Advanced Analysis ("PHINGE": Refined Plastic Hinge)

1) Accounting for

- Stability Effect (Geometric Nonlinear)
- Gradual Yielding (Material Nonlinear)
  - Residual Stresses
  - Flexure

2) Not accounting for

- Geometric Imperfection (Erection tolerance)
- Strength Reduction Factor

$\Sigma \gamma_i Q_i \le \phi R_n$

ϕ ← Reduction Factor

$\phi_c = 0.85$

$\phi_b = 0.9$

Practical Advanced Analysis Method (PAAM)

1) Modeling with geometric imperfection
   - ① Method 1 : Explicit imperfection modeling : $0.002\,L_c$
   - ② Method 2 : Equivalent notional load : $0.002\,\Sigma P$
   - ③ Method 3 : Further reduced tangent modulus : $0.85\,E_t$

2) Analysis ("PHINGE")

3) Reduction Factor

Simply use $\phi = 0.9$

Ultimate load carrying capacity, P_u from "PHINGE" OUTPUT

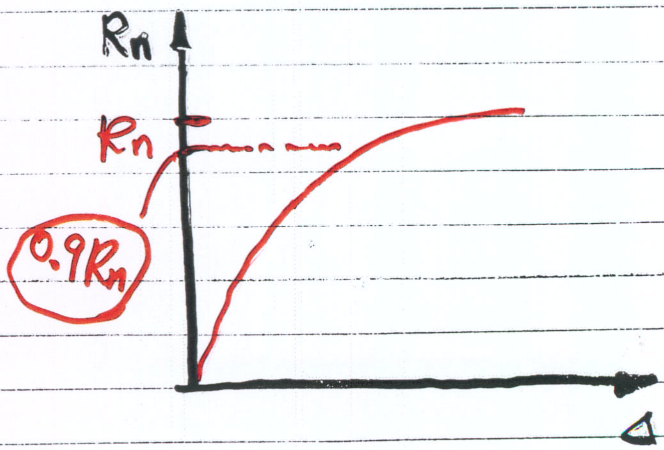
Max. load carrying capacity $= 0.9\,P_u$

4) Compare applied factored load and load carrying capacity

$$\Sigma \gamma_i Q_i \le \phi R_n$$

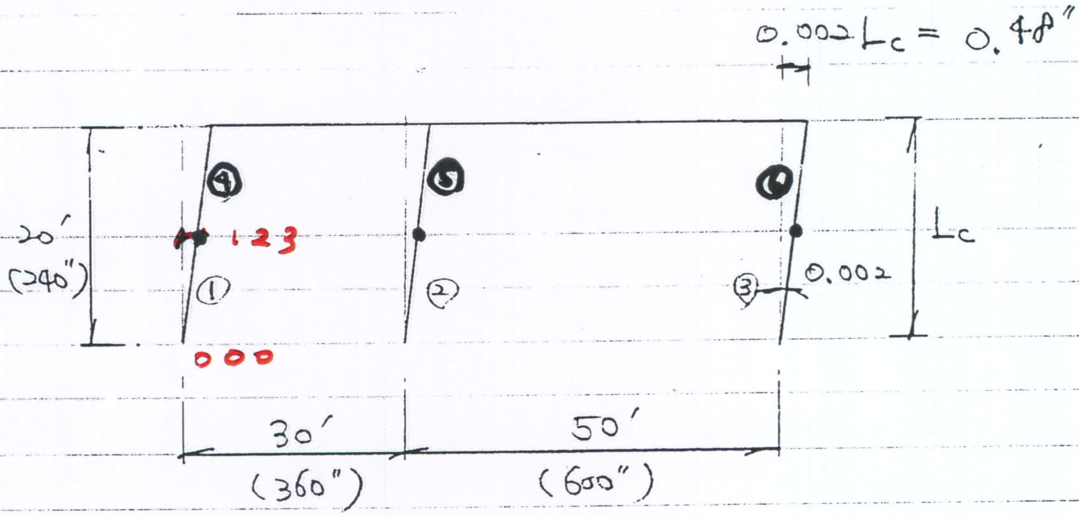
1.7 3.0 0.9

51



Modeling

1) Explicit Imperfection Modeling

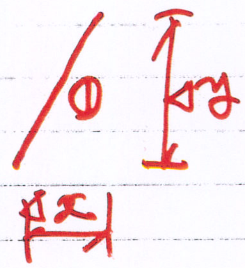


Data Set 11. Fram element data and geometry (P479)

Elem No	X	Y	Section Type	- - -
①	0.24	120		
②	0.24	120		
⋮	⋮	⋮		
⑥	0.24	120		
⑦				

⇑

0.002 × 120



H.W. for chap 8, Part 1;analysis problem, refined plastic-hinge analysis

```
  1
  1    1
 27  100     1     1
  0    2     0
  0   11     0
  1       13.3        586      82.3      29000        36
  2       12.6        428      69.6      29000        36
  1          0        120    2    0    0    0    1    2    3
  2          0        120    2    0    0    0    4    5    6
  3          0        120    2    0    0    0    7    8    9
  4          0        120    2    1    2    3   10   11   12
  5          0        120    2    4    5    6   19   20   21
  6          0        120    2    7    8    9   25   26   27
  7         90          0    1   10   11   12   13   14   15
  8        180          0    1   13   14   15   16   17   18
  9         90          0    1   16   17   18   19   20   21
 10        300          0    1   19   20   21   22   23   24
 11        300          0    1   22   23   24   25   26   27
 10          1
 14         -1
 17         -1
 23         -1
```

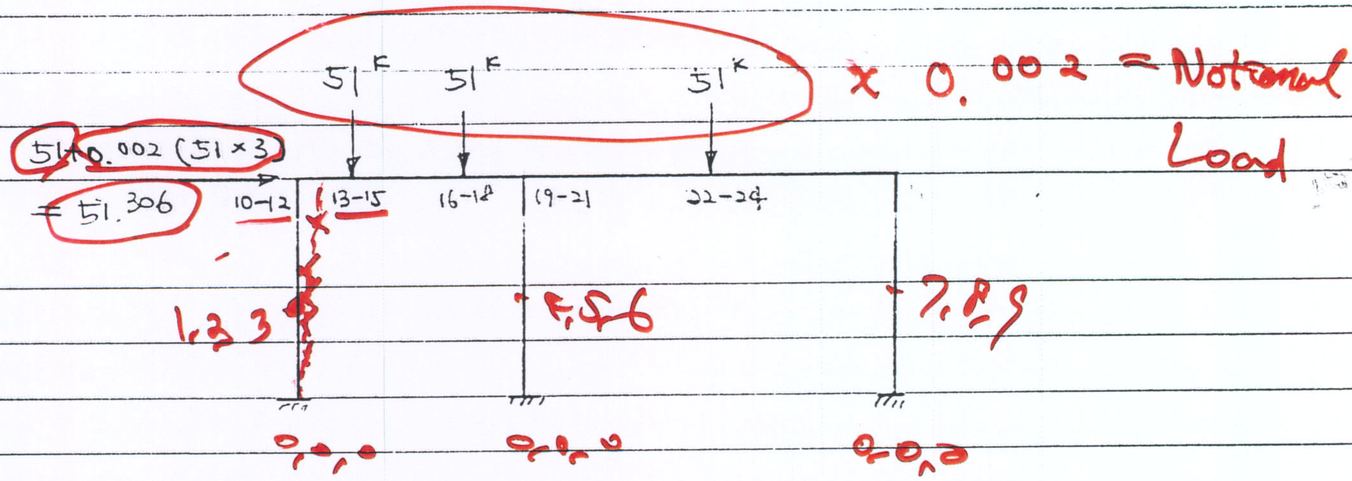
Section Properties

Element Data

Loading Condition

Input Data w/o Geometric Imperfection

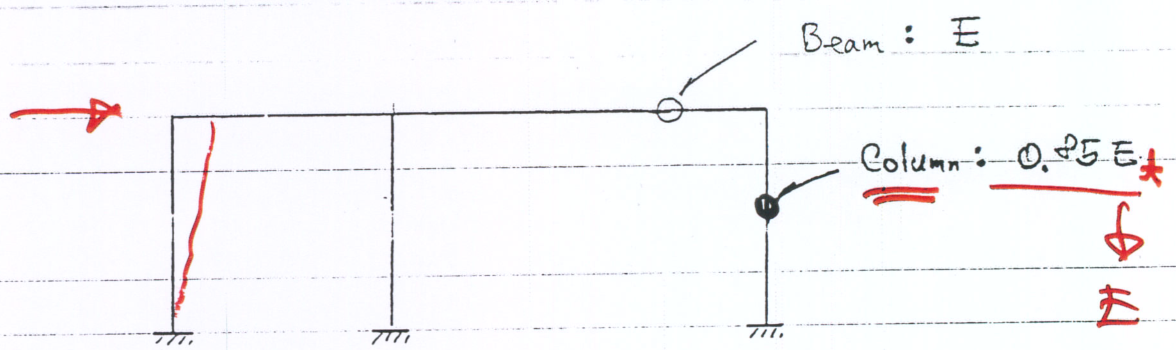
2) Equivalent Notional Load



Data Set 13 : Nodal load (P4f0)

10	1.006	⟸ 51.306 × $\frac{1}{51}$
14	-1	
17	-1	$51 \times \frac{1}{51} = -1$
23	-1	

3) Further Reduced Tangent Modulus (P478)



Data Set 8 : Frame element properties

	Set. Type	A	I	Z	E	Fy
Beam →	1	--	--	--	29,000	--
Column →	2	--	--	--	24,650	--

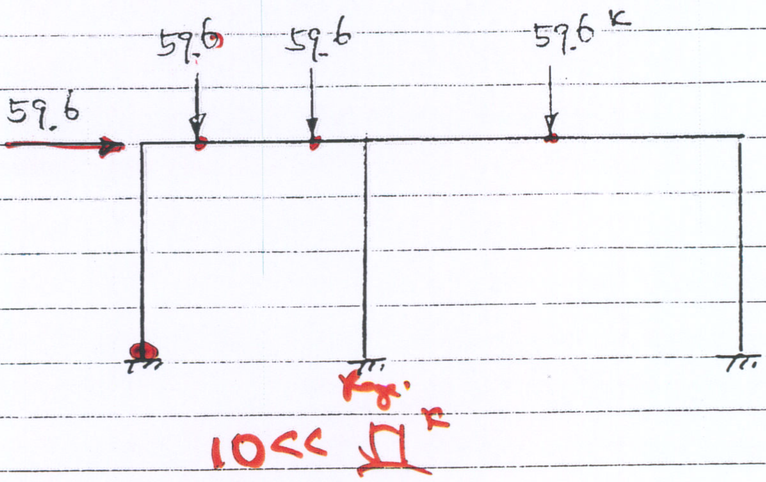
↑ $(0.85)(29,000)$

Reduction Factor Application

```
-------------------
- LOAD STEP 103 -
-------------------
```

LOAD SEQUENCE 1
DETERMINANT OF STIFFNESS MATRIX = 0.34956 TIMES 10 TO THE POWER 104
TRACE OF STIFFNESS MATRIX = 0.90177 TIMES 10 TO THE POWER 7

DOF	NODAL FORCE	NODAL DISPLACEMENT
1	0.00000D+00	0.97421D+00
2	0.00000D+00	-0.15881D-01
3	0.00000D+00	-0.13943D-01
4	0.00000D+00	0.10436D+01
5	0.00000D+00	-0.31118D-01
6	0.00000D+00	-0.14169D-01
7	0.00000D+00	0.13650D+01
8	0.00000D+00	-0.17019D-01
9	0.00000D+00	-0.15193D-01
10	0.59602D+02	0.28880D+01
11	0.00000D+00	-0.44805D-01
12	0.00000D+00	-0.16030D-01
13	0.00000D+00	0.28739D+01
14	-0.59602D+02	-0.12490D+01
15	0.00000D+00	-0.85075D-02
16	0.00000D+00	0.28609D+01
17	-0.59602D+02	-0.84563D+00
18	0.00000D+00	0.95143D-02
19	0.00000D+00	0.28515D+01
20	0.00000D+00	-0.72724D-01
21	0.00000D+00	-0.13650D-01
22	0.00000D+00	0.27876D+01
23	-0.59602D+02	-0.56277D+01
24	0.00000D+00	0.16179D-02
25	0.00000D+00	0.27229D+01
26	0.00000D+00	-0.33945D-01
27	0.00000D+00	0.15694D-01



$P_{max} = \Phi P_u$

$= (0.9)(59.6)$

$= 53.6$ k

$P_{applied} = 51$ k

$P_{max} > P_{applied}$ O.K

100k > 51k

Summary

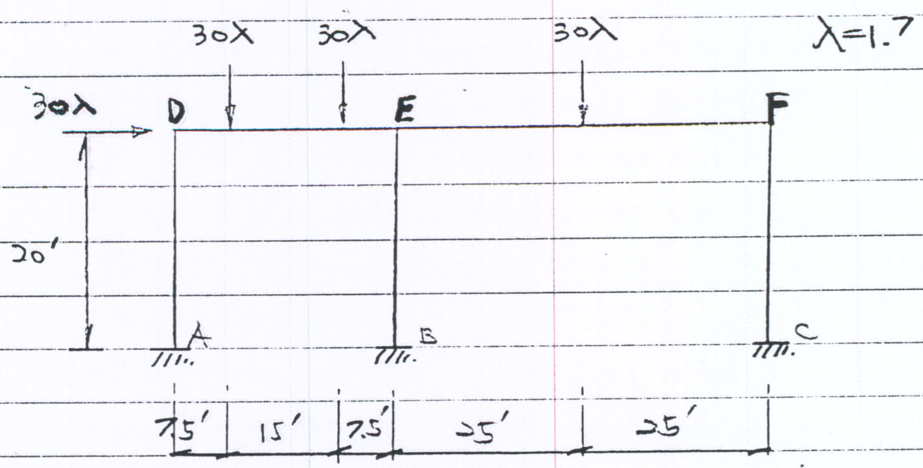
– Plastic Analysis Methods and Their Consideration

Analysis / Considerations	Chapter 7: 1st-Order Elastic-Plastic (FOPA)	Chapter 8: 2nd-Order Elastic-Plastic ("PHINGE")	Chapter 8: 2nd-Order Refind Plastic ("PHINGE")
1) Elastic-Plastic in Material	O	O	O
2) Gradual Yield with flexure			O
3) Residual Stresses along member			O
4) Second-Order Effect		O	O
5) Geometric Imperfection			△

note △: considered by explicit modeling rather than by the program in general.

2 Bay Frame Design

1. Frame Configuration and Load Condition



A36 ($F_y = 36$ ksi, $E = 29{,}000$ ksi)

Use W16 for beam section (All beam sizes are identical)

W14 for column section (All column sizes are identical)

Choose lightest sections

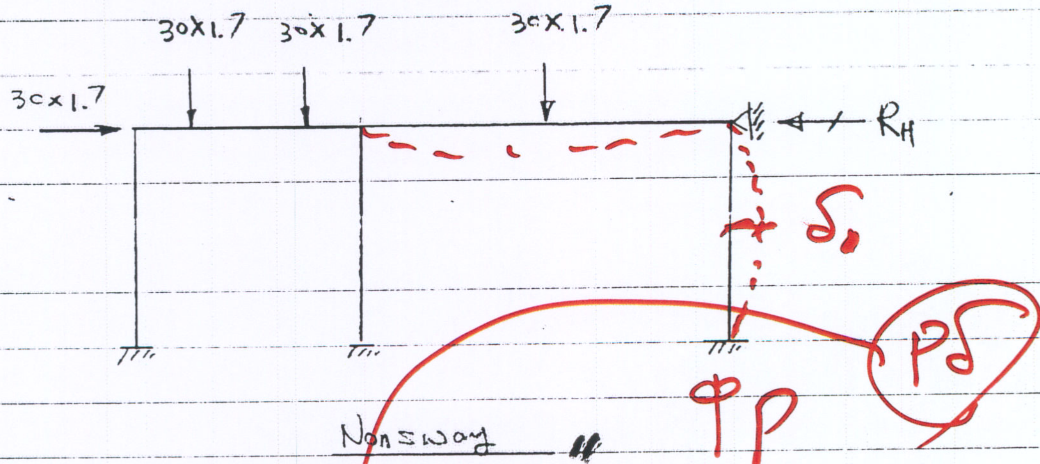
Laterally fully braced

2. Design Methods

1) LRFD Method

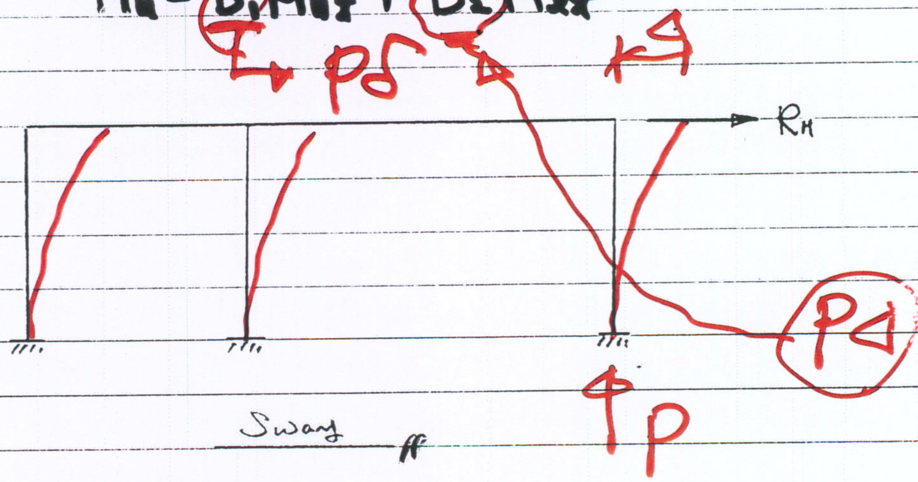
2) Practical Advanced Analysis Method

Elastic Analysis in LRFD



Nonsway

$$M_u = B_1 M_{nt} + B_2 M_{lt}$$



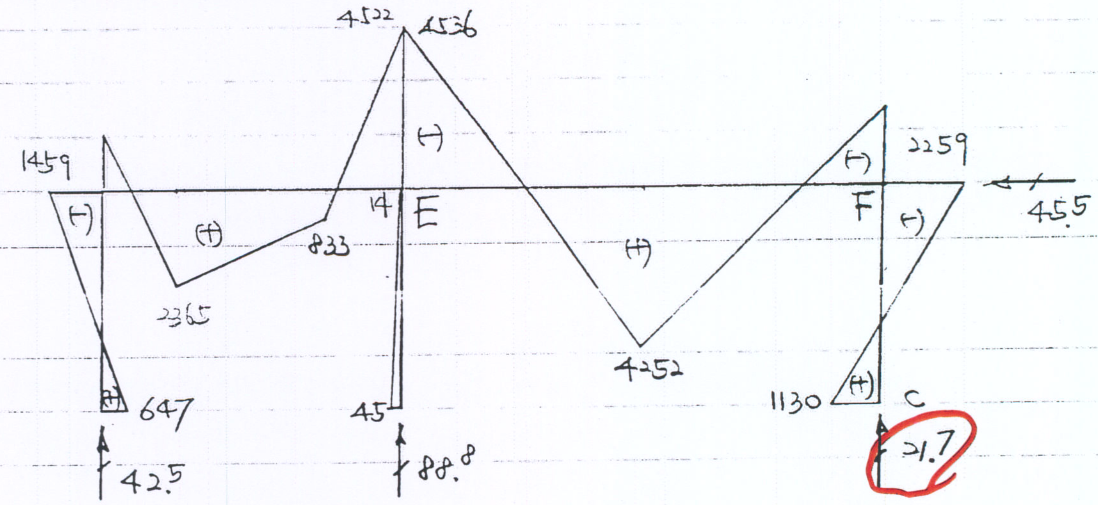
Sway

Member Size Assumption for LRFD Method

Beam W16x89 (A = 26.2, I = 1300, Z = 175, r = 7.05)

Col W14x68 (A = 20.0, I = 723, Z = 115, r = 6.01)

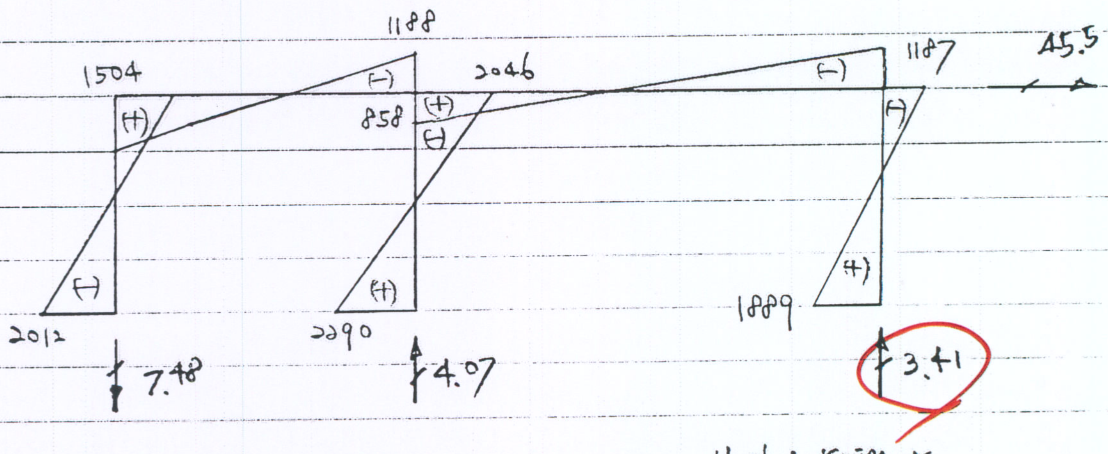
Moment Diagram



Unit: K·in, K

Moment for Nonsway

Mnt



Unit: K-in, K

Moment for Sway

M

LRFD Design Equation

(a) For $\frac{P_u}{\phi P_n} \geq 0.2$

$$\frac{P_u}{\phi P_n} + \frac{8}{9}\left(\frac{M_{ux}}{\phi_b M_{nx}} + \frac{M_{uy}}{\phi_b M_{ny}}\right) \leq 1.0 \qquad \text{(H1-1a)}$$

(b) For $\frac{P_u}{\phi P_n} < 0.2$

$$\frac{P_u}{2\phi P_n} + \left(\frac{M_{ux}}{\phi_b M_{nx}} + \frac{M_{uy}}{\phi_b M_{ny}}\right) \leq 1.0 \qquad \text{(H1-1b)}$$

$$P_n = A_g F_{cr} \qquad \text{(E2-1)}$$

(a) For $\lambda_c \leq 1.5$

$$F_{cr} = (0.658^{\lambda_c^2})F_y \qquad \text{(E2-2)}$$

(b) For $\lambda_c > 1.5$

$$F_{cr} = \left[\frac{0.877}{\lambda_c^2}\right]F_y \qquad \text{(E2-3)}$$

where

$$\lambda_c = \frac{Kl}{r\pi}\sqrt{\frac{F_y}{E}} \qquad \text{(E2-4)}$$

$$M_u = B_1 M_{nt} + B_2 M_{lt} \qquad \text{(C1-1)}$$

$$B_1 = \frac{C_m}{(1 - P_u / P_{e1})} \geq 1 \qquad \text{(C1-2)}$$

$$P_{e1} = A_g F_y / \lambda_c^2$$

$$\lambda_c = \frac{Kl}{r\pi}\sqrt{\frac{F_y}{E}}$$

$$C_m = 0.6 - 0.4(M_1 / M_2) \qquad \text{(C1-3)}$$

$$B_2 = \frac{1}{1 - \Sigma P_u\left(\frac{\Delta_{oh}}{\Sigma HL}\right)} \qquad \text{(C1-4)}$$

or

$$B_2 = \frac{1}{1 - \frac{\Sigma P_u}{\Sigma P_{e2}}} \qquad \text{(C1-5)}$$

$$P_{e2} = A_g F_y / \lambda_c^2$$

Member Capacity Check

1) Column CF

- Interaction Equation

$$\frac{P_u}{\phi P_n} + \frac{8}{9}\frac{M_u}{\phi M_n} \le 1.0 \quad \text{for } \frac{P_u}{\phi P_n} \ge 0.2$$

$$\frac{P_u}{2\phi P_n} + \frac{M_u}{\phi M_n} \le 1.0 \quad \text{for } \frac{P_u}{\phi P_n} < 0.2$$

- P_n

$$G_C = \frac{\Sigma(EI/L)_c}{\Sigma(EI/L)_b} = \frac{723/20}{1300/50} = 1.39$$

$$G_F = \frac{\Sigma(EI/L)_c}{\infty} = 0$$

$K \approx 1.2$ by Alignment Chart

$$\lambda_c = \frac{KL}{\pi r}\sqrt{\frac{F_y}{E}} = \frac{(1.2)(20)(12)}{\pi(6.01)}\sqrt{\frac{36}{29000}} = 0.537 < 1.5$$

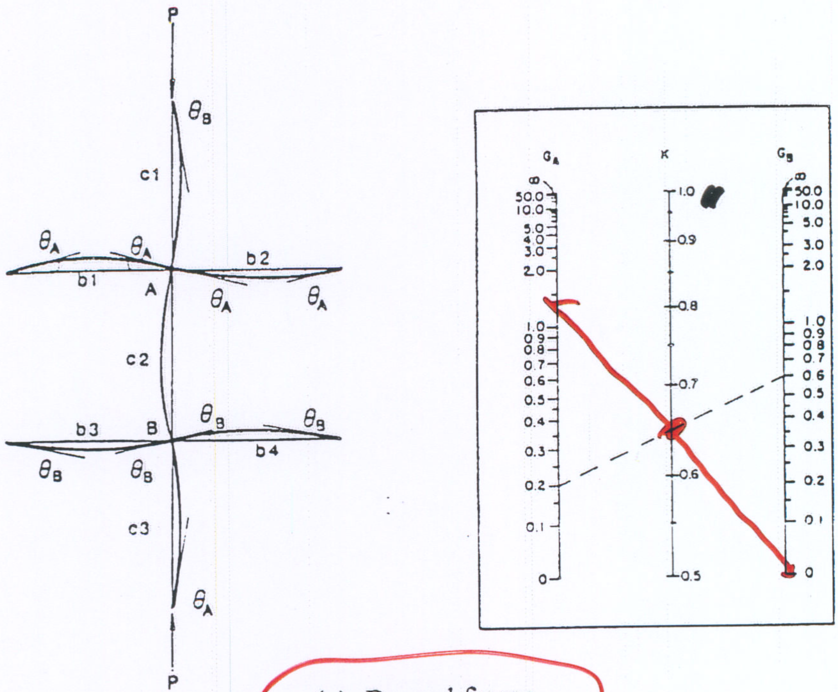
$$P_n = (0.658)^{\lambda_c^2} F_y A = (0.658)^{(0.537)^2}(36)(20.0) = 638^k$$

- M_n

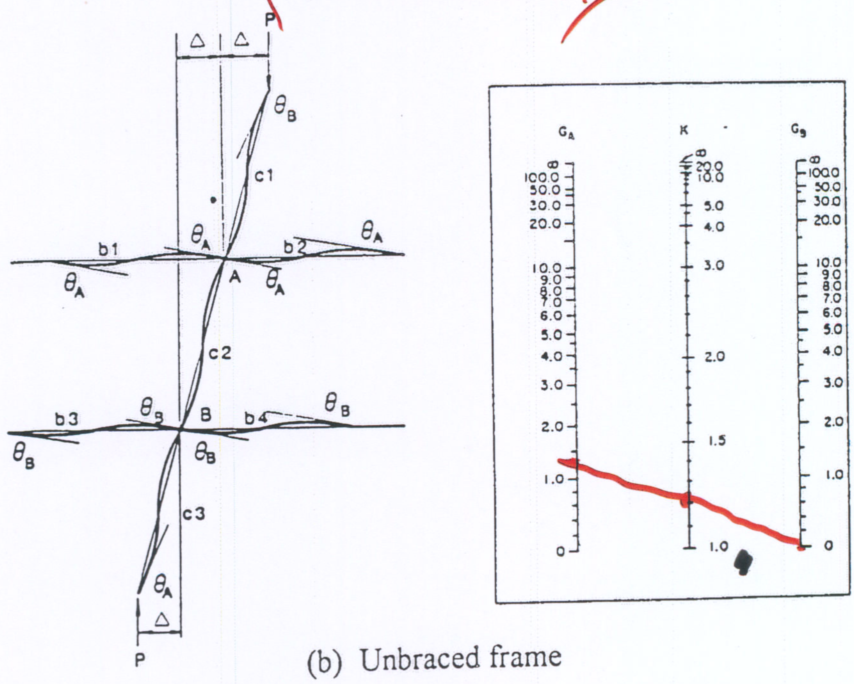
$M_n = M_p = Z \cdot F_y = (115)(36) = 4140^{k\text{-}in}$; Laterally Braced

- P_u

$$P_u = P_{nonsway} + P_{sway} = 21.7 + 3.41 = 25.1$$



(a) Braced frame



(b) Unbraced frame

Figure 2.7 Alignment chart

− M_u

$$M_u = B_1 M_{nt} + B_2 M_{\ell t}$$

$$B_1 = \frac{C_m}{1 - P_u/P_{e1}}$$

$$C_m = 0.6 - 0.4\,(M_1/M_2) = 0.6 - 0.4\,(1130/2259) = 0.40$$

$K_{braced} = 0.64$ from Alignment Chart

$$P_{e1} = \frac{\pi^2 EI}{(KL)^2} = \frac{\pi^2 (29000)(723)}{(0.64 \times 20 \times 12)^2} = 8771^k$$

$$B_1 = \frac{0.40}{1 - \frac{25.11}{8771}} = 0.40 < 1.0 \quad \text{Use } 1.0$$

$$B_2 = \frac{1}{1 - \frac{\Sigma P_u}{\Sigma P_{e2}}}$$

$$\Sigma P_u = 30 \times 1.7 \times 3 = 153^k$$

$$\Sigma P_{e2} = \Sigma \frac{\pi^2 EI}{(KL)^2} = \frac{\pi^2 EI}{L^2}\left(\Sigma \frac{1}{K^2}\right)$$

Unbraced K

$$K_{FC} \approx 1.2$$

$$K_{DA} \approx 1.13 \quad \begin{cases} G_D = \dfrac{723/20}{1300/30} = 0.834 \\ G_A = 0 \end{cases}$$

$$K_{EB} \approx 1.10 \quad \begin{cases} G_E = \dfrac{723/20}{1300/30 + 1300/50} = 0.521 \\ G_B = 0 \end{cases}$$

$$\Sigma P_{e2} = \frac{\pi^2 (29000)(723)}{(20 \times 12)^2}\left(\frac{1}{(1.2)^2} + \frac{1}{(1.13)^2} + \frac{1}{(1.10)^2}\right)$$

$$= 8278^k$$

$$B_2 = \frac{1}{1 - \frac{153}{8278}} = 1.02$$

$M_u = (1.0)(-2259) + (1.02)(-1187) = 3470^k$ Top ← Control

$M_u = (1.0)(1130) + (1.02)(1889) = 3057^k$ Bottom

- Interaction Check

$$\frac{P_u}{\phi P_n} = \frac{25.11}{(0.85)(638)} = 0.046 < 0.2$$

$$\frac{P_u}{2\phi P_n} + \frac{M_u}{\phi M_n} = \frac{0.046}{2} + \frac{3470}{(0.9)(4140)} = 0.95 < 1.0$$

O.K

Use W 14x68

2) Beam EF

Neglect axial force

$$\frac{P_u}{2\phi P_n} + \frac{M_u}{\phi M_n} < 1.0$$

$M_u = 4252$

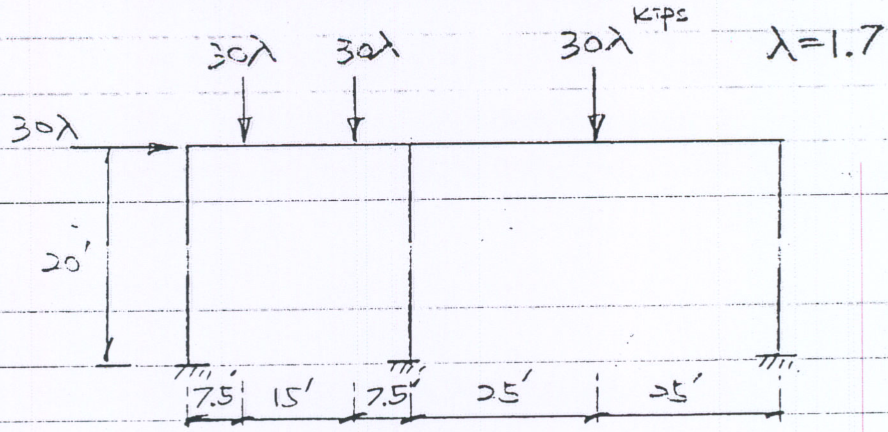
$M_n = Z_x F_y = (175)(36) = 6300$

$$\frac{4536}{(0.9)(6300)} = 0.8 \ll 1.0 \quad \text{O.K}$$

Use W 16x89

Homework Chapter 8 Part II (Due Nov. 30 1995)

(Ph.D student : Obligatory
Master Student : Strongly Recommended)



A36
(F_y = 36 ksi, E = 29,000 ksi)

Assume laterally fully braced

Use W16 for beam section (All beam sizes are identical)
W14 for column section (All column sizes are identical)

1. Determine lightest sections using "Practical Advanced Analysis Method." You can use one among three geometric imperfection methods.

2. Which geometric imperfection method did you use for "Problem No 1". Please discuss briefly why you use that specific geometric imperfection method.

3. Please compare member sizes determined by LRFD method and by Practical Advanced Analysis Method. If there are some differences in member sizes determined by two method, Please discuss the reason briefly.

4. If you are an engineer for a consulting company, which method between LRFD and "PAAM" will you use? Please discuss briefly why you use that specific method.