Design for Stability
Direct Analysis Method
CE 470 (Fall 2016)

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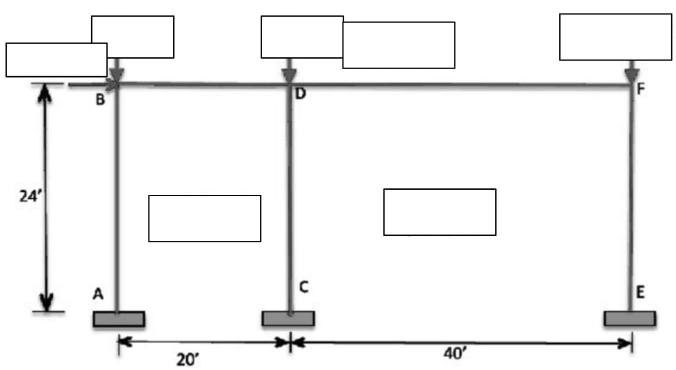
HOW WILL YOU DESIGN??



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STABILITY

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- "the capacity of a compression member, element, or frame to remain in position and support load, even if forced slightly out of line or position by an added lateral force" (Galambos, 1998)

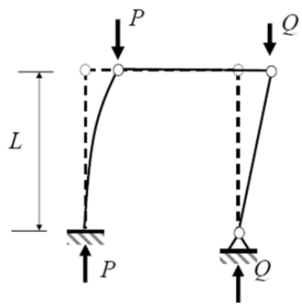

Figure from NASCC: The Steel Conference 2014, Session N40, Geschwindner

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AISC DESIGN FOR STABILITY

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- Stability to be provided for structure as whole, and each elements.
- Discusses the effects that need to be considered
- Any rational method considering these effects can be used
- Methods identified
  - Chapter C: Direct Analysis Method (DAM)
  - Appendix 7: Alternative Methods (effective length method & first order analysis methods) subject to constraints

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5 FACTORS THAT INFLUENCE STABILITY

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- Member, component, and connection deformations
- Second-order effects (P-Δ and P-δ)
- Geometric imperfections (out-of-plumbness or out-of-straightness)
- Stiffness reductions due to inelasticity (residual stresses)
- Variability in component and system stiffness

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SECOND ORDER EFFECTS

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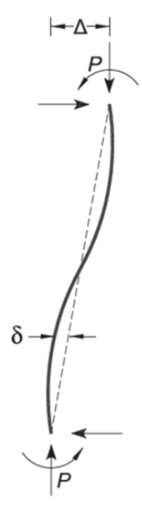

P-Δ = Effect of loads acting on the displaced location of joints or nodes in a structure.

P-δ = Effect of loads acting on the deflected shape of a member between joints or nodes.

Fig. C-C2.1. P-Δ *and* P-δ *effects in beam-columns.*

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CHAPTER C
DAM: ANALYSIS REQUIREMENTS

- Consider axial, flexural, and shear deformations in members, and connection deformations: accounted for directly by analysis
- Consider second order effects: perform rigorous analysis or use approximate method in Appendix 8
- All loads influencing the stability need to be considered. For LRFD, use combinations. For ASD, use 1.6 times the combinations for analysis, divide the demands by 1.6

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SECOND ORDER ANALYSIS

- Rigorous non-linear analysis in the software considering second order effects
- Approximate second order analysis (Appendix 8)
  - Multipliers B_1 and B_2 to consider the second order effects

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CHAPTER C
DAM: INITIAL IMPERFECTIONS

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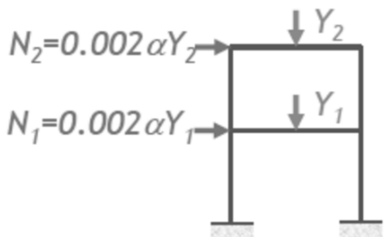
- Directly model the imperfections
- Use Notional Loads



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CHAPTER C
DAM: INITIAL IMPERFECTIONS

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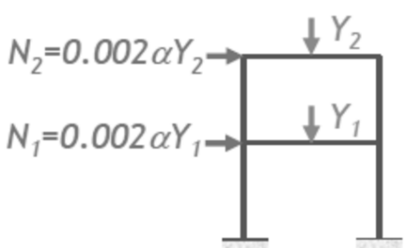
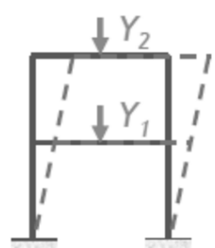


OR



Notional Loads

Direct Modeling of Imperfections

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Chapter C
DAM: Stiffness

- Reduce stiffness contributing to stability by 20%
- Further reduce flexural stiffness by a factor τ_b, depending of the ratio of axial compression demand and yield strength

(a) When $\alpha P_r/P_y \le 0.5$

$$\tau_b = 1.0 \quad \text{(C2-2a)}$$

(b) When $\alpha P_r/P_y > 0.5$

$$\tau_b = 4(\alpha P_r/P_y)[1-(\alpha P_r/P_y)] \quad \text{(C2-2b)}$$

where

α = 1.0 (LRFD); α = 1.6 (ASD)

P_r = required axial compressive strength using *LRFD* or *ASD load combinations*, kips (N)

P_y = axial *yield strength* (= $F_y A_g$), kips (N)

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Chapter C
DAM: Available Strengths

- Provisions of Chapters D, E, F, G, H, I, J, K.
- **Effective length, K=1**

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5 FACTORS THAT INFLUENCE STABILITY (DAM)

- Member, component, and connection deformations: addressed directly in analysis
- Second-order effects (P-Δ and P-δ) : rigorous second-order analysis or first-order with B1-B2
- Geometric imperfections (out-of-plumbness [notional loads *or direct modeling*] or out-of-straightness [column design equations*; and reduced stiffness for effect on structure stiffness*]

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5 FACTORS THAT INFLUENCE STABILITY (DAM)

- Stiffness reductions due to inelasticity (residual stresses) : column design equations; *and reduced stiffness for effect on structure stiffness*
- Variability in component and system stiffness: in resistance and safety factors!

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App. 7
Effective Length Method (ELF): Limitations

- Gravity loads supported primarily by vertical columns, walls or frames
- $\frac{\Delta_{2-order}}{\Delta_{1-order}} \leq 1.5$

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App. 7
Effective Length Method (ELF)

- Required Strength: Analysis same as for DAM, except stiffness reduction is not applied. Notional load is applied, second order analysis is performed.
- Available Strength: with provisions of Chapters D-K.
  - K needs to be calculated for each case
  - Alignment charts provided in the commentary can be used

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Effective Length Method

- Design process
  - Apply notional loads, $N_i = 0.002\alpha Y_i$ in the gravity only load cases
  - Perform a second-order elastic analysis
  - Determine K-factor from a sidesway buckling analysis
  - Check strength using interaction equations

NASCC: The Steel Conference, Toronto, March, 2014
There's always a solution in steel!

N40.78

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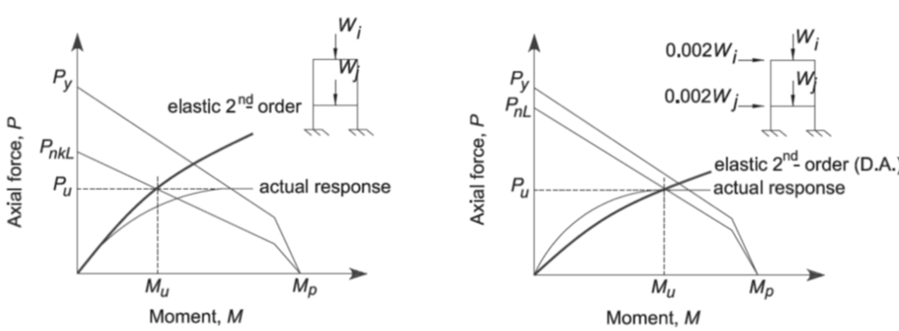
COMPARISON



(a) Effective length method (b) Direct analysis method

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AISC C-C2.3

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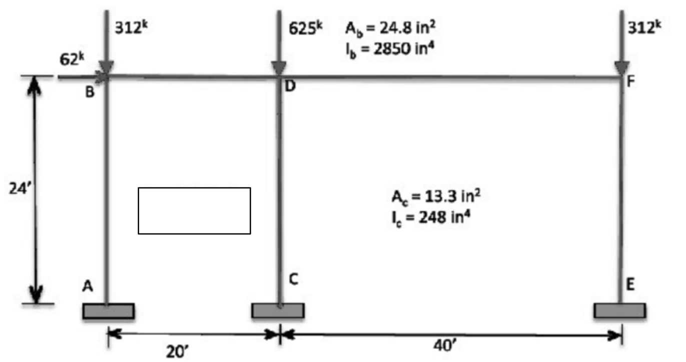
How Will You Design??



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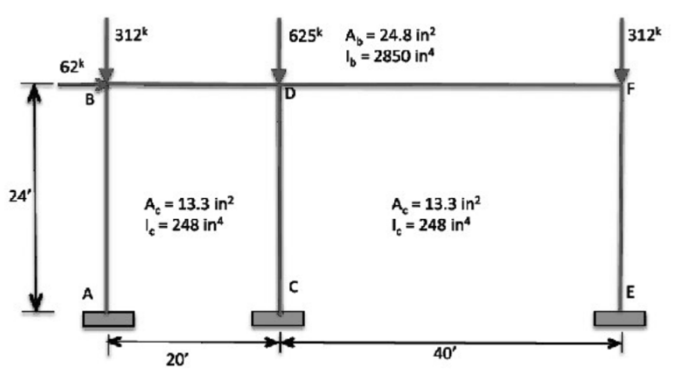
Direct Analysis Method: Example

- SAP 2000 is used to analyze the frame shown below, using the provisions of Chapter C.



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DAM EXAMPLE: ASSUMPTIONS

- The loads provided are factored loads from combinations
- Self-weight is included in the loads provided
- Since there is a lateral load applied, notional load is considered in one direction

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DAM EXAMPLE: PROCEDURE

- Check if the software to be used considers the P-Δ and P-δ effects
- This is done using the benchmarking problems provided in the commentary to Chapter C
- An elastic first order analysis is performed, then a second order analysis based on Chapter C is performed
- The results of both the analysis are compared

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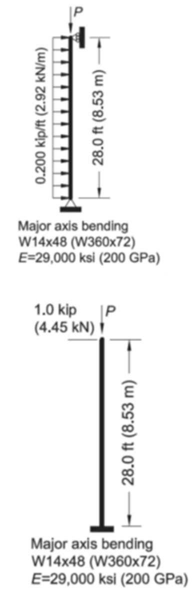
DAM EXAMPLE: BENCHMARKING



PROBLEM 1	P(KIPS)	0	150	300	450
SAP	M(kip-in)	235.2	269.62	315.35	378.92
	Δ(in)	0.2011	0.22986	0.26797	0.3209
ERROR %	M	0.085106	-0.14074	-0.2057	-0.28421
	Δ	-0.44554	-0.06087	-0.3829	-0.34161
PROBLEM 2	P(KIPS)	0	100	150	200
SAP	M(kip-in)	336	468.41	597.11	843.49
	Δ(in)	0.90542	1.3344	1.75325	2.5571
ERROR %	M	0	-0.3383	-0.64725	-1.46145
	Δ	-0.1742	-0.41791	-0.94633	-1.65

DAM EXAMPLE: ELASTIC ANALYSIS

- The frame is modeled with W shapes chosen according to the section properties in problem (Beam section: W 27x84 , Column Section: W 10x45).
- Linear Static Loading category is selected and the given loads are applied.
- Model is analyzed and member forces and story drifts are noted.

DAM EXAMPLE: NON-LINEAR ANALYSIS

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- The Loading is changed to Non-Linear static category and P-Δ effects are selected (to take care of second order effects).
- P-δ effects are considered by creating nodes along the length of the members.
- The top ends of columns are offset by H/500 (to take care of initial out-of plumbness, instead of applying notional load). Notional load can be applied by selecting notional loads from 'More' submenu under Load patterns.

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DAM EXAMPLE: NON-LINEAR ANALYSIS

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- The stiffness of all beam columns is reduced by 20% by using area and inertia reduction factors (to take into account the residual stresses in the elements). Can also be done by reducing E value (will need to be changed again if design is performed by the software)
- For central column, Pr > 0.5 × Py . Hence, its flexural stiffness needs to be further reduced by τ_b. Instead of doing this, an additional Notional Load of 0.1% of the Gravity Load is applied at the corresponding locations of the gravity loads (SAP has option to automatically calculate τ_b, but one needs to design and then go back and analyze again).
- Model is analyzed and member forces and story drifts are noted.

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DAM EXAMPLE: COMPARISON

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REQUIRED FORCES	MEMBER	LINEAR ELASTIC	DIRECT ANALYSIS	MOMENT AMPLIFICATION RATIO	MOMENT AMPLIFICATION %
AXIAL (Pr) (kips)	AB	-295.9	-265.82		
	BD	-41.77	-27.89		
	DC	-630.93	-646.47		
	DF	-20.27	-26.47		
	FE	-322.17	-336.59		
SHEAR (Vr) (kips)	AB	20.23	-35.6		
	BD	16.1	47.29		
	DC	21.5	-2.87		
	DF	10.17	25.2		
	FE	20.27	-27.59		
MOMENT (Mr) (kips-ft)	AB	249.82	689.36	2.76	175.94
		-235.68	-667.55	2.83	183.24
	BD	235.68	667.55	2.83	183.24
		-86.31	-277.5	3.22	221.52
	DC	-256.68	-648.14	2.53	152.51
		259.64	648.95	2.50	149.94
	DF	170.02	370.64	2.18	118.00
		-236.77	-638	2.69	169.46
	FE	236.77	-638	2.69	169.46
		249.76	663.41	2.66	165.62
STORY DRIFT (Δ/L)	AB	0.021652431	0.0772583		
	CD	0.021603819	0.0772167		
	EF	0.021556597	0.0771417		

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DAM EXAMPLE: CONCLUSION

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- The moment magnification is of the order of 2.5. This is due to high magnitude of forces being applied.
- The second order drift is about three times the first order drift.
- When designed, it is observed that the member demands (considering second order effects) exceed the member design strengths.

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THANKS!!

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