Structural Example – Reinforced-Concrete Frame: Building the Model

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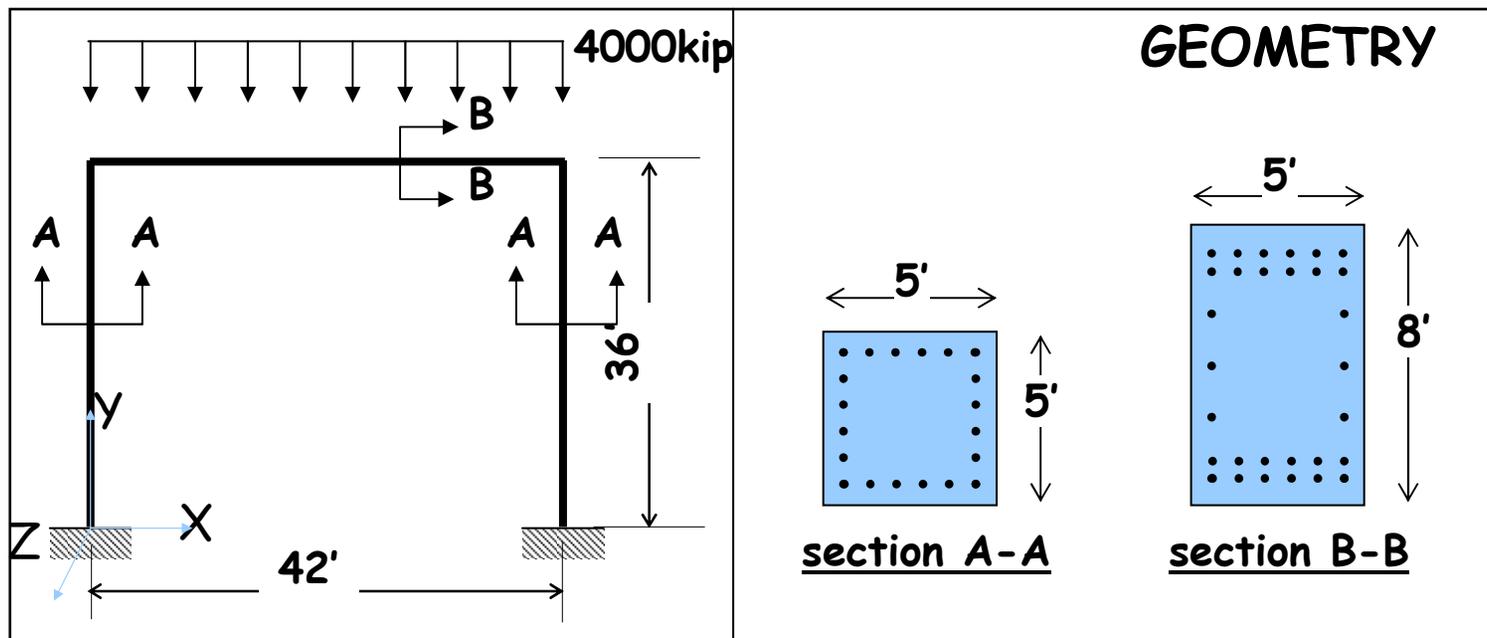
OpenSees User Workshop

26 August 2005

problem statement

- Reinforced-Concrete Portal Frame
- start with ALL elastic elements (At a more advanced level, these elements can be replaced by more refined element models)
- use kip, inch and sec as basic units

4000kip

GEOMETRY

36

42'

5'
5'
section A-A

5'
8'
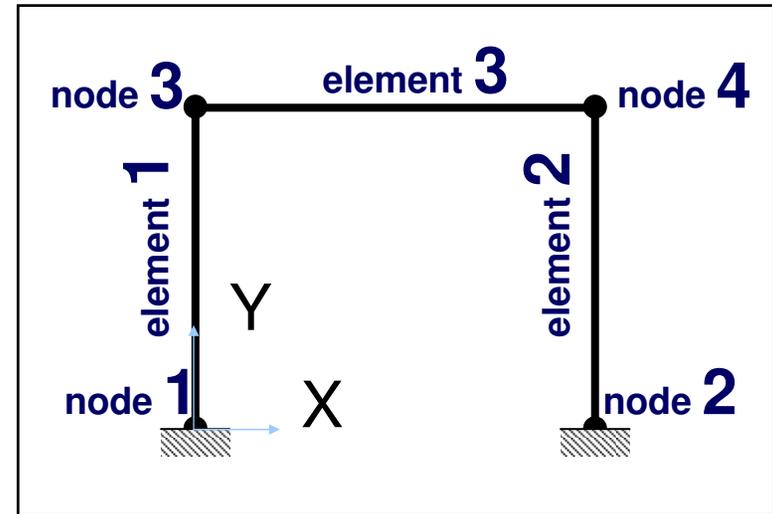section B-B

Model Builder command

- Defining the model builder expands the Tcl command library to include OpenSees-specific commands, such as node and element definition, etc. Currently, there is only one model builder available, basic model builder, this is the model builder that includes all the commands presented in this library.

- The model builder also defines the number of dimensions (ndm) and degrees of freedom per node (ndf).

- For a 2-D problem, you really only need three degrees of freedom at each node, the two translations in the plane and the rotation about the plane's normal:

model basic -ndm 2 -ndf 3

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Nodes

- ## nodal coordinates:
  node 1 0 0
  node 2 504 0
  node 3 0 432
  node 4 504 432

- ## bondary conditions:
  fix 1 1 1 1
  fix 2 1 1 1
  fix 3 0 0 0
  fix 4 0 0 0

- ## nodal masses:
  mass 3 5.18 0. 0.
  mass 4 5.18 0. 0.

element 3

node 3   element 3   node 4

element 1   element 2

Y

node 1   X   node 2

$$mass = \dfrac{\dfrac{4000\,kip}{2}}{\left(32.2 \cdot \dfrac{ft}{sec}\right) \cdot \left(\dfrac{12 \cdot inch}{1 \cdot ft}\right)} = 5.18$$

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Elements -- properties

	columns	beam
area	3600 $\left[(5{\cdot}\text{ft}){\cdot}\left(12{\cdot}\dfrac{\text{inch}}{\text{ft}}\right)\right]{\cdot}\left[(5{\cdot}\text{ft}){\cdot}\left(12{\cdot}\dfrac{\text{inch}}{\text{ft}}\right)\right]$	5760 $\left[(5{\cdot}\text{ft}){\cdot}\left(12{\cdot}\dfrac{\text{inch}}{\text{ft}}\right)\right]{\cdot}\left[(8{\cdot}\text{ft}){\cdot}\left(12{\cdot}\dfrac{\text{inch}}{\text{ft}}\right)\right]$
moment of inertia Iz	1080000 $\dfrac{1}{12}{\cdot}\left[(5{\cdot}\text{ft}){\cdot}\left(12{\cdot}\dfrac{\text{inch}}{\text{ft}}\right)\right]{\cdot}\left[(5{\cdot}\text{ft}){\cdot}\left(12{\cdot}\dfrac{\text{inch}}{\text{ft}}\right)\right]^{3}$	4423680 $\dfrac{1}{12}{\cdot}\left[(5{\cdot}\text{ft}){\cdot}\left(12{\cdot}\dfrac{\text{inch}}{\text{ft}}\right)\right]{\cdot}\left[(8{\cdot}\text{ft}){\cdot}\left(12{\cdot}\dfrac{\text{inch}}{\text{ft}}\right)\right]^{3}$

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Elements – orientation and connectivity

- transformation:
  - local element coordinates ➔ global model coordinates. In a 2D problem, element orientation does not need to be considered, and same for all elements

    geomTransf Linear 1

- connectivity:
  - arguments: $eleTag $iNode $jNode $A $E $Iz $transfTag

    element elasticBeamColumn 1 1 3 3600 4227 1080000 1

    element elasticBeamColumn 2 2 4 3600 4227 1080000 1

    element elasticBeamColumn 3 3 4 5760 4227 4423680 1

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Gravity Loads – member-end forces

- Gravity loads are independent of the type of lateral loading and here they are considered part of the structural model.

- Equivalend member-end forces for distributed loads along an elastic element:

$$\text{Force} = \frac{4000 \cdot \text{kip}}{2} = 2000 \cdot \text{kip}$$

$$\text{DistributedLoad} = \frac{4000 \cdot \text{kip}}{(42 \cdot \text{ft}) \cdot \left(12 \cdot \frac{\text{inch}}{\text{ft}}\right)} = 7.94 \cdot \frac{\text{kip}}{\text{inch}}$$

$$\text{Moment} = \frac{\text{DistributedLoad} \cdot \text{BeamLength}^2}{12} = \frac{\left(7.94 \cdot \frac{\text{kip}}{\text{inch}}\right) \cdot \left(42 \cdot \text{ft} \cdot 12 \cdot \frac{\text{inch}}{\text{ft}}\right)^2}{12} = 168074 \cdot \text{kip} \cdot \text{in}$$

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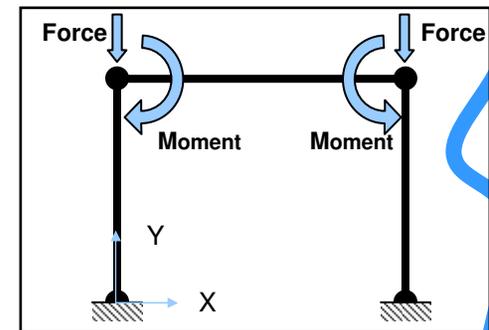
Gravity Loads – definition

- Define load pattern:

```
pattern Plain 1 Linear {
    load 3 0.0 -2000 -168074
    load 4 0.0 -2000 168074
}
```

Recorders

- horizontal and vertical displacements at node 3 into a file named Node3.out:

  `recorder Node -file Node3.out -time -node 3 -dof 1 2 disp`

- local element forces for element 1 into file Element1.out:

  `recorder Element -file Element1.out -time -ele 1 force`

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Summary: example.tcl

model basic -ndm 2 -ndf 3

nodal coordinates:

node 1 0 0

node 2 504 0

node 3 0 432

node 4 504 432

bondary conditions:

fix 1 1 1 1

fix 2 1 1 1

fix 3 0 0 0

fix 4 0 0 0

nodal masses:

mass 3 5.18 0. 0.

mass 4 5.18 0. 0.

```
# transformation:
geomTransf Linear 1
# connectivity:
element elasticBeamColumn 1 1 3 3600 4227
    1080000 1
element elasticBeamColumn 2 2 4 3600 4227
    1080000 1
element elasticBeamColumn 3 3 4 5760 4227
    4423680 1
# Define gravity load pattern:
pattern Plain 1 Linear {
    load 3 0.0 -2000 -168074
    load 4 0.0 -2000 168074
}
# recorders
recorder Node -file Node3.out -time -node 3 -
    dof 1 2 disp
recorder Element -file Element1.out -time -ele
    1 force
```

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execute: line commands
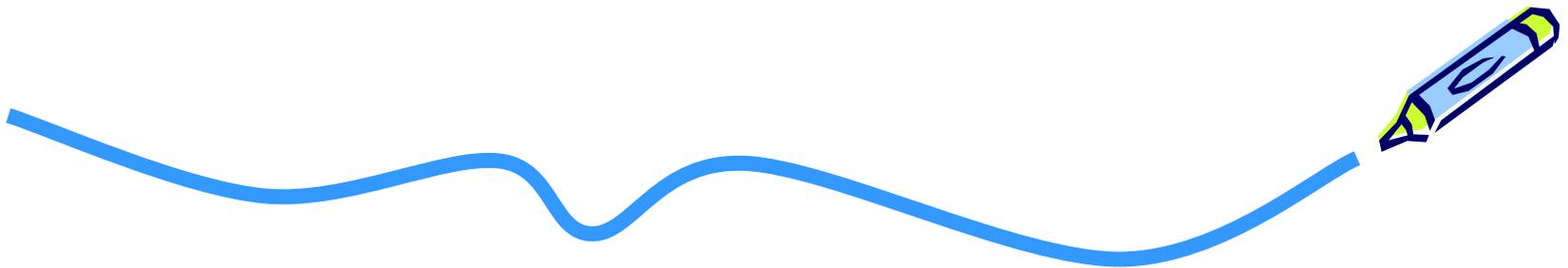
```
C:\Users\AAsilvia\AAprojects\OpenSees\OSWorkshops\2004OSWorkshopSept\Presentations\MyPre...
             Pacific Earthquake Engineering Research Center -- Version 1.5.3

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                             All Rights Reserved


OpenSees > model basic -ndm 2 -ndf 3
OpenSees > node 1 0 0
OpenSees > node 2 504 0
OpenSees > node 3 0 432
OpenSees > node 4 504 432
OpenSees > fix 1 1 1 1
OpenSees > fix 2 1 1 1
OpenSees > fix 3 1 1 1
OpenSees > fix 3 0 0 0
OpenSees > fix 4 0 0 0
OpenSees > mass 3 5.18 0 0
OpenSees > mass 4 5.18 0 0
OpenSees > geomTransf Linear 1
OpenSees > element elasticBeamColumn 1 1 3 3600 4227 1080000 1
OpenSees > element elasticBeamColumn 2 2 4 3600 4227 1080000 1
OpenSees > element elasticBeamColumn 3 3 4 5760 4227 4423680 1
OpenSees > pattern Plain 1 Linear {
load 3 0.0 -2000 -168074
load 4 _
```

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execute: source input file

example.tcl - Notepad

File Edit Format View Help

```
model basic -ndm 2 -ndf 3
# nodal coordinates:
node 1 0 0
node 2 504 0
node 3 0 432
node 4 504 432
# bondary conditions:
fix 1 1 1 1
fix 2 1 1 1
fix 3 0 0 0
fix 4 0 0 0
# nodal masses:
mass 3 5.18 0. 0.
mass 4 5.18 0. 0.
# transformation:
geomTransf Linear 1
# connectivity:
element elasticBeamColumn 1 1 3 3600 4227 1080000 1
element elasticBeamColumn 2 2 4 3600 4227 1080000 1
element elasticBeamColumn 3 3 4 5760 4227 4423680 1
# Define gravity load pattern:
pattern Plain 1 Linear {
        load 3 0.0 -2000 -168074
        load 4 0.0 -2000 168074
}
# recorders
```

C:\Users\AAsilvia\AAprojects\OpenSees\OSWorkshops\2004OSWorkshopSept\Presentations\...

C:\Users\AAsilvia\AAprojects\OpenSees\OSWorkshops\2004OSWorkshopSept\Presentations\MyPresentatio

```
        OpenSees -- Open System For Earthquake Enginee
        Pacific Earthquake Engineering Research Center

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OpenSees > source example.tcl
OpenSees >
```

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Let's redo the example

.....my way!!

…..remember what I told you about Tcl?

- Tcl is a string based scripting language
- enables variables and variable substitution (use variables to define units!!!)
- Expression evaluation
- Array management
- Basic control structures (if , while, for, foreach)
- Procedures
- File manipulation

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problem statement

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- start with ALL elastic elements (At a more advanced level, these elements can be replaced by more refined element models)
- use kip, inch and sec as basic units
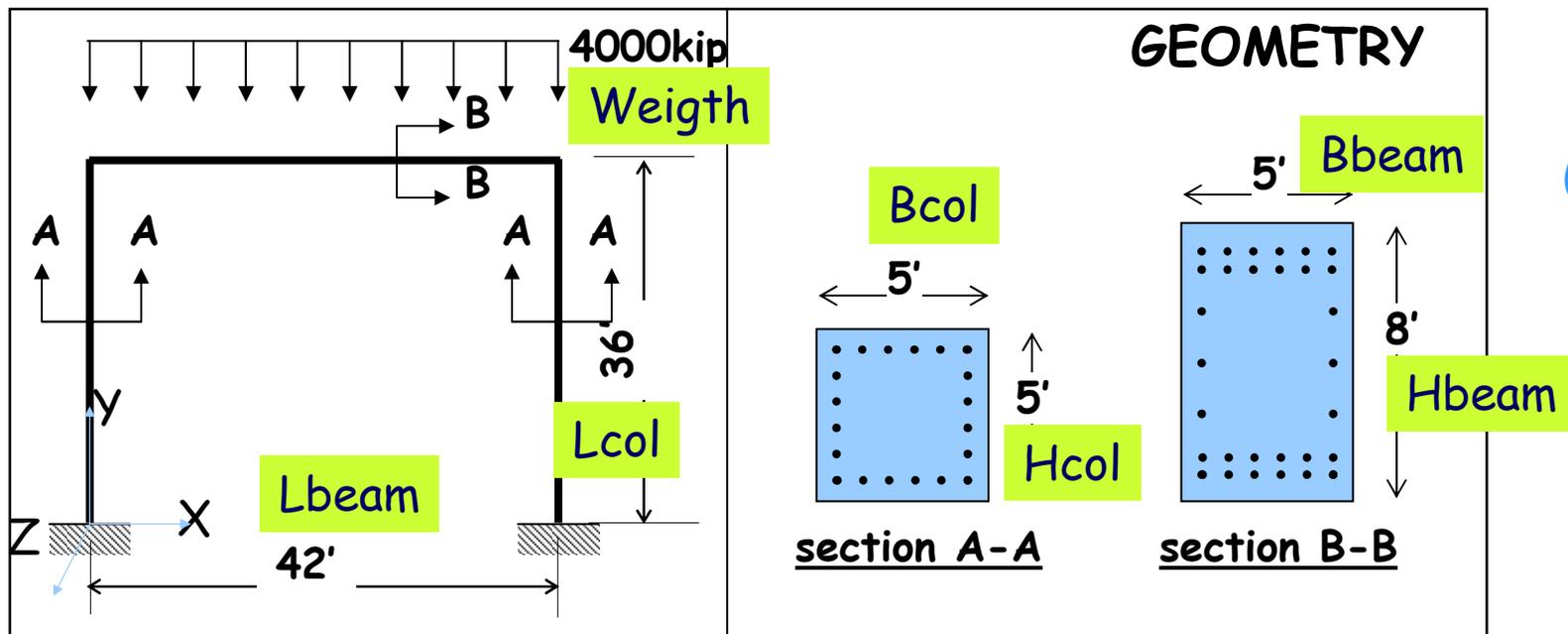
Model Builder command -- same

- Defining the model builder expands the Tcl command library to include OpenSees-specific commands, such as node and element definition, etc. Currently, there is only one model builder available, basic model builder, this is the model builder that includes all the commands presented in this library.

- The model builder also defines the number of dimensions (ndm) and degrees of freedom per node (ndf).

- For a 2-D problem, you really only need three degrees of freedom at each node, the two translations in the plane and the rotation about the plane's normal:

model basic -ndm 2 -ndf 3

Now: Units/constants

- set in   1.;   # basic units
- set sec   1.;   # basic units
- set kip   1.;   # basic units
- set ft   [expr 12.*$in];   # engineering units
- set ksi   [expr $kip/pow($in,2)];
- set psi   [expr $ksi/1000.];
- set in2   [expr $in*$in];   # inch^2
- set in4   [expr $in*$in*$in*$in];   # inch^4
- set PI   [expr 2*asin(1.0)];   # define constants
- set g   [expr 32.2*$ft/pow($sec,2)];   # grav. acc.
- set Ubig   1.e10;   # a large number
- set Usmall   [expr 1/$Ubig];   # a small number
- set cm   [expr $in/2.54];   # SI unit

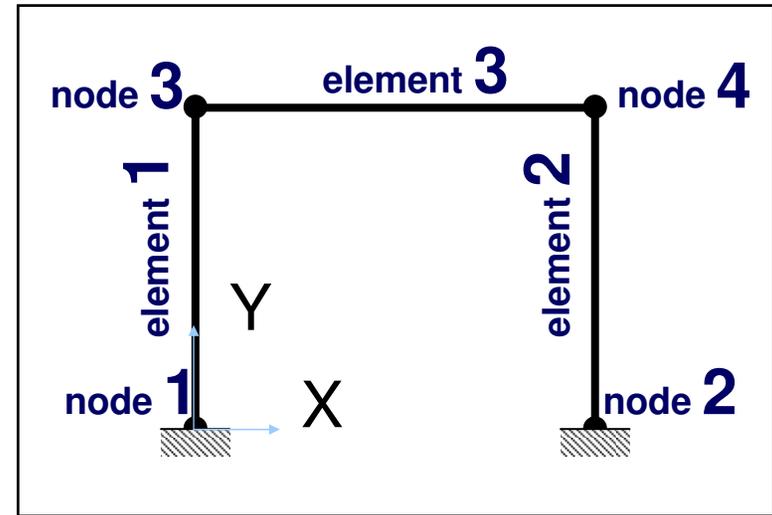OpenSees NEESit

Now: Define variables

```
set Lcol [expr 36.*$ft];          # column length
set Lbeam [expr 42.*$ft];         # beam length
set Bcol [expr 5.*$ft];           # column width
set Hcol [expr 5.*$ft];           # column depth
set Bbeam [expr 5. *$ft];         # beam width
set Hbeam [expr 8.*$ft];          # beam depth
set Dmax [expr 15.*$in];          # max displacement
set Weight [expr 4000.*$kip];     # Weight
set Ec [expr 4227*$ksi];          # Young's Modulus


set Wnode [expr $Weight/2];       # node Weight
set Mnode [expr $Wnode/$g];       # node Mass
```

Nodes

- ## # nodal coordinates:
  node 1 0 0
  node 2 $Lbeam 0
  node 3 0 $Lcol
  node 4 $Lbeam $Lcol

- ## # bondary conditions:
  fix 1 1 1 1
  fix 2 1 1 1
  fix 3 0 0 0
  fix 4 0 0 0

- ## # nodal masses:
  mass 3 $Mnode 0. 0.
  mass 4 $Mnode 0. 0.

node **3**   element **3**   node **4**

element **1**   element **2**

Y

node **1**   X   node **2**

$$\text{mass} = \dfrac{\dfrac{4000\,\text{kip}}{2}}{\left(32.2 \cdot \dfrac{\text{ft}}{\text{sec}}\right) \cdot \left(\dfrac{12 \cdot \text{inch}}{1 \cdot \text{ft}}\right)} = 5.18$$

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Elements -- properties

	columns	beam
area	3600 $\left[(5 \cdot \text{ft}) \cdot \left(1 \boxed{\text{Bcol*Hcol}} \frac{\text{inch}}{\text{ft}}\left(12 \cdot \frac{\text{inch}}{\text{ft}}\right)\right)\right]$	5760 $\left[(5 \cdot \text{ft}) \cdot \left(12 \boxed{\text{Bbeam*Hbeam}}\right)\right]$
moment of inertia Iz	1080000 $\frac{1}{12}\left[(5 \boxed{\text{1/12*Bcol*Hcol}^3} \frac{\text{nch}}{\text{ft}}\right)\right]^3$	4423680 $\left[\boxed{\text{1/12*Bbeam*Hbeam}^3}\right)\right]^3$

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Elements orientation & connectivity

- transformation:
  - local element coordinates ➔ global model coordinates.

  set IDtransf 1

  geomTransf Linear $IDtransf

- connectivity:
  - arguments: $eleTag $iNode $jNode $A $E $Iz $transfTag

  set Acol [expr $Bcol*$Hcol];

  set Abeam [expr $Bbeam*$Hbeam];

  set Icol [expr 1/12*$Bcol*pow($Hcol,3)];

  set Ibeam [expr 1/12*$Bbeam*pow($Hbeam,3)];

  element elasticBeamColumn 1 1 3 $Acol $Ec $Icol $IDtransf

  element elasticBeamColumn 2 2 4 $Acol $Ec $Icol $IDtransf

 **element elasticBeamColumn 3 3 4 $Abeam $Ec $Ibeam $IDtransf**

Gravity Loads – member-end forces

- Gravity loads are independent of the type of lateral loading and here they are considered part of the structural model.

- Equivalend member-end forces for distributed loads along an elastic element:

$$\text{Force} = \frac{40\ldots}{2} \quad \boxed{Pdl = Weight/2}$$

$$\text{DistributedLoad} = \frac{\ldots}{(42 \cdot ft) \cdot \left(12 \cdot \dfrac{inch}{ft}\right)} \quad \boxed{w = Weight/Lbeam}$$

$$\text{Moment} = \frac{\text{DistributedLoad} \cdot \text{BeamLength}^2}{12} = \boxed{Mdl = 1/12 * w * Lbeam^2} = \frac{\left(7.94 \cdot \dfrac{kip}{inch}\right) \cdot \left(42 \cdot ft \cdot 12 \cdot \dfrac{inch}{ft}\right)^2}{\ldots} = 168074 \cdot kip \cdot in$$
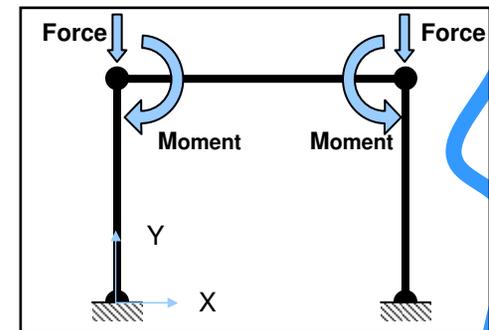
Gravity Loads – definition

- Define load pattern:

```
set Pdl [expr $Weight/2];
set w [expr $Weight/$Lbeam];
set Mdl [expr 1/12*$w*pow($Lbeam,2)]
set Dsupp [expr 0.001*$in];
pattern Plain 1 Linear {
   load 3 0.0 -$Pdl -$Mdl
   load 4 0.0 -$Pdl $Mdl
    sp 1 2 $Dsupp
   }
```

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Recorders

- horizontal and vertical displacements at node 3 into a file named Node3.out:

set Analysis "pushover"

recorder Node -file Node3$Analysis.out -time -node 3 -dof 1 2 disp

- local element forces for element 1 into file Element1.out:

recorder Element -file Element1.out -time -ele 1 force

summary example.tcl

```
set ft      [expr 12.*$in];                # engineering units
set ksi     [expr $kip/pow($in,2)];
set psi     [expr $ksi/1000.];
set in2     [expr $in*$in];                 # inch^2
set in4     [expr $in*$in*$in*$in];         # inch^4
set PI      [expr 2*asin(1.0)];             # define constants
set g       [expr 32.2*$ft/pow($sec,2)];    # grav. acc.
set Ubig    1.e10;                          # a large number
set Usmall          [expr 1/$Ubig];         # a small number
set cm      [expr $in/2.54];                # SI unit


set Lcol [expr 36*$ft];                     # column length
set Lbeam [expr 42*$ft];                    # beam length
set Weight [expr 4000*$kip];                # Weight
set Bcol [expr 5*$ft];                      # column width
set Hcol [expr 5*$ft];                      # column depth
set Bbeam [expr 5 *$ft];                    # beam width
set Hbeam [expr 8*$ft];                     # beam depth


set Wnode [expr $Weight/2];                 # node Weight
set Mnode [expr $Wnode/$g];                 # node Mass


node 1 0 0
node 2 $Lbeam 0
node 3 0 $Lcol
node 4 $Lbeam $Lcol
```

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summary example.tcl (cont)

```
fix 1 1 1 1; fix 2 1 1 1; fix 3 0 0 0; fix 4 0 0 0
mass 3 $Mnode 0. 0.
mass 4 $Mnode 0. 0.
set IDtransf 1
geomTransf Linear $IDtransf
set Acol [expr $Bcol*$Hcol];
set Abeam [expr $Bbeam*$Hbeam];
set Icol [expr 1/12*$Bcol*pow($Hcol,3)];
set Ibeam [expr 1/12*$Bbeam*pow($Hbeam,3)];
set Ec [expr 4227*$ksi];
element elasticBeamColumn 1 1 3 $Acol $Ec $Icol $IDtransf
element elasticBeamColumn 2 2 4 $Acol $Ec $Icol $IDtransf
element elasticBeamColumn 3 3 4 $Abeam $Ec $Ibeam $IDtransf


set Pdl [expr $Weight/2];
set w [expr $Weight/$Lbeam];
set Mdl [expr 1/12*$w*pow($Lbeam,2)]
set Dsupp [expr 0.001*$in]
pattern Plain 1 Linear {
    load 3 0.0 -$Pdl -$Mdl
    load 4 0.0 -$Pdl $Mdl
    sp 1 2 $Dsupp
}


recorder Node -file Node3.out -time -node 3    -dof 1 2 disp
recorder Element -file Element1.out -time -ele 1 force
```

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