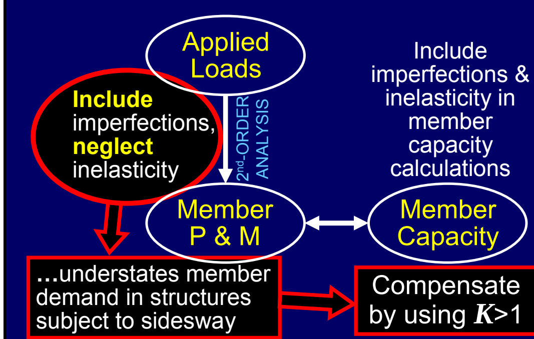
Nair 206

~~*Conventional design approach (pre-2005)*~~ *Direct Analysis Method*

- ~~*… indicates incorrect design moments (unconservative error)*~~
- ~~*… requires calculation of K-- how?*~~
- ~~*… sometimes, too conservative*~~

Nair 207

Effective Length Method



Nair 208

~~*Conventional design approach (pre-2005)*~~ *Effective Length Method*

- ~~*… indicates incorrect design moments (unconservative error)*~~
- *… requires calculation of K-- how?*
- *… sometimes, too conservative*

Nair 209

First-Order Analysis Method

- *… is the Direct Analysis Method by the back door*
- *… uses mathematical manipulation to get roughly the same results as the DAM for typical structures*

First-Order Analysis Method

… is the Direct Analysis Method by the back door

… uses mathematical manipulation to get roughly the same results as the DAM for typical structures

… generally same benefits as DAM

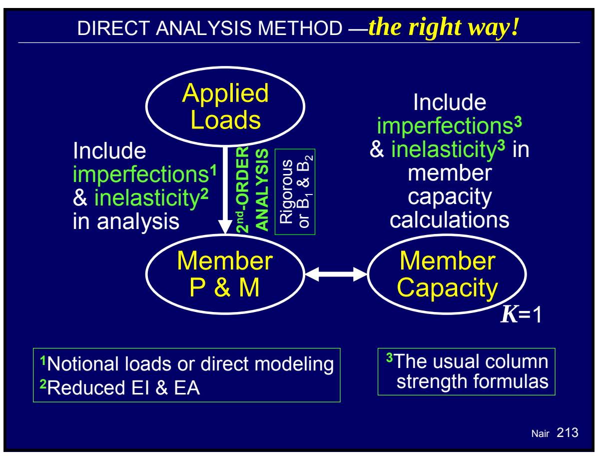
First-Order Analysis Method

… is the Direct Analysis Method by the back door

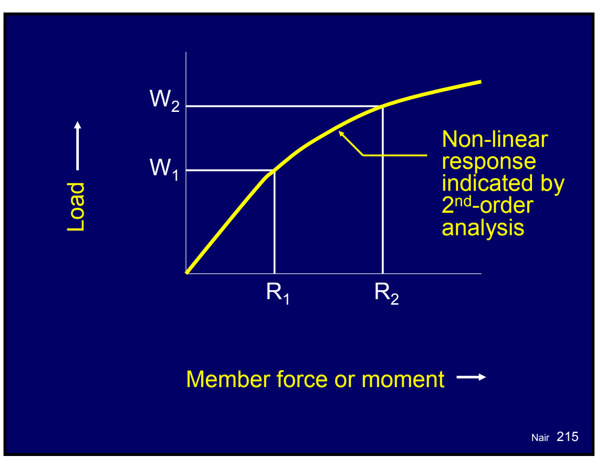
… uses mathematical manipulation to get roughly the same results as the DAM for typical structures

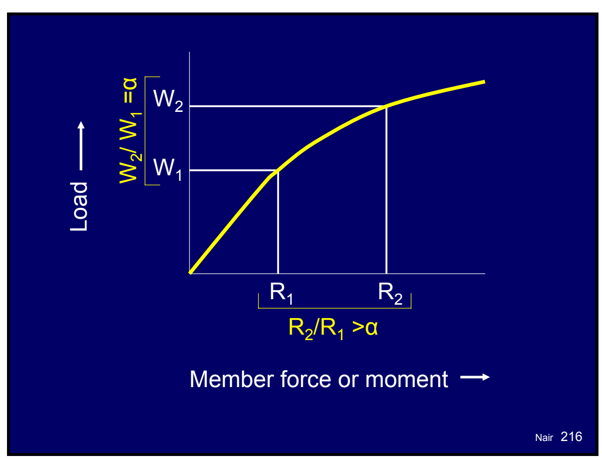
… generally same benefits as DAM

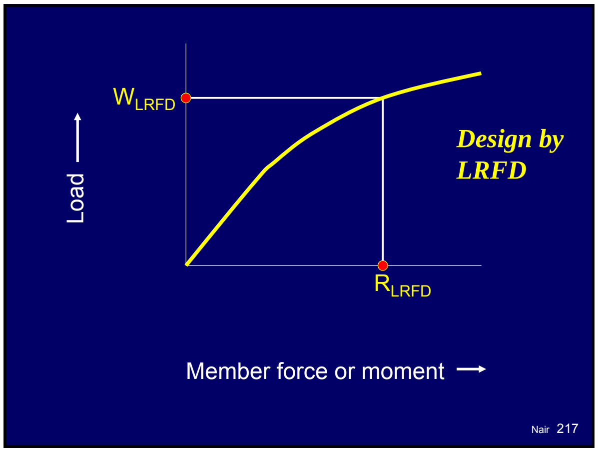
… but do not apply by rote; learn DAM first

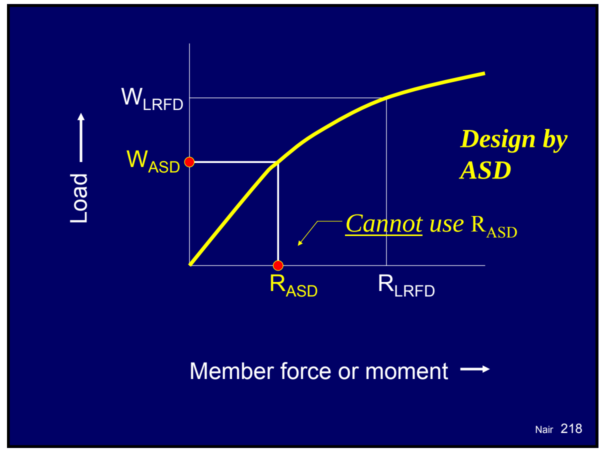


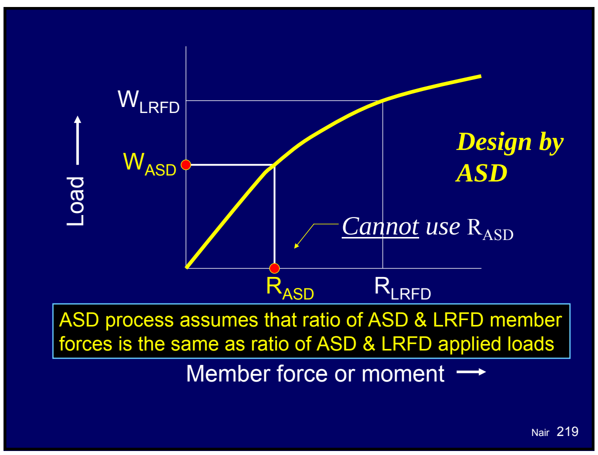
… a word about loading

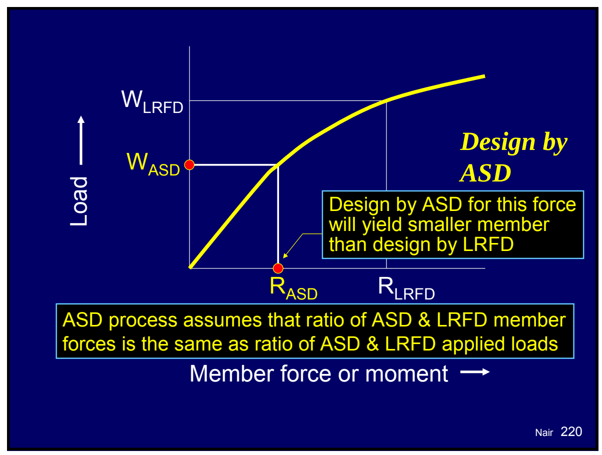


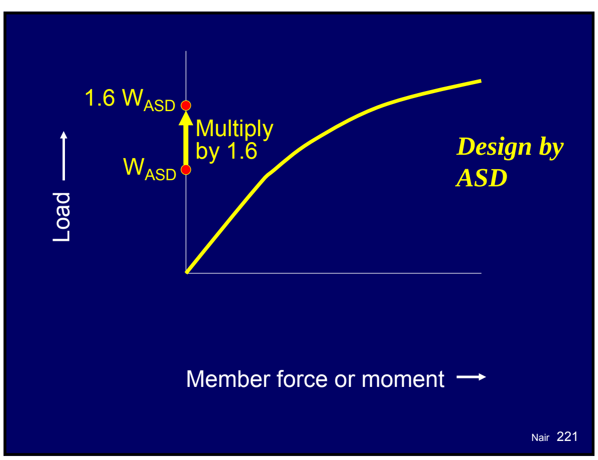


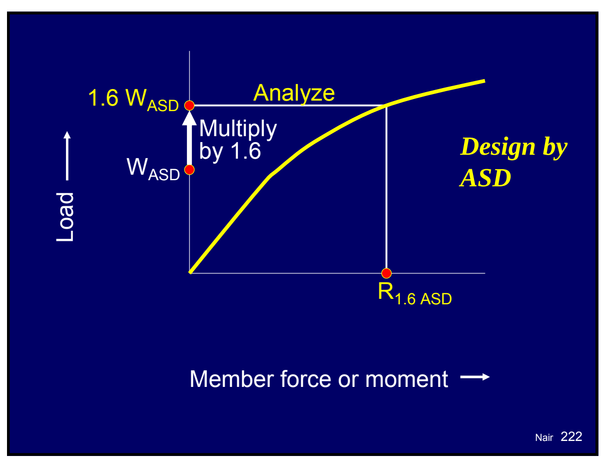

W_{LRFD}
Load
Design by LRFD
R_{LRFD}
Member force or moment
Nair 217

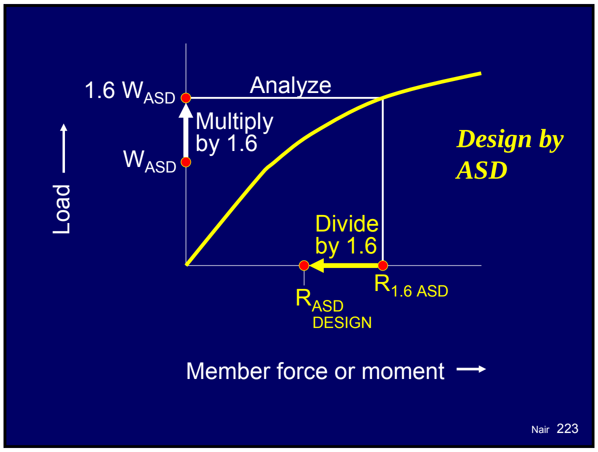

W_{LRFD}
W_{ASD}
Load
Design by ASD
Cannot use R_{ASD}
R_{ASD}
R_{LRFD}
Member force or moment
Nair 218

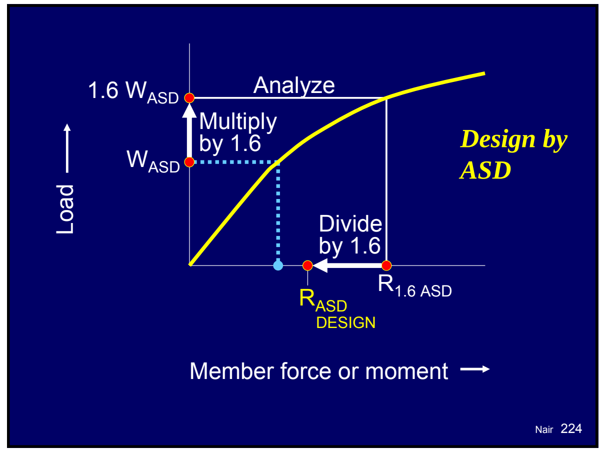

W_{LRFD}
W_{ASD}
Load
Design by ASD
Cannot use R_{ASD}
R_{ASD}
R_{LRFD}
ASD process assumes that ratio of ASD & LRFD member forces is the same as ratio of ASD & LRFD applied loads
Member force or moment
Nair 219


W_{LRFD}
W_{ASD}
Load
Design by ASD
Design by ASD for this force will yield smaller member than design by LRFD
R_{ASD}
R_{LRFD}
ASD process assumes that ratio of ASD & LRFD member forces is the same as ratio of ASD & LRFD applied loads
Member force or moment
Nair 220


1.6 W_{ASD}
Multiply by 1.6
W_{ASD}
Load
Design by ASD
Member force or moment
Nair 221


1.6 W_{ASD}
Analyze
Multiply by 1.6
W_{ASD}
Load
Design by ASD
$R_{1.6\ ASD}$
Member force or moment
Nair 222





Members of AISC TC-10 (Stability)

Shankar Nair — Chairman
Greg Deierlein — Vice-Chairman
Bill Baker
Reidar Bjorhovde
Charlie Carter
Shu-Jin Fang
Jim Fisher
Ted Galambos
Larry Griffis
Jerry Hajjar
Todd Helwig
Richard Henige
Leroy Lutz
Clint Rex
Steve Thomas
Don White
Ron Ziemian

Nair 225

Members of AISC TC-10 (Stability)

Much of the early work on the 2005 stability provisions was done under the leadership of former TC-10 chairman Joe Yura

Shankar Nair — Chairman
Greg Deierlein — Vice-Chairman
Bill Baker
Reidar Bjorhovde
Charlie Carter
Shu-Jin Fang
Jim Fisher
Ted Galambos
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Todd Helwig
Richard Henige
Leroy Lutz
Clint Rex
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Don White
Ron Ziemian

Nair 226

Looking ahead…

The paper in the 2007 NASCC proceedings (for this presentation) includes a model specification written exclusively around the Direct Analysis Method.

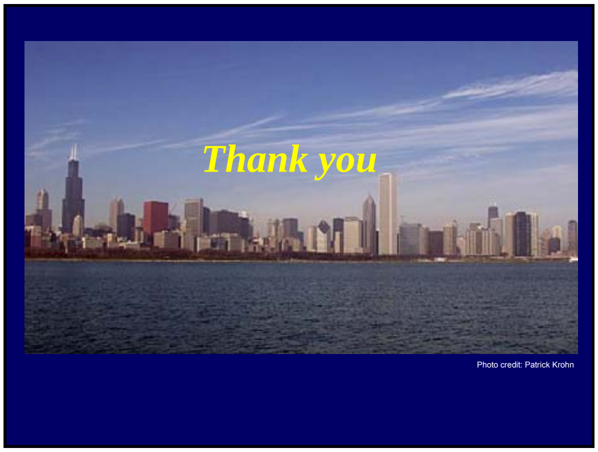
Nair 227

Looking ahead…

The paper in the 2007 NASCC proceedings (for this presentation) includes a model specification written exclusively around the Direct Analysis Method.

That model specification is a tentative preview of the stability section of the 2010 AISC Specification.

Nair 228


Thank you
Photo credit: Patrick Krohn