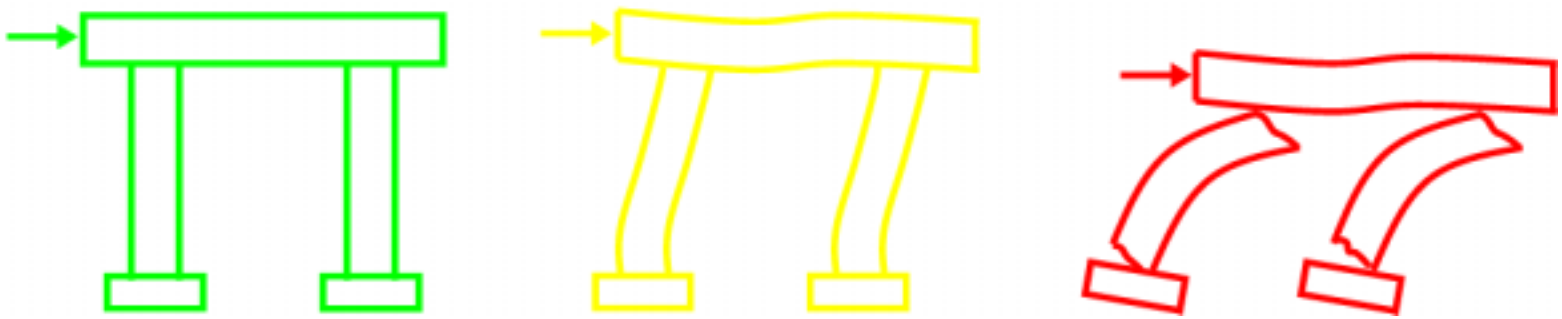
NONLINEAR STATIC ANALYSIS

- Nonlinear static analysis, commonly referred to as pushover analysis, is a method for determining the ultimate load and deflection capability of a structure.

- Local nonlinear effects, such as flexural hinges at the member joints, are modeled and the structure is deformed or "pushed" until enough hinges form to develop a collapse mechanism or until the plastic deformation limit of a hinge is reached.



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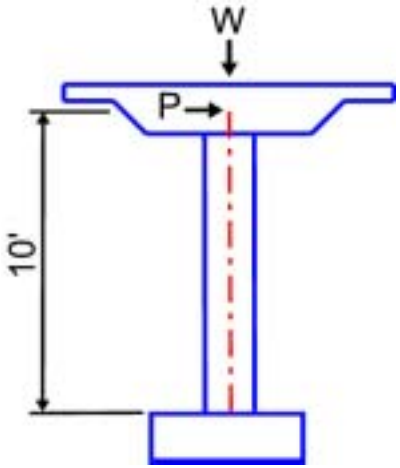
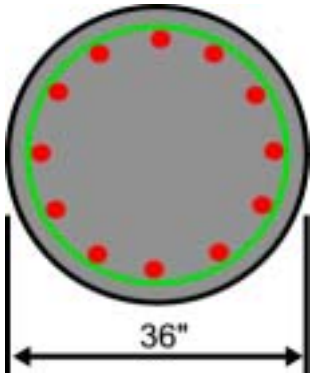
- The pushover concept can be illustrated with a cantilevered column.





CONFINED CONCRETE SECTION

24" diameter reinforced concrete column
12 #9 rebars at r = 14.75"
#4 spiral (d_s = 0.5") at pitch s_t = 3"
spiral diameter to centerline D_c = 31.5 inches
cracked moment of inertia I_{cr} = 33063 in^4
modulus E = 4110 ksi
axial load P = 1000 kips

  - o Conventional axial-moment interaction analysis

    Nominal moment M_n = 1652 k-ft
    Lateral load capacity P = 1652 / 10 = 165 kips
    Lateral deflection = P L^3 / (3 E I) = 165 x $(120)^3$ / (3 x 4110 x 33063) = 0.7 inches

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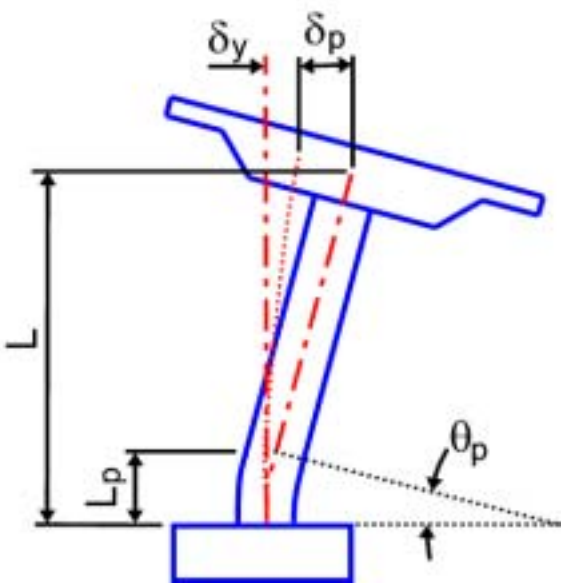
o Pushover analysis

- Results of moment-curvature analysis

Plastic moment M_p = 1703 k-ft
Lateral load capacity P = 1703 / 10 = 170 kips

Idealized yield curvature ϕ^i_y = 0.00015038 rad/in
Ultimate curvature ϕ_u = 0.001229 rad/in



- Plastic rotation

Plastic hinge length $L_p = 0.08L + 0.15\, f_{ye}\, d_b \geq 0.3\, f_{ye}\, d_b$
$L_p = 0.08 \times 120 + 0.15 \times 68 \times 1.125 = 21$ in
$L_p = \geq 0.3 \times 68 \times 1.125 = 23$ in (controls)

Plastic rotation $\theta_p = L_p\, (\phi_u - \phi^i_y)$
$\theta_p = 23(0.001229 - 0.00015038) = 0.0248$ rad

- Lateral deflection

Yield deflection $\delta_y = \phi^i_y\, L^2 / 3$
$\delta_y = (0.00015038)(120)^2 / 3 = 0.72$ in

Plastic deflection $\delta_p = \theta_p\, (L - L_p / 2)$
$\delta_p = 0.0248\, (120 - 23 / 2) = 2.69$ in

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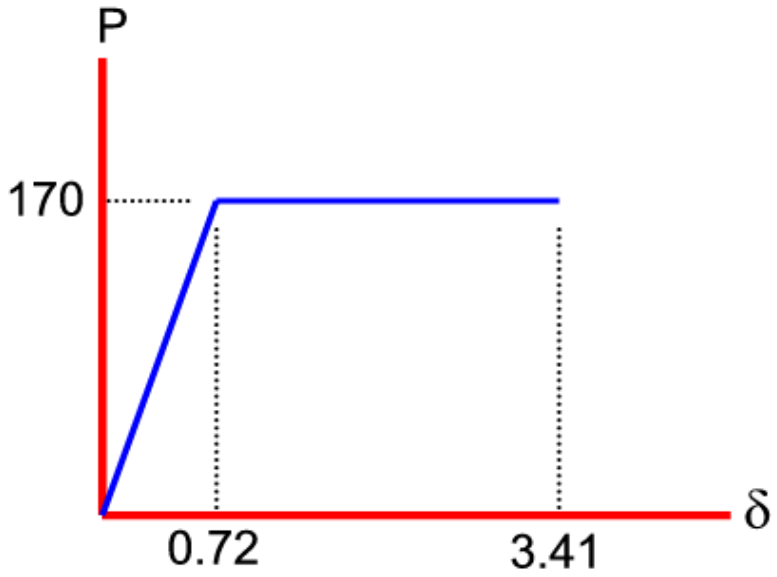
Total deflection = 0.72 + 2.69 = 3.41"
Local deflection ductility = 3.41 / 0.72 = 4.7

- Load vs. deflection curve



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- Computer tools available for pushover analysis

  - SAP2000 Nonlinear (Computers and Structures, Inc.)

    Commercial windows finite element program works with complex geometry and monitors deformations at all hinges to determine ultimate deformation. Built-in defaults for ACI 318 material properties and ATC 40 and FEMA 273 hinge properties. Capability for inputting any material or hinge property.

  - wFRAME (Caltrans)

    Caltrans program of 2D frame pushover analysis. DOS program with English units only. Able to model extended pile foundations with nonlinear p-y curves.

  - DRAIN-2DX

    Research tool capable of modeling 2D frames with flexural hinges.

  - ADINA (ADINA R&D, Inc.)

    Commercial windows step-by-step nonlinear dynamic finite element program. Complex program is extremely versatile at the expense of production efficiency.

  - SC-Push3D (SC Solutions)

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- REFERENCES

1. Priestley, Seible, Calvi, "Seismic Design and Retrofit of Bridges", John Wiley & Sons,1996.
2. ATC 40, Seismic Evaluation and Retrofit of Concrete Buildings.
3. FEMA 273 & 274, NEHRP Guidelines for the Seismic Rehabilitation of Buildings.

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