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College of Engineering
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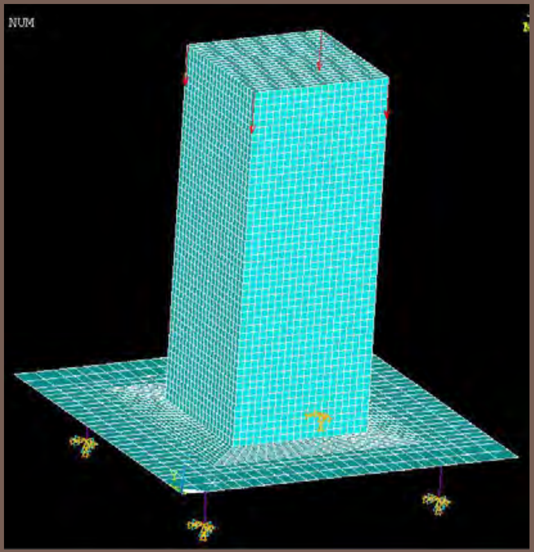

Non-linear Finite Element Analysis of Steel Base Plates on Leveling Nuts

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(Supervisor)

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Outline

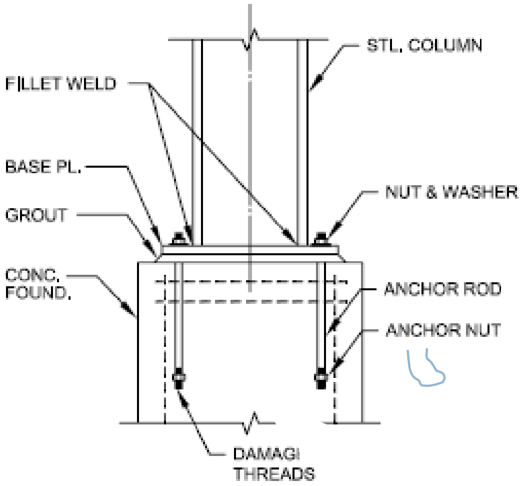
- Introduction
- Statement of Problem
- Objectives
- Background
- Scope
- Laboratory Testing
- Finite Element Modeling
- Results
- Conclusions
- Recommendations

Introduction

- Highway signs, Traffic signals, and Luminaries in parks, stadiums and transport facilities all require base plates on leveling nuts for support to foundation.

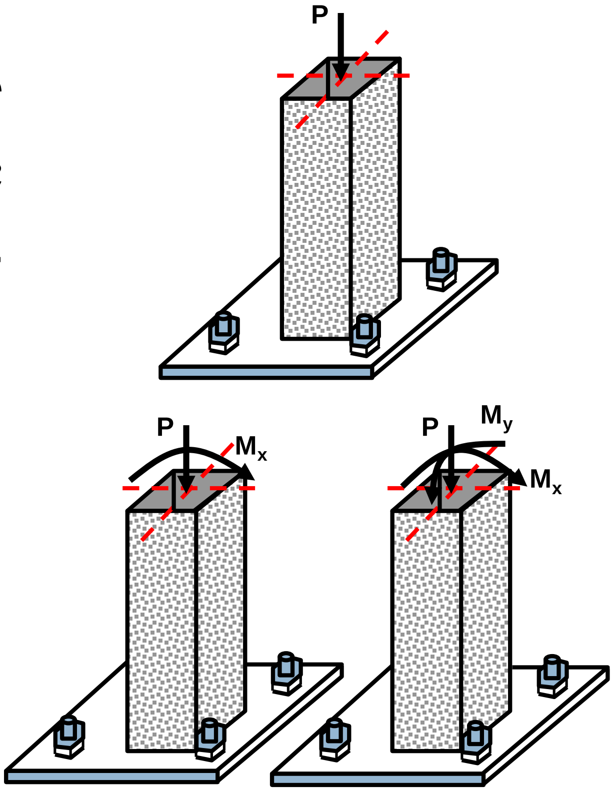
Introduction

- Base plates with leveling nuts are regularly used for structural supports of utility poles and other columns. The purpose of leveling nuts is to attain the required alignment of the vertical member.
- Base plates and columns come welded from factory before being assembled on site with nuts on anchor bolts.



Introduction

- Base plates are preferably fabricated from ASTM A36 steel (F_y=250 MPa) due to their high ductility demand.
- Cast in place anchor bolts are commonly used with the base plate; Preferred specification is ASTM F1554 (F_y=380 MPa).
- The loading on the base plates can be:
  1. Concentric axial loads
  2. Uniaxial Bending
  3. Biaxial Bending

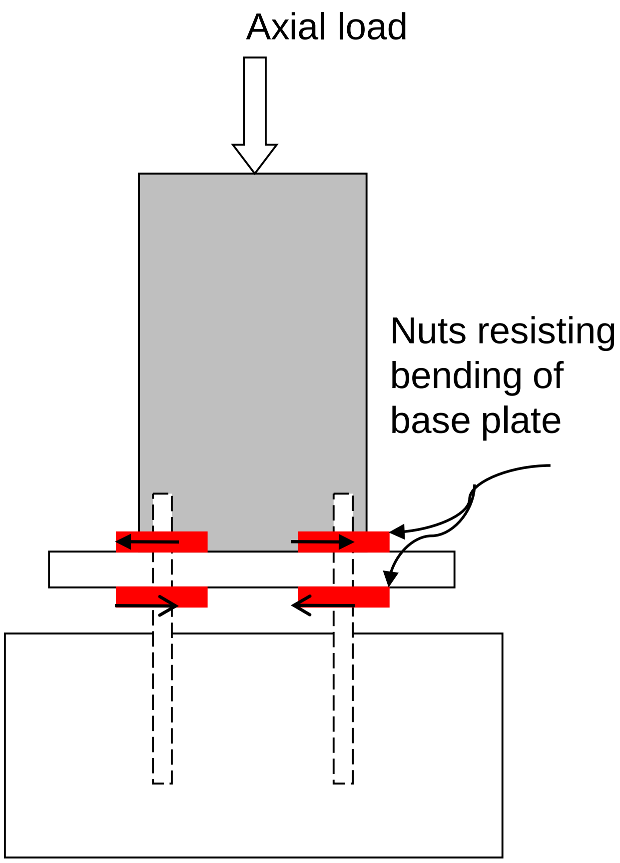


Introduction

- The loading from the column into the connection mainly induces:
  - Flexural stresses in the steel base plate
  - Axial forces (compression or tension) in the anchor bolts.
- Bolt reactions can be approximately obtained with reasonable accuracy by assuming the base plate to be infinitely rigid on elastic supports (i.e. as a pile cap).
- Shear stresses in the base plate are negligibly small.

Introduction

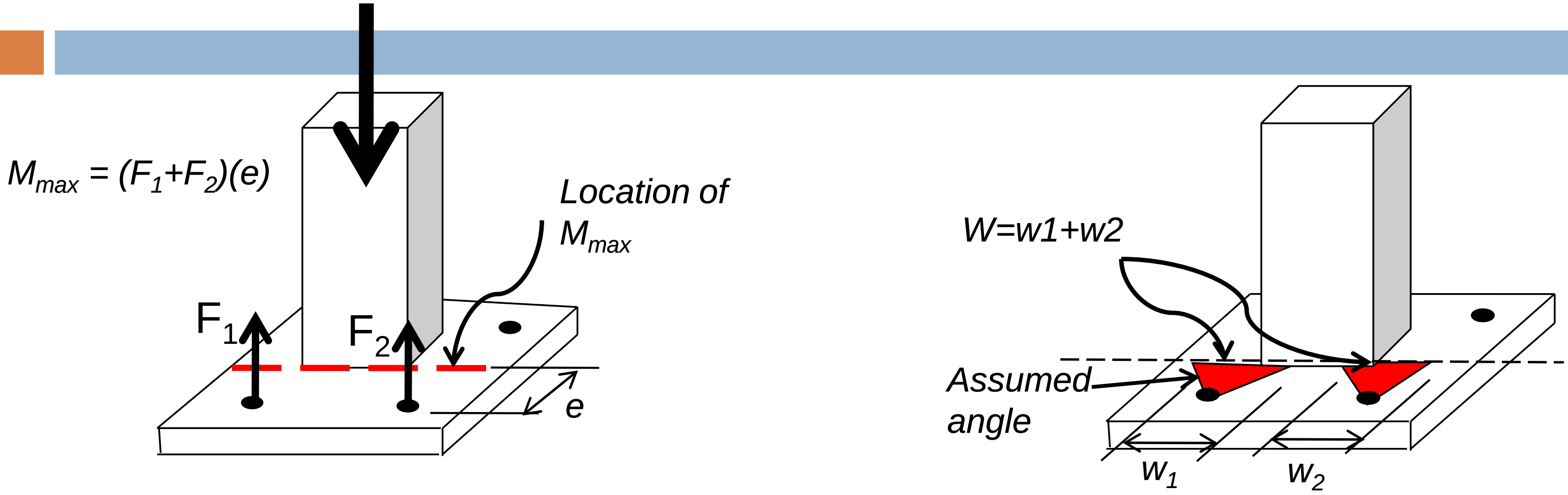
- Membrane stresses may also be created by either gravity or lateral loads.
- The empty space between base plate and concrete foundation is often filled by grout to prevent corrosion and deterioration of the base plate and anchor bolts.
- However, the grout cannot be counted for any structural strength as it is prone to cracking with temperature changes and shrinkage effects.



Statement of Problem

- It has been reported that in the last five years, at least 80 defective poles installed have been taken down in Texas because of cracks and other signs of structural failure.
- About 33% of signal supports inspected in United States were having cracks in either the base plates or the concrete foundation due to fatigue.
- Limited Research on the base plates column connection.

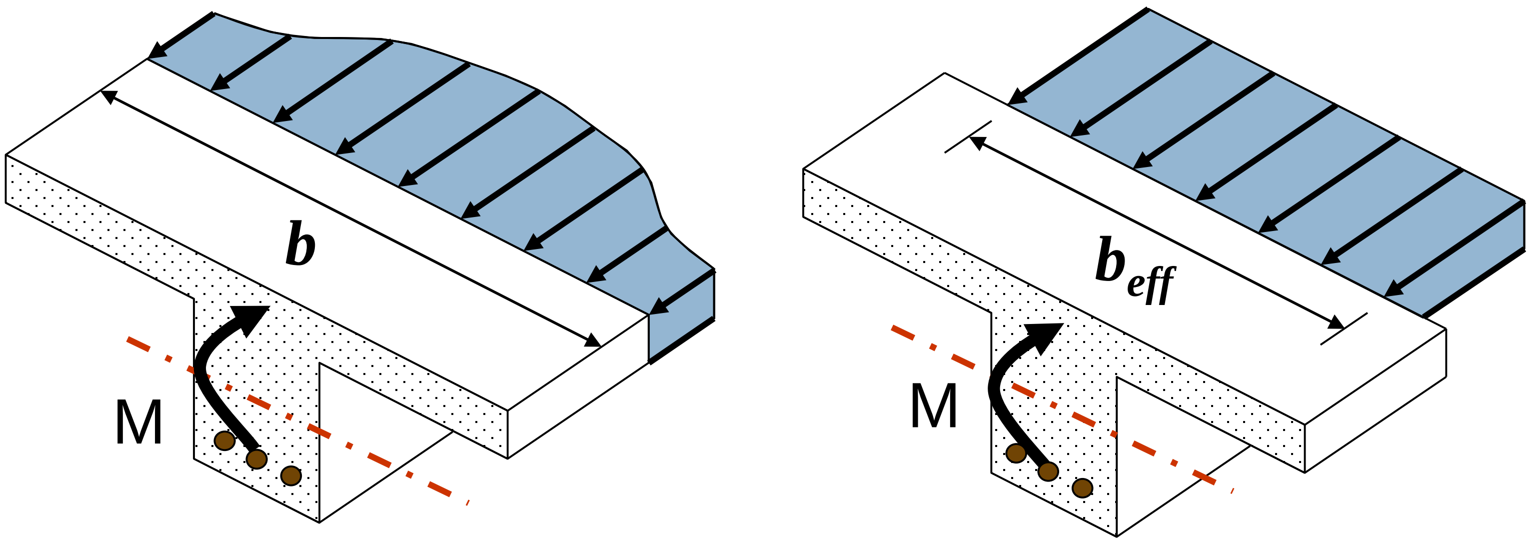
Background



$$\mathbf{M = (Z\ or\ S)^{*}\ F_y}$$

- Section Moduli “S” and “Z” must be determined in order to calculate bending stresses in the base plate.
- In finding S or Z, some engineers use the effective width, while others the complete width of the plate to calculate section modulus.

Background



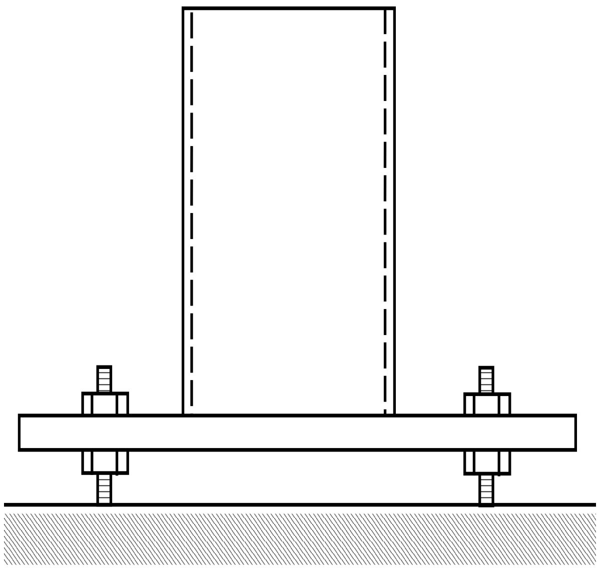
Theoretical stress distribution

Simplified rectangular stress distribution

- Determining an effective width of a base plate on leveling nuts due to moment generated by the bolts is analogous to using an effective flange width in a concrete T-beam!

Objectives

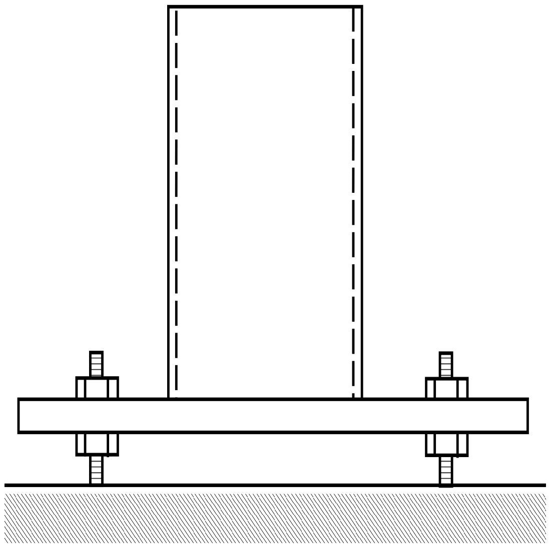
- The main objective of this study is to develop a procedure, based on the *Load and Resistance Factor Design* format, that can help structural engineers in the utility industry proportion and size base plates on leveling nuts.
- Nonlinear finite element structural analysis will be used as the basis behind the development of the procedure.



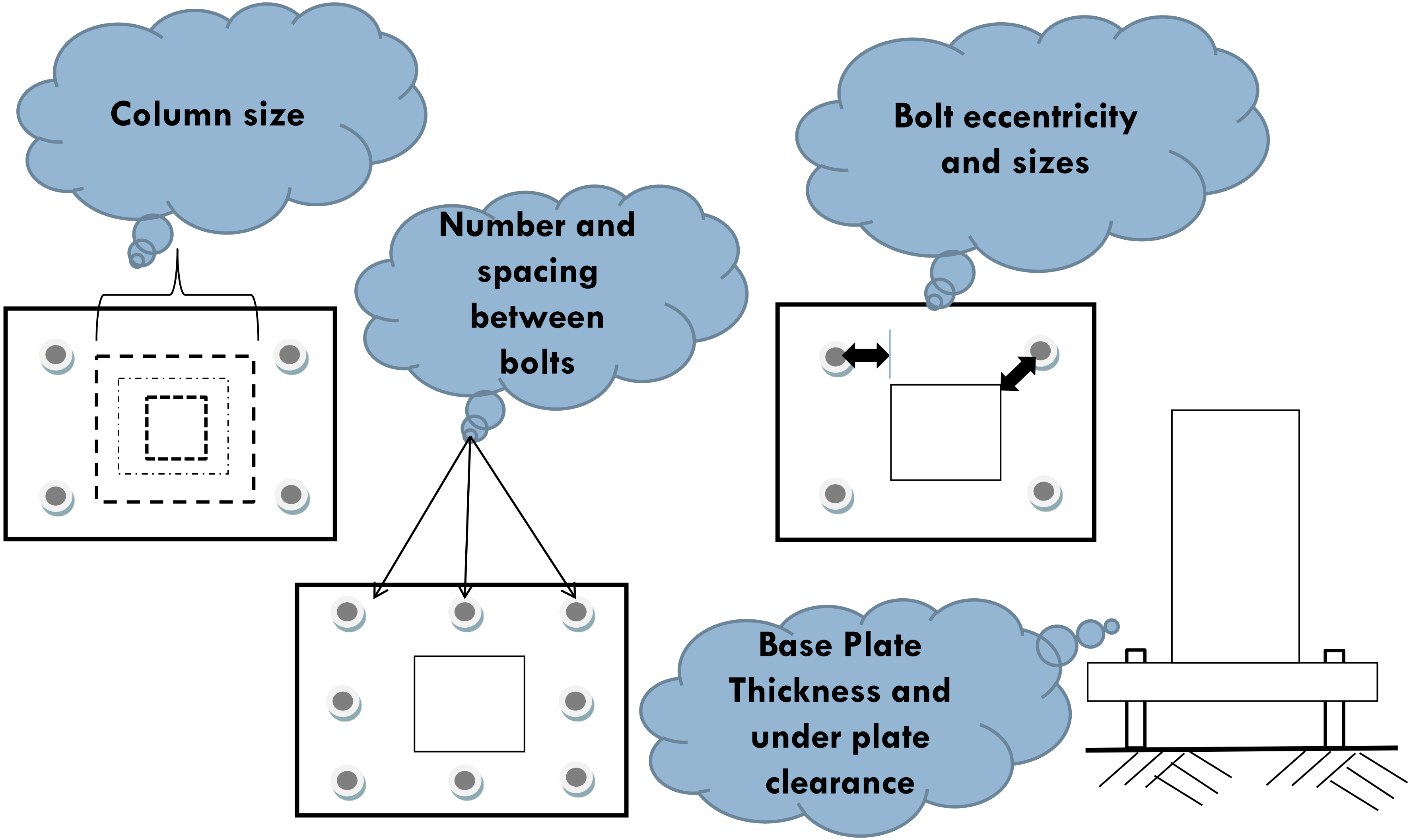
Objectives

To accomplish the stated objective, we will:

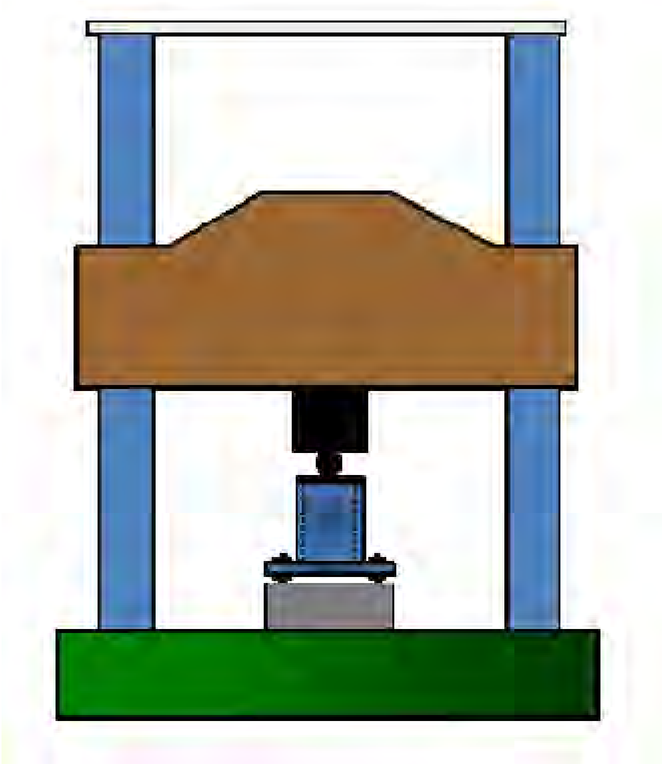
- Research the published literature on steel base plates on leveling nuts.
- Carry out laboratory testing of steel base plates on leveling nuts.
- Conduct a parametric analysis on base plates to better understand the structural behavior.
- Develop simple expressions of the influence angle that help in computing an effective width of the base plate when the connection is subjected to concentric or eccentric loads.



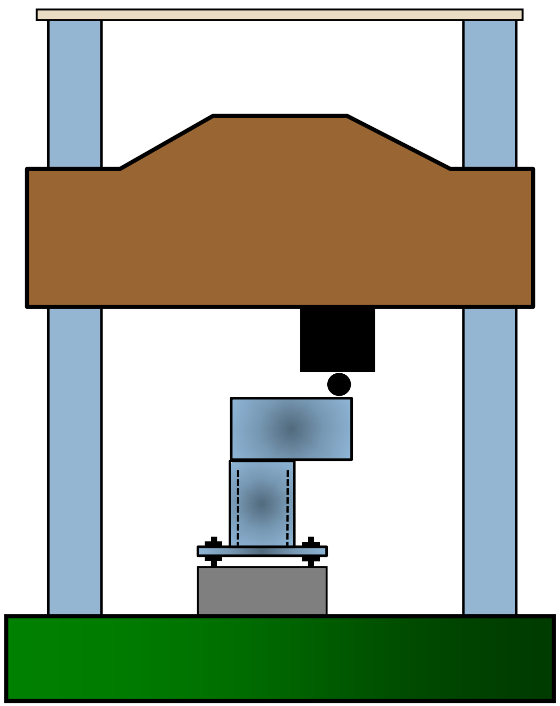
Scope


Column size
Number and spacing between bolts
Bolt eccentricity and sizes
Base Plate Thickness and under plate clearance

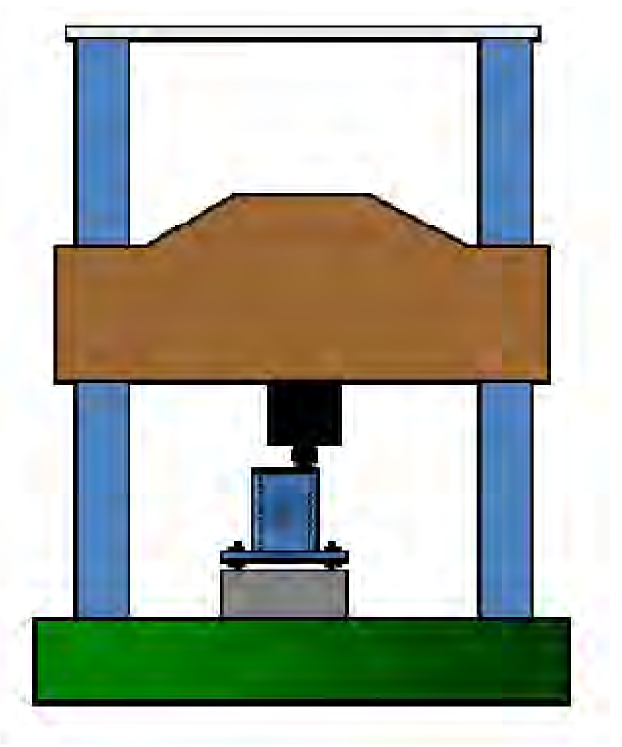
Scope



Concentric Axial Load



Uniaxial Bending Load



Biaxial Bending Load

Laboratory Testing

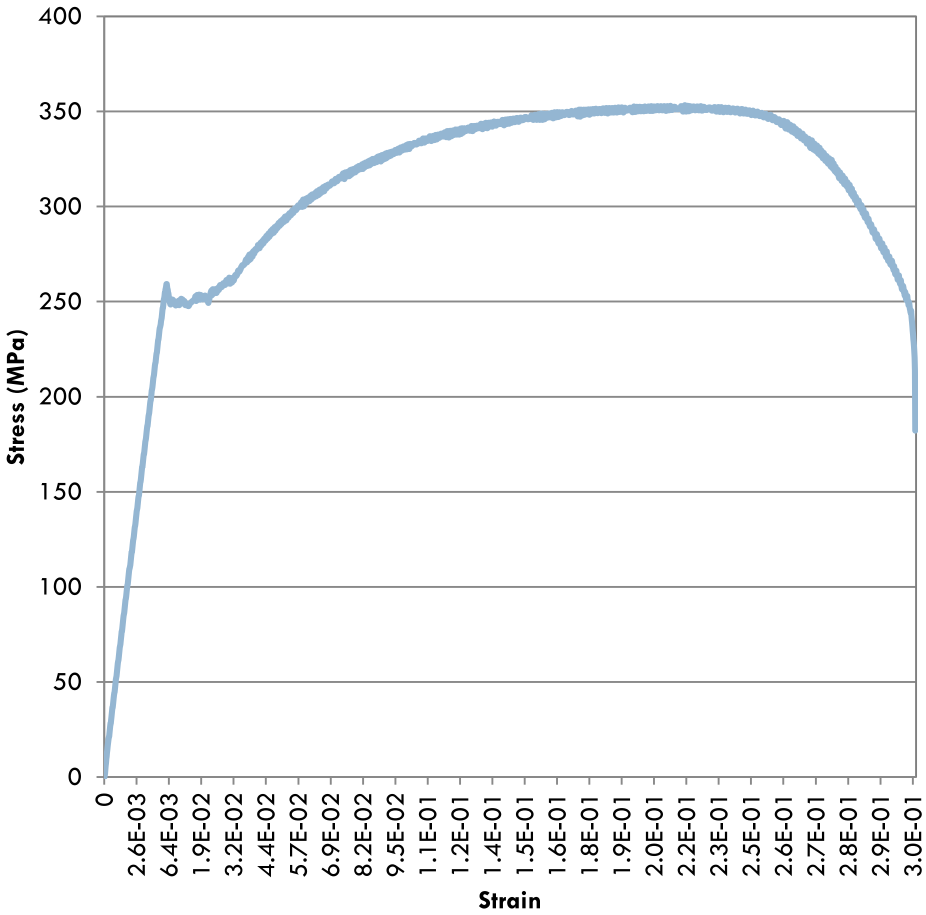
(a) Concentric

(b) Biaxial Bending

(c) Uniaxial Bending

Laboratory Testing

Steel Coupon test



Laboratory Testing

Tying of Stirrups/ties

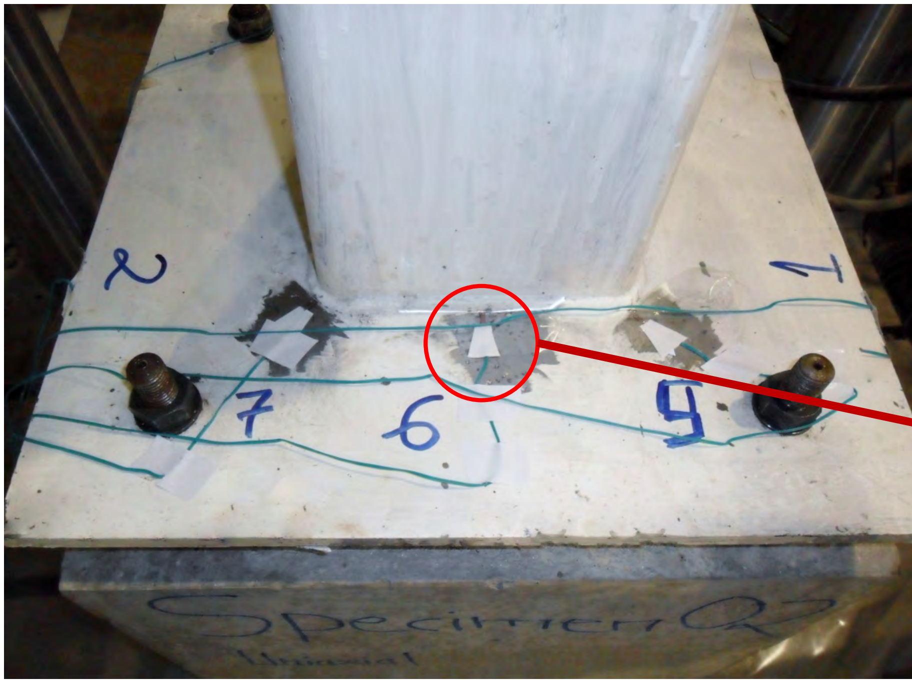
Erecting Formwork

Laboratory Testing

Vibration of Concrete

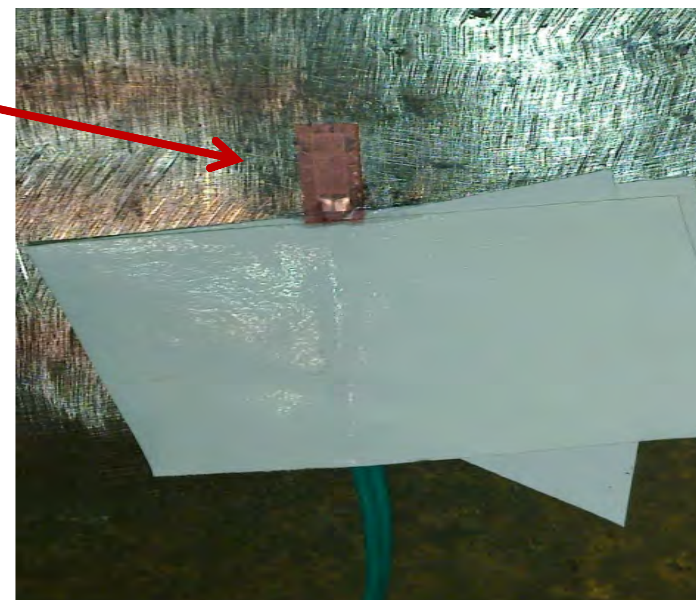
Final adjustment of base plate

Laboratory Testing



Installation of Strain Gauges

Type: N11-FA-5-120-11VSE3
Gauge Length: 5 mm
Resistance: 120 (+/- 0.3%)
Gauge Factor: 2.10 (+/- 1%)
Thermal Expansion: 11 PPM/ºC



Laboratory Testing – Concentric Load

Before application of load

Clear spacing under the plate

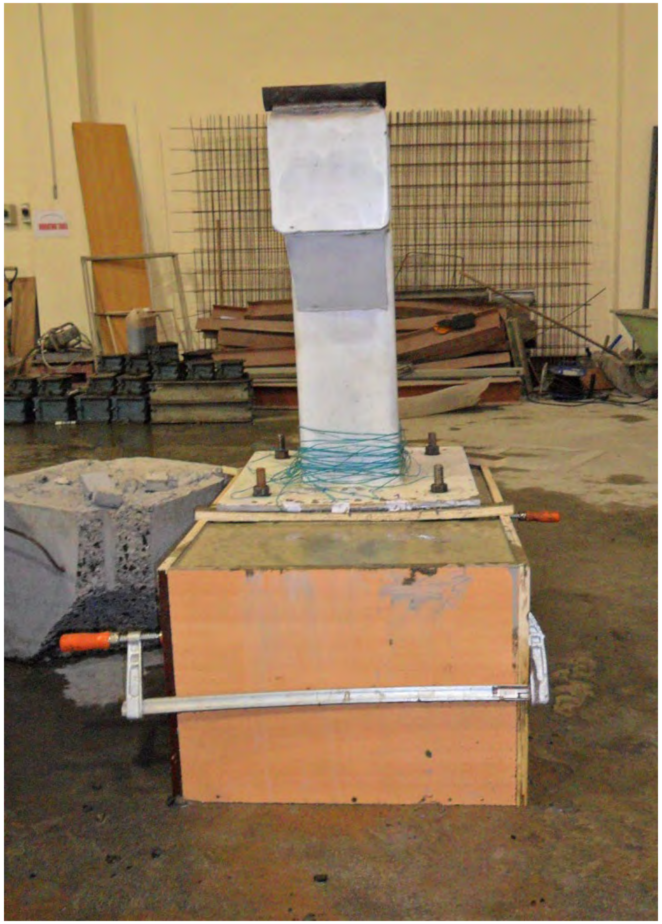
Laboratory Testing – Concentric Load

Base Plate at Failure

Deflection in Base Plate

Laboratory Testing – Unieccentric Load

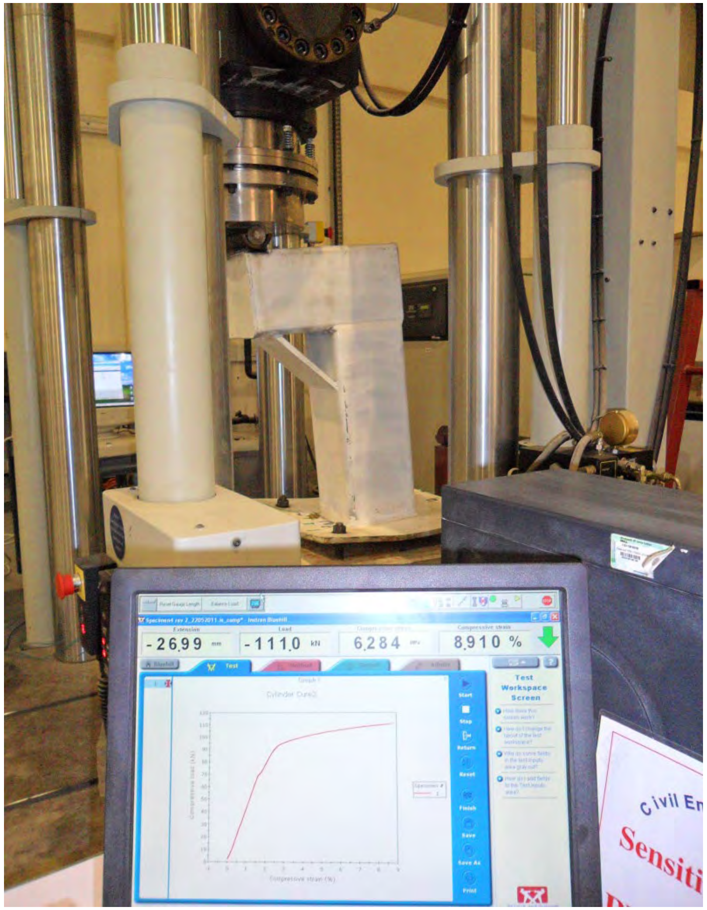
Welding Cylinder on top



Concrete poured in the formwork

Laboratory Testing –Unieccentric Load

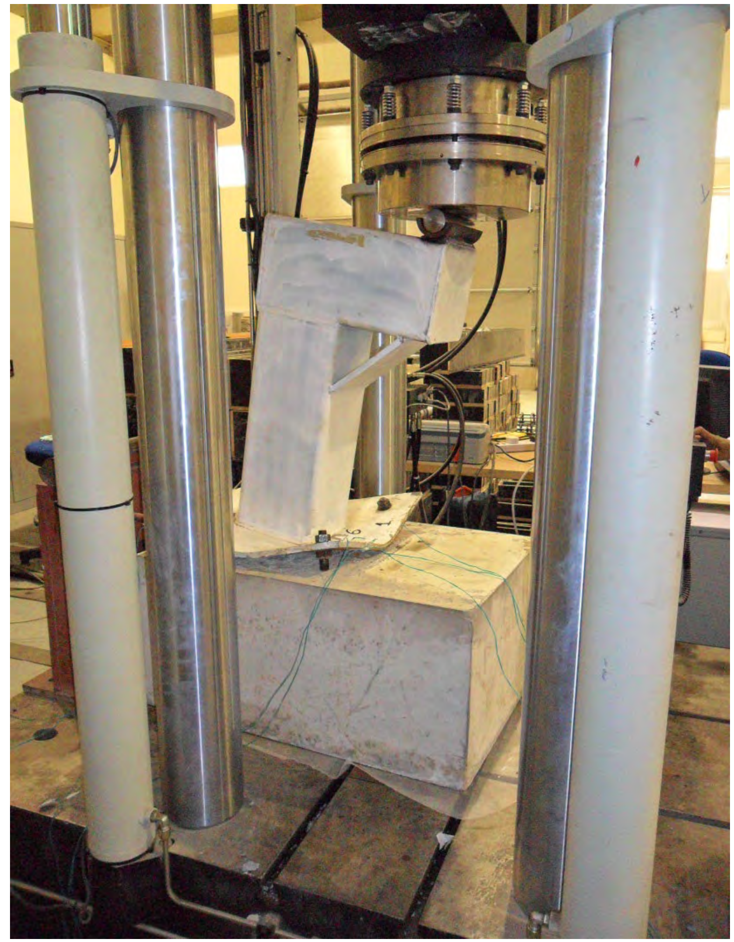
Before application of load



Specimen under load

Laboratory Testing – Unieccentric Load

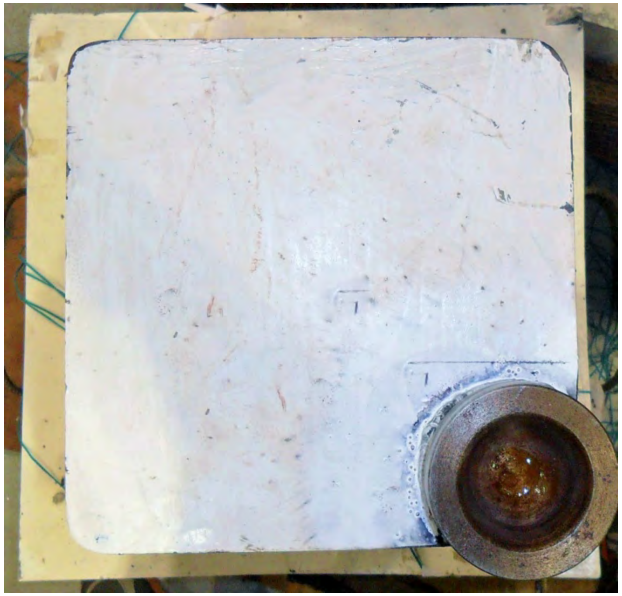
Specimen at Failure



Deflection in Base Plate

Laboratory Testing – Biaxial Load

Welding of sphere holder on column head



Top view of column

Laboratory Testing – Biaxial Load

Applying load during testing

At Failure

Finite Element Modeling

- The Concept

  The object is divided into many smaller bodies or elements interconnected at common points called nodes or boundary lines.

- Nodal Displacements

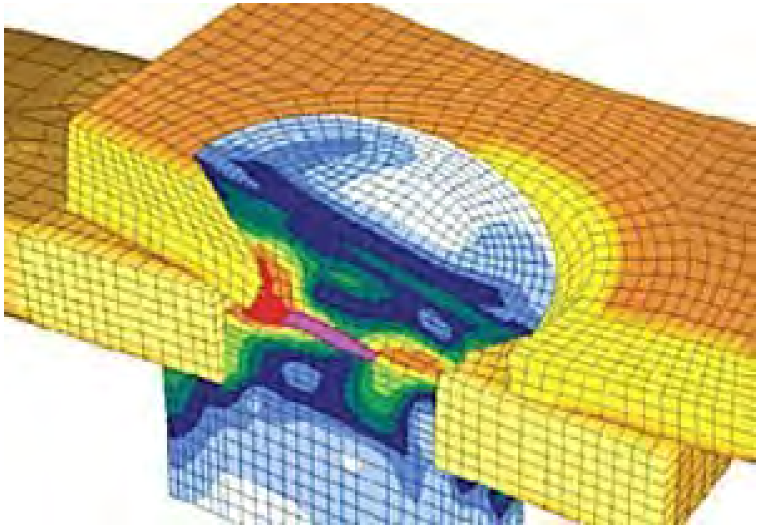
  In structural cases, the unknowns are nodal displacements or stresses created by the applied force. These stresses and displacements are found at each node constituting the element.

- Equilibrium Equations

  Algebraic equations are expressed in terms of nodal displacements using the equations of equilibrium.

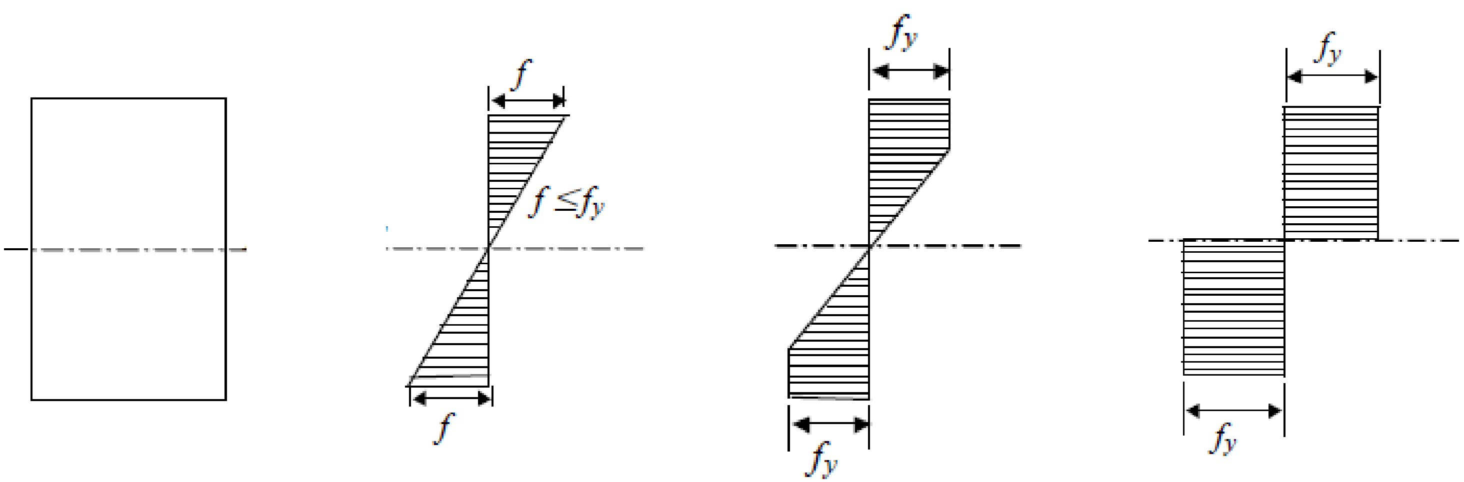
Finite Element Modeling

- Finite Elements
  - Solid Elements (3 DOF's)
  - Structural Elements (6 DOF's)
- Type of Structural Elements
  - Beam Elements
  - Shell elements
- Non-Linear Analysis
  - Ductile Metals (Reduced Modulus)
  - Set of Nonlinear Equations
  - Iteration (Total load applied through small increments)



Finite Element Modeling

- When the load is applied to a steel specimen, initially the specimen behaves entirely elastic.
- When the load is further increased, the stress in the extreme fibers reaches the yield stress. Zones of yielding across the depth are developed (plastic zone) with further increase in load.



Finite Element Modeling

- **ANSYS**

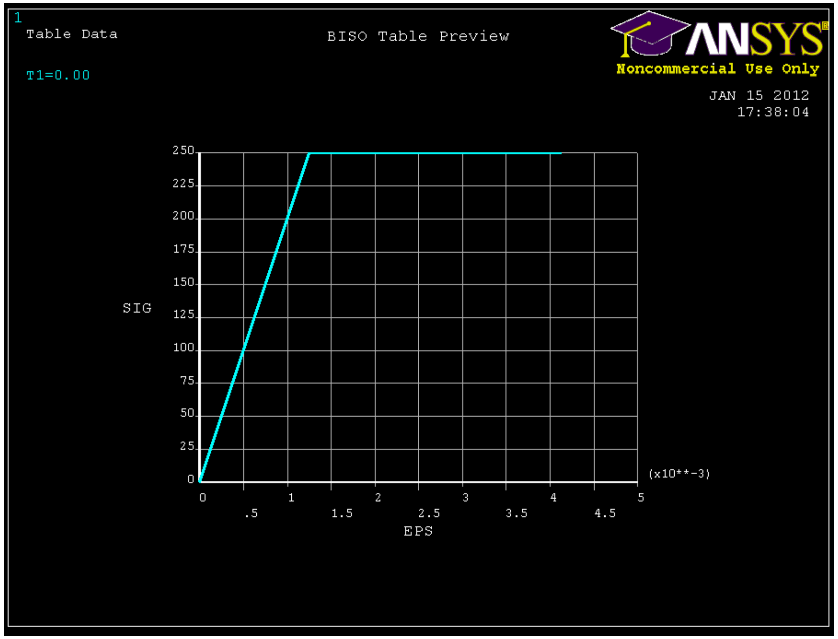
Software to solve finite element problems

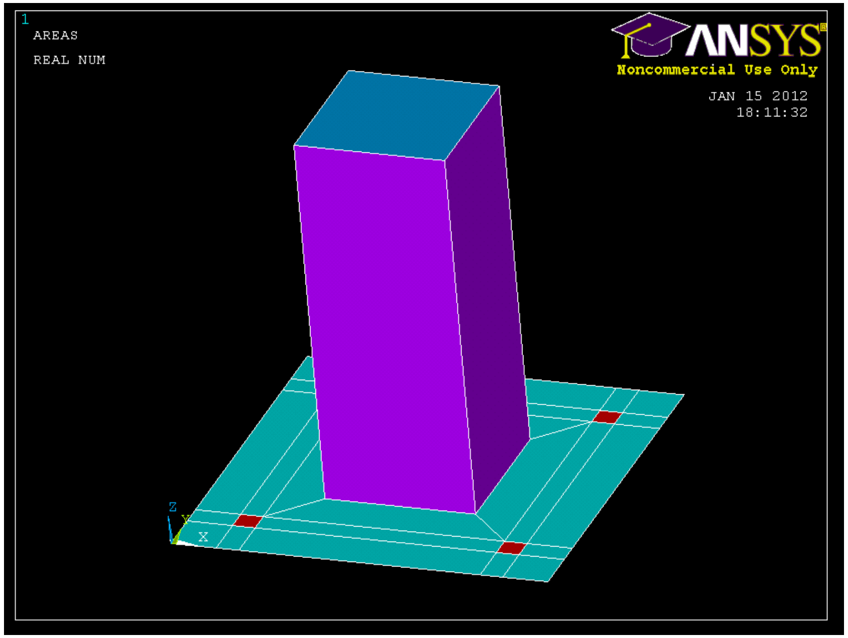
Material Properties, Applied load, Boundary Conditions and type of Analysis.

Component	ANSYS Element	Nodes Per Element	DOF Per Node
Base Plate	SHELL 43	Four	3 Translational 3 Rotational
Column	SHELL 43	Four	
Anchor Bolt	BEAM 188	Two	
Leveling Nuts	SHELL 43	Four	

Finite Element Modeling

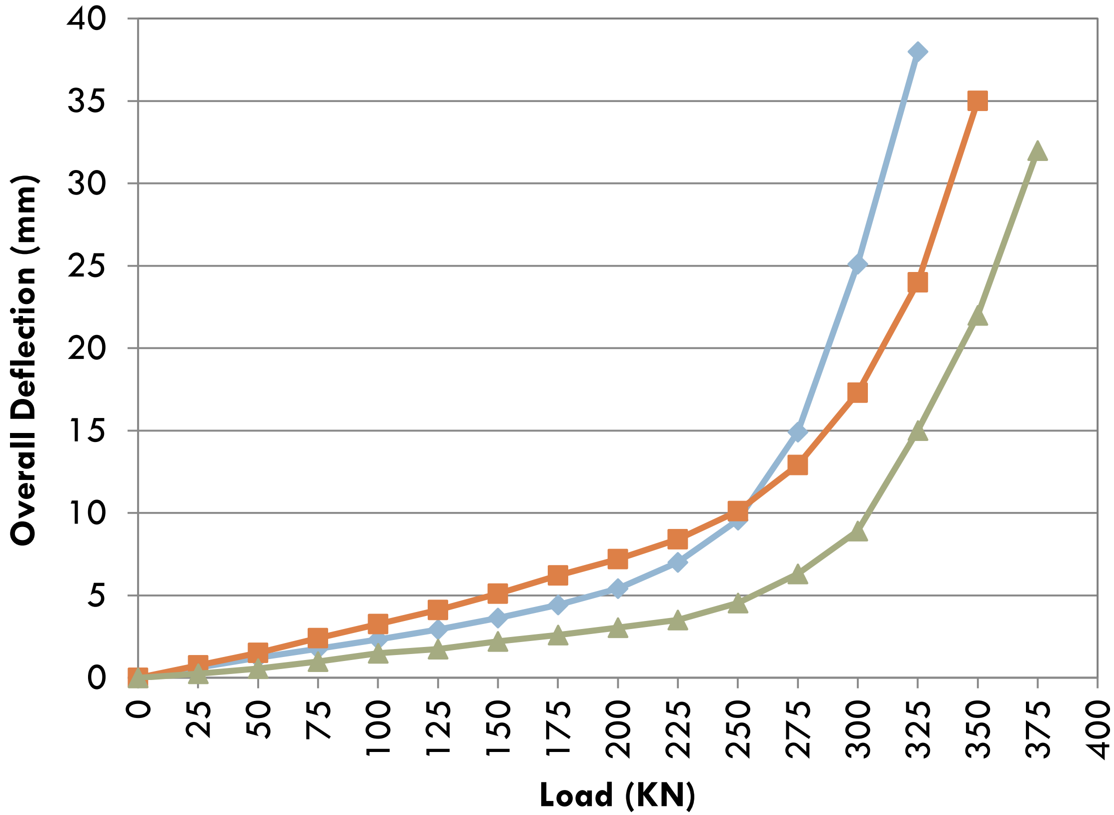
- Material & Section Properties





Finite Element Modeling

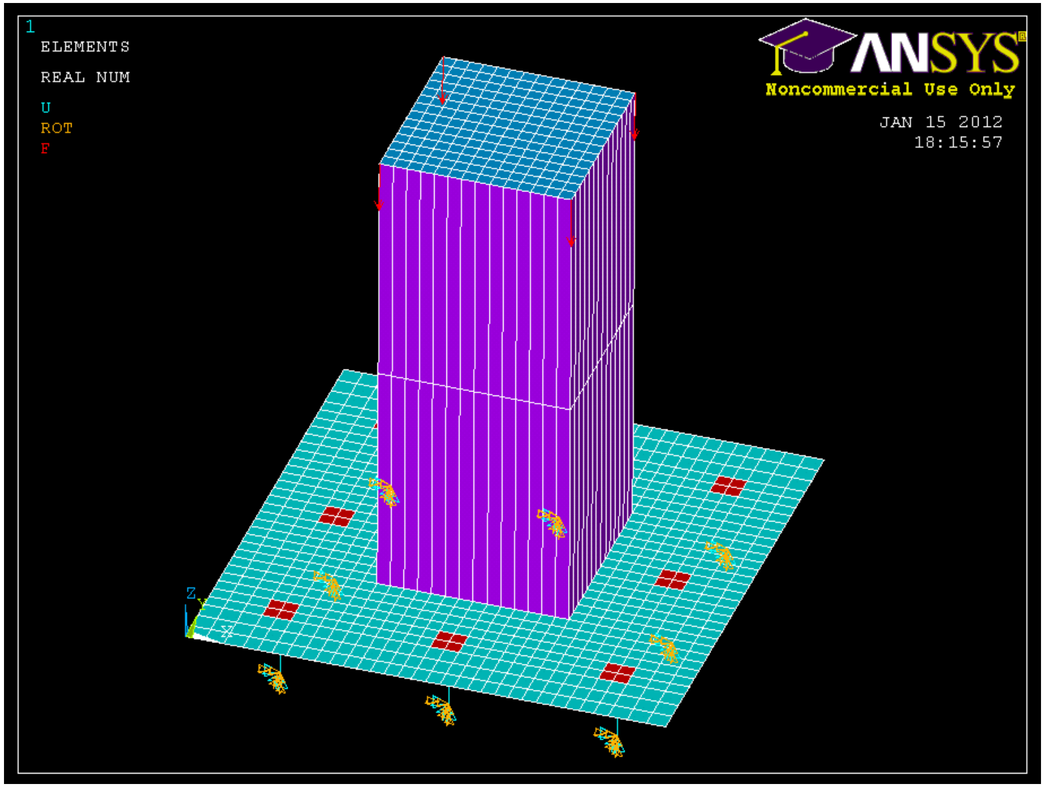
- Verification of ANSYS model (Deflection of Column Head)

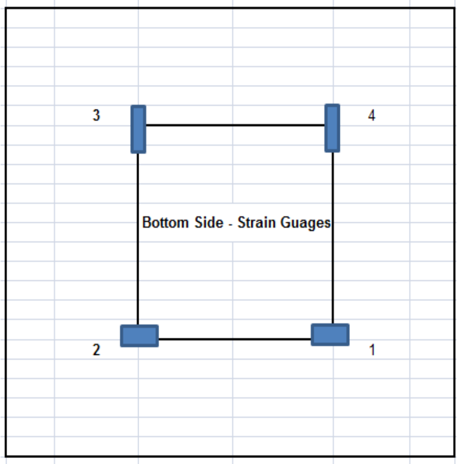


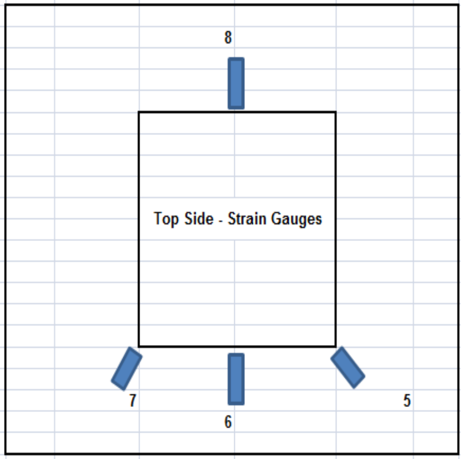
(a) Concentric

Finite Element Modeling

Concentric Load Model & Strain Gauge Locations

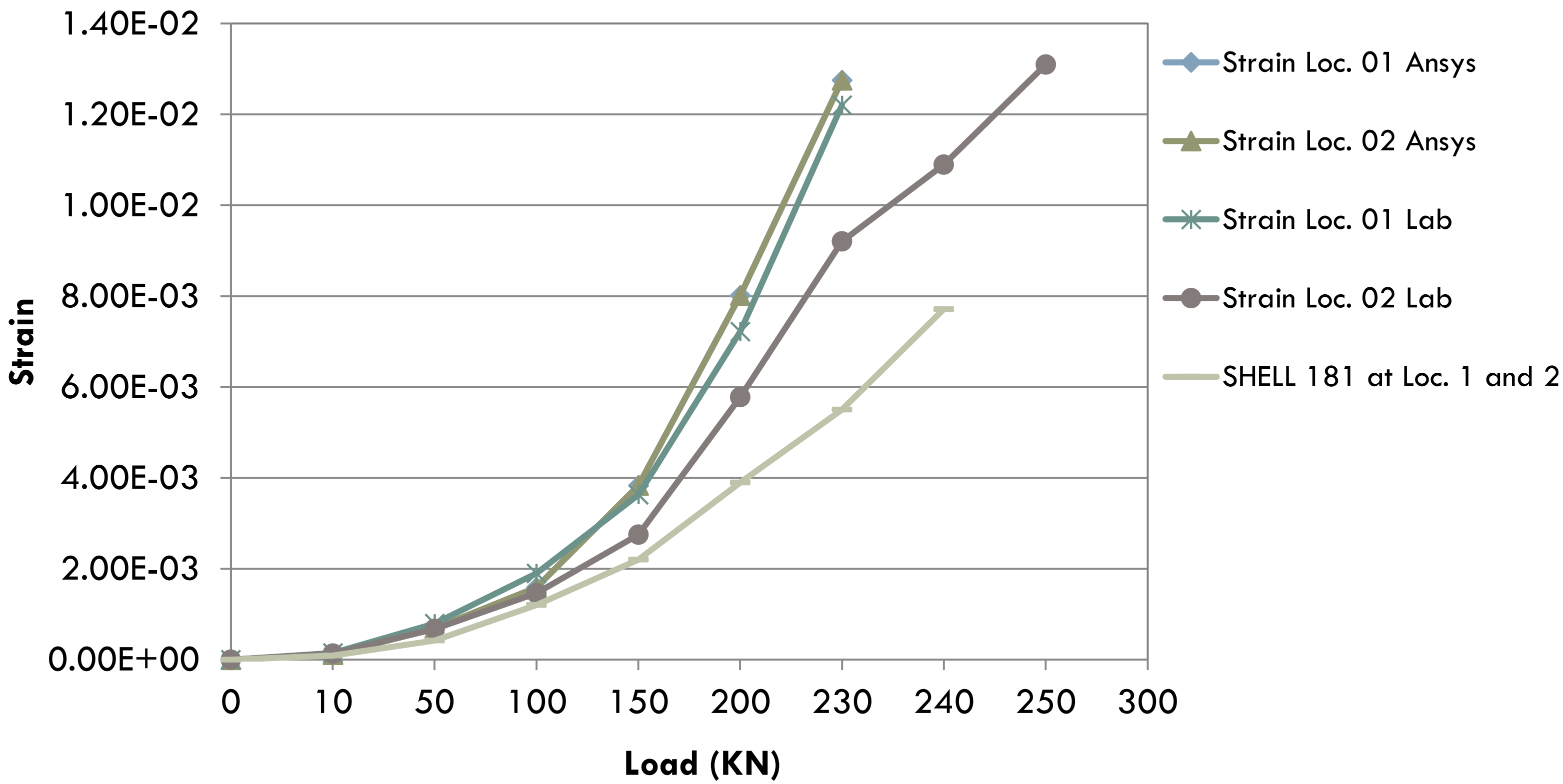






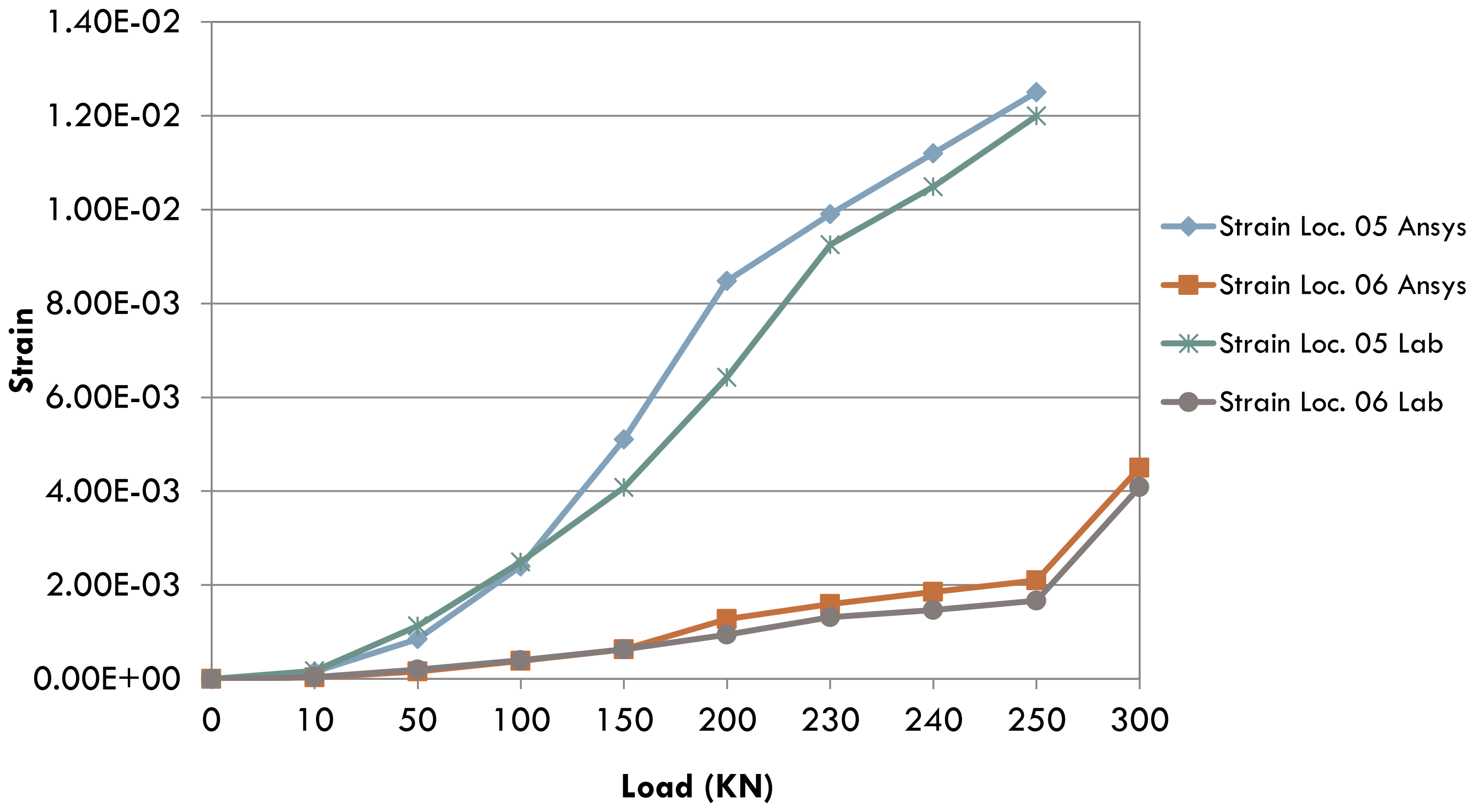
Finite Element Modeling

Verification of Concentric Load Model



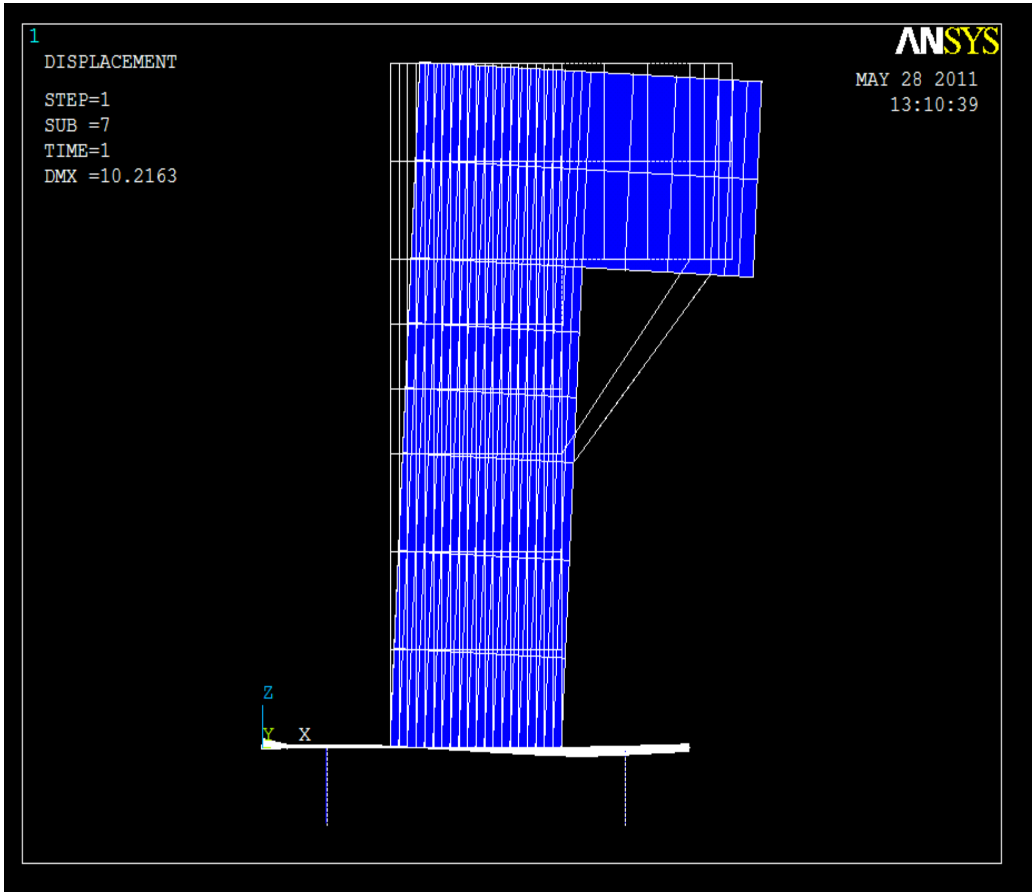
Finite Element Modeling

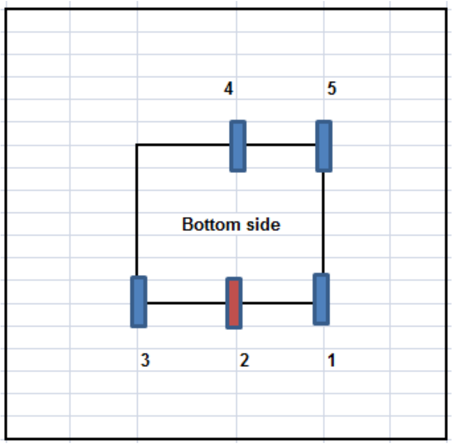
Verification of Concentric Load Model

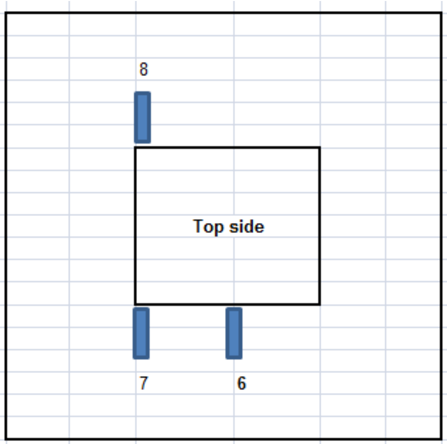


Finite Element Modeling

Uniaxial Bending Load Model & Strain Gauge Locations

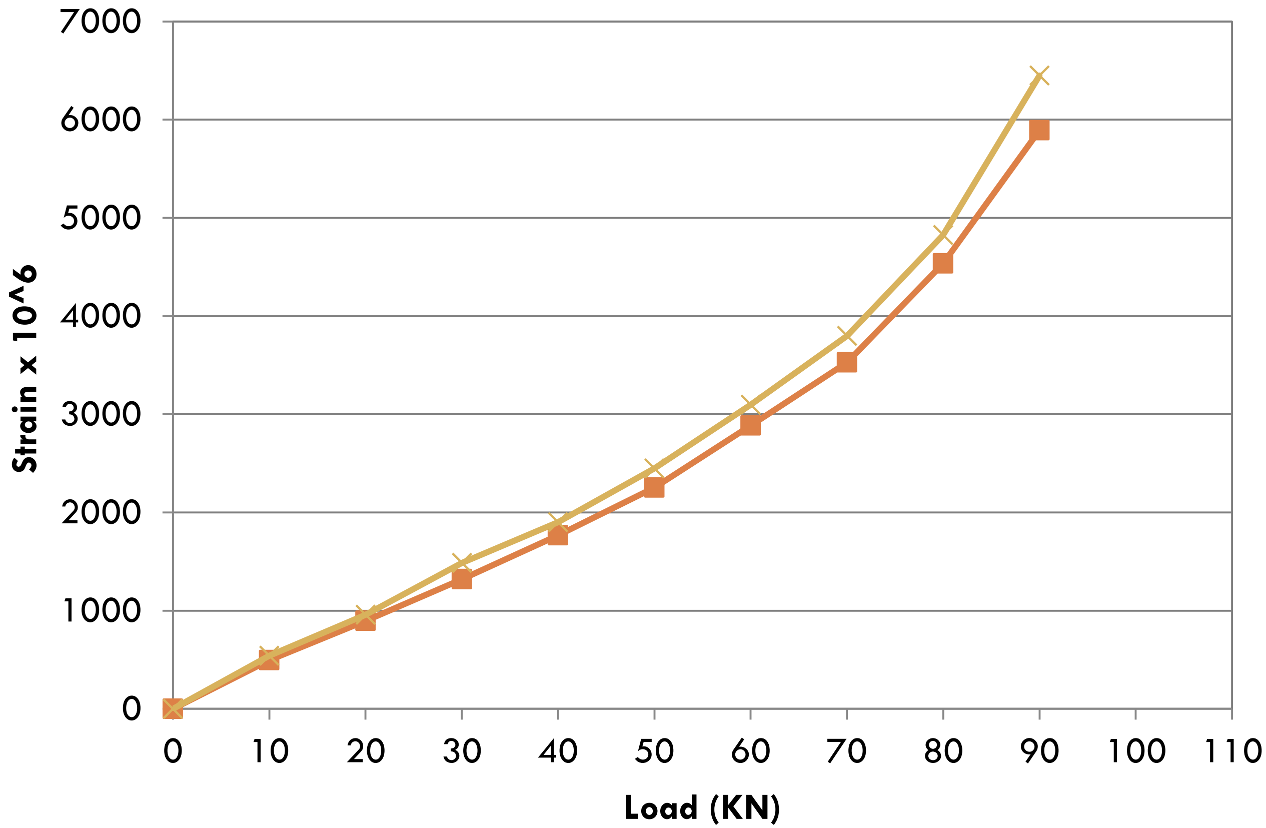






Finite Element Modeling

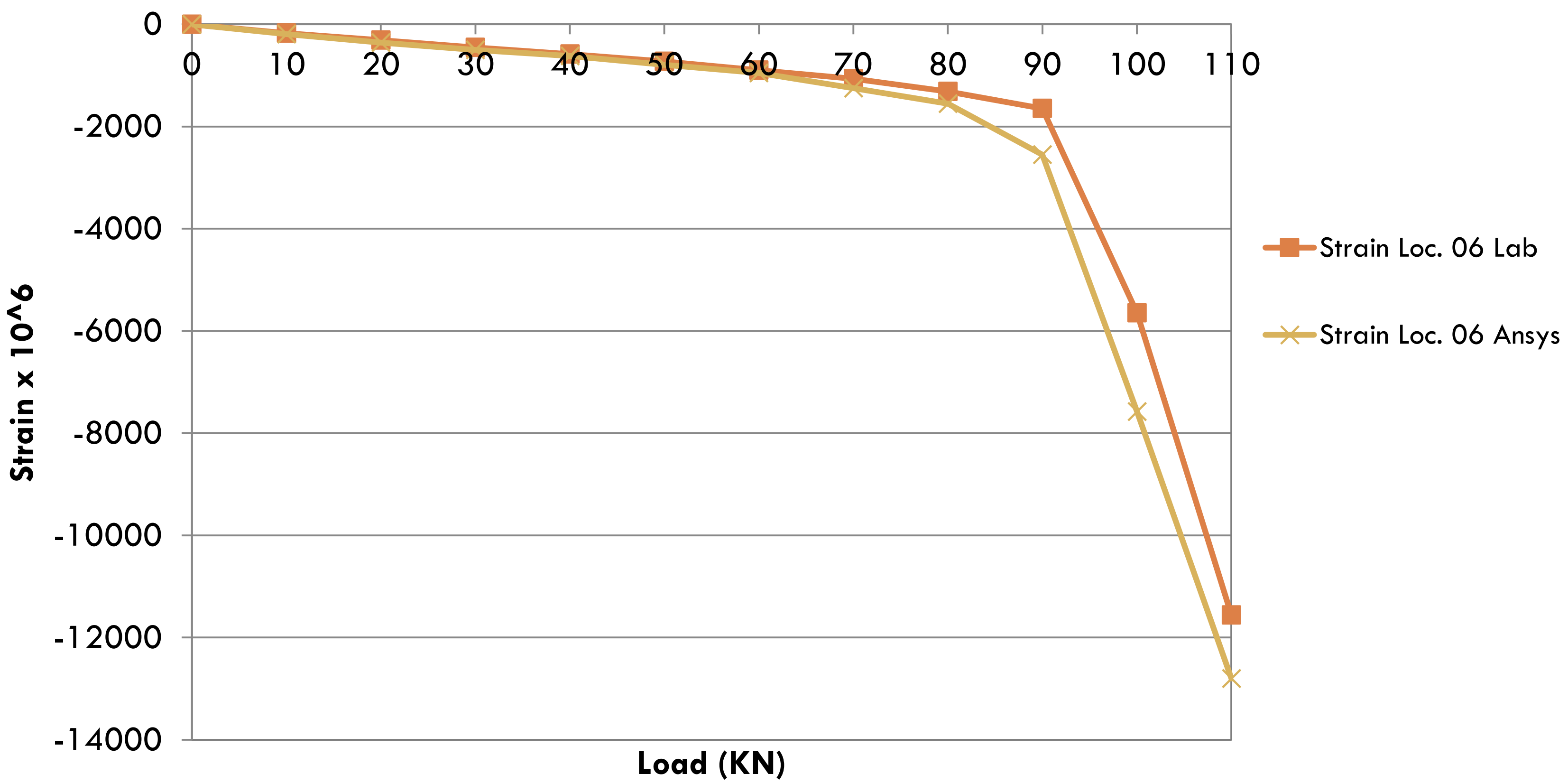
Uniaxial Bending Model Verification



(c) Uniaxial Bending

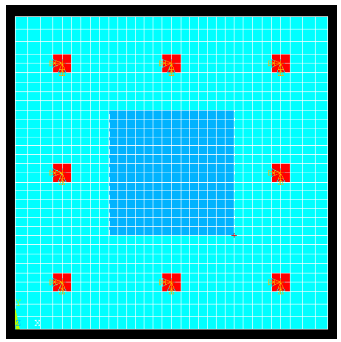
Finite Element Modeling

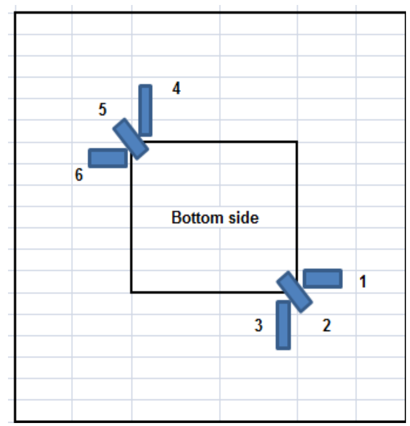
Uniaxial Bending Model Verification

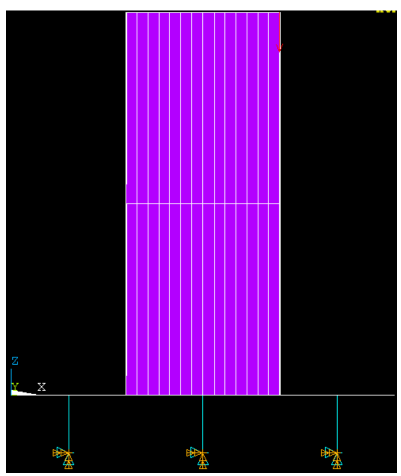


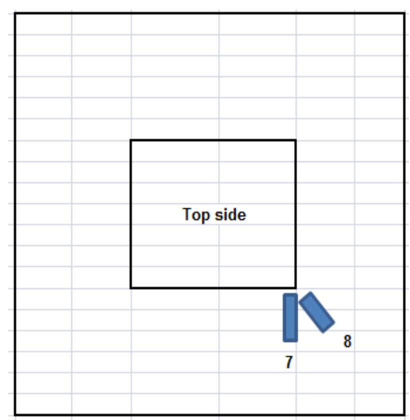
Finite Element Modeling

Biaxial Bending Load Model & Strain Gauge Locations



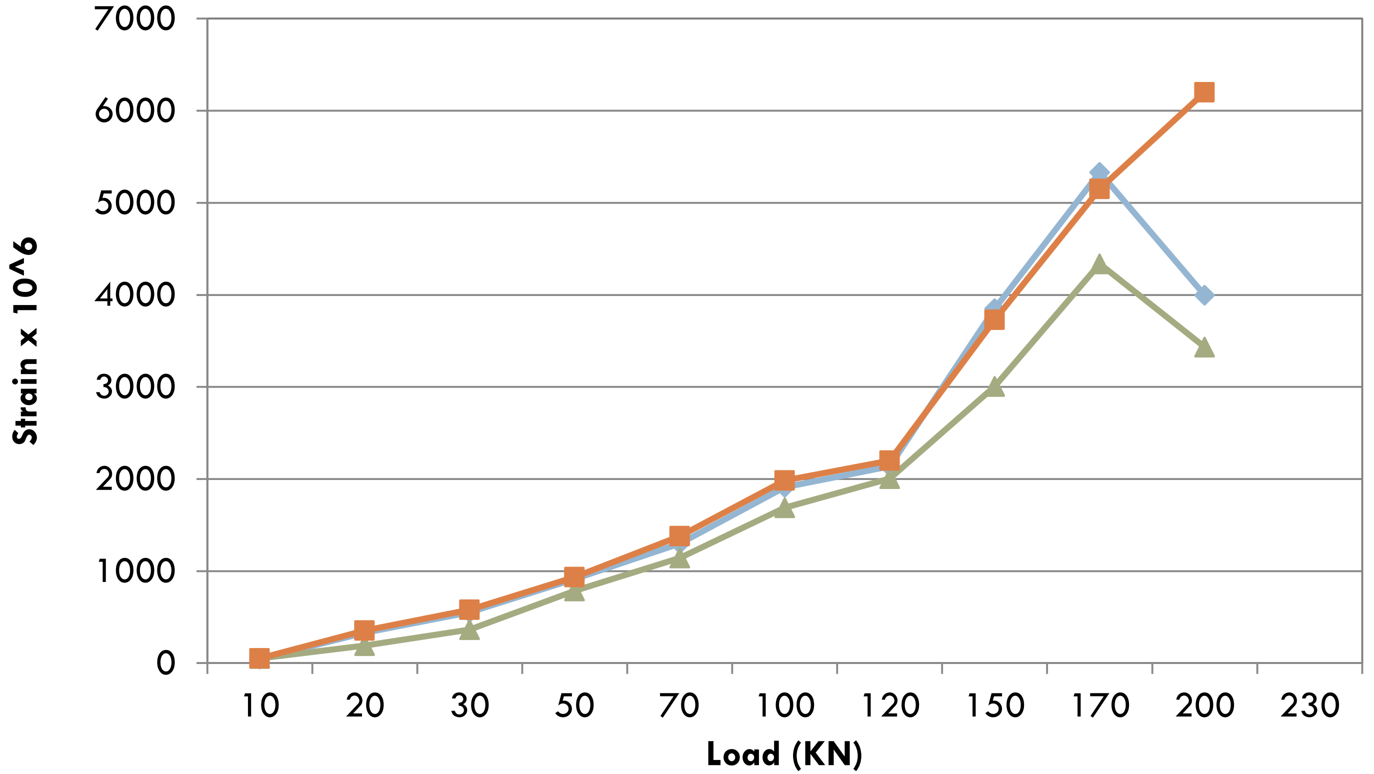






Finite Element Modeling

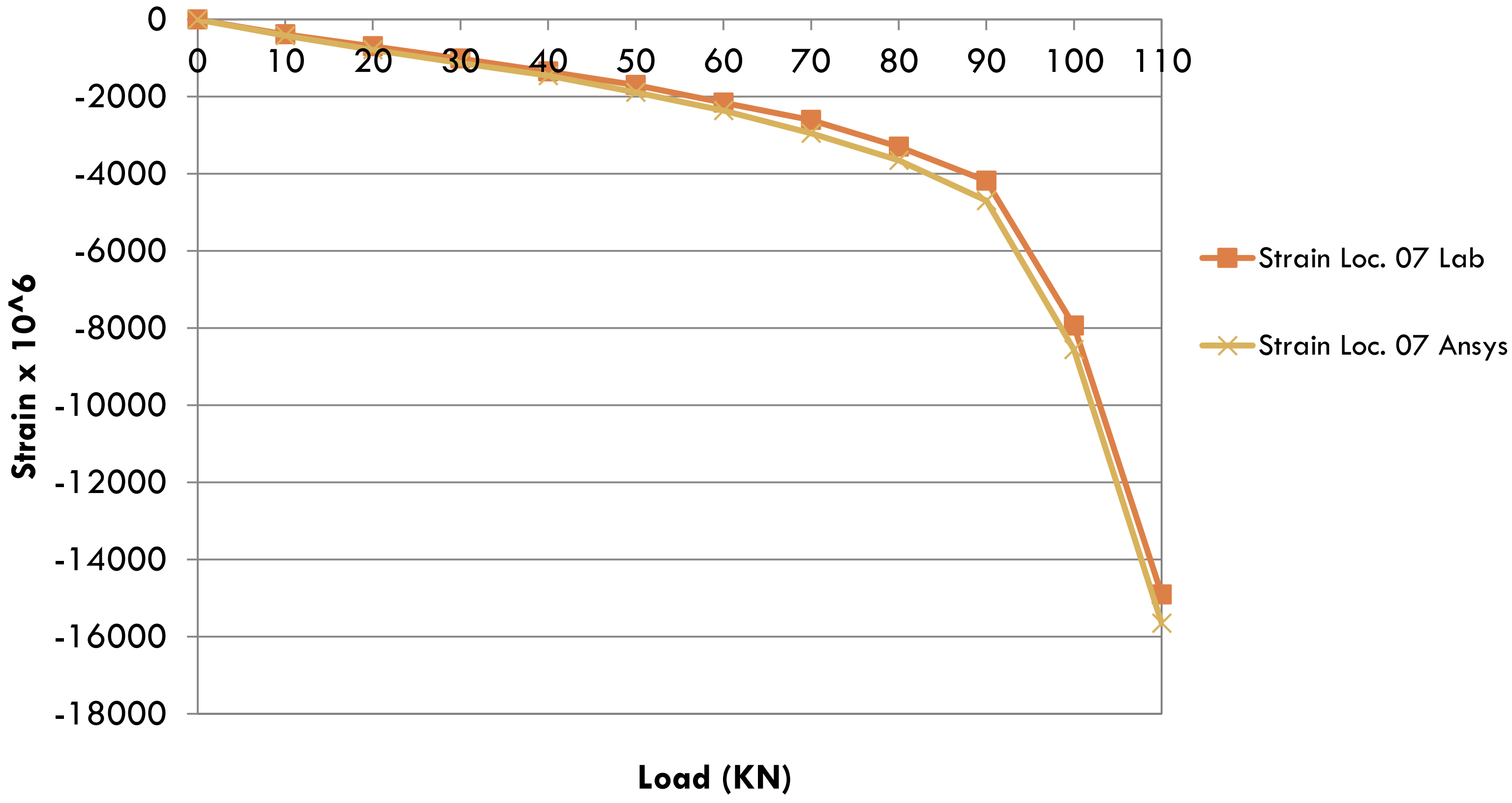
Biaxial Bending Model Verification



(b) Biaxial Bending

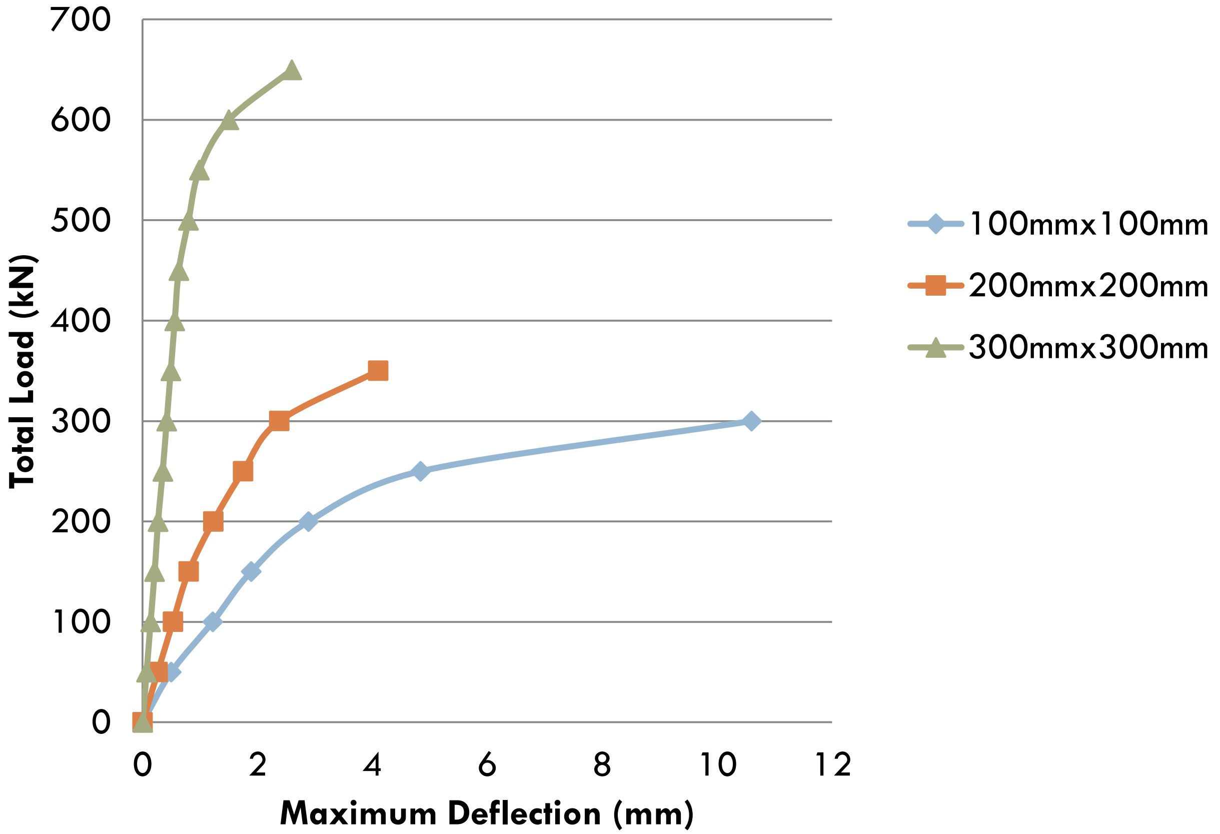
Finite Element Modeling

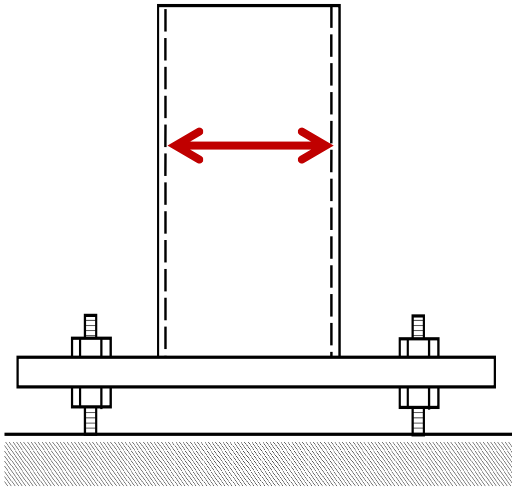
Biaxial Bending Model Verification



Deflection Curves – Concentric Load

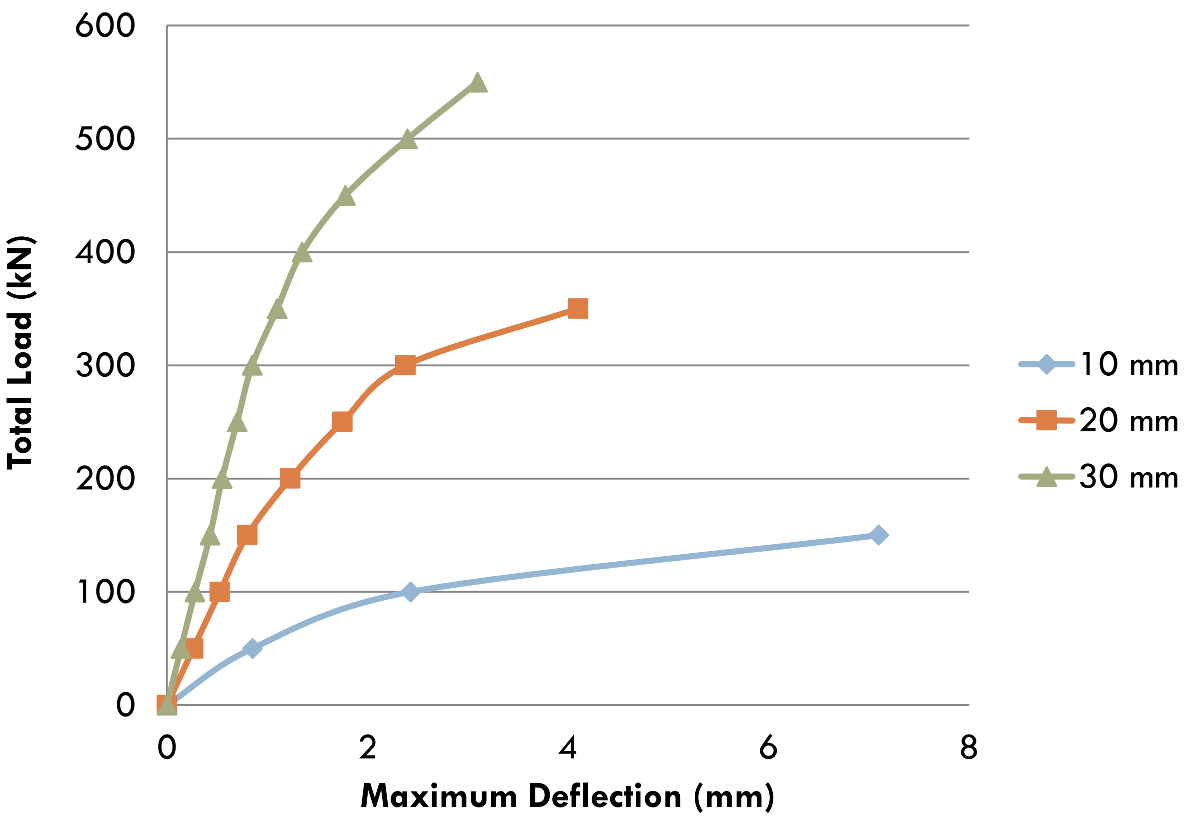
Column Size

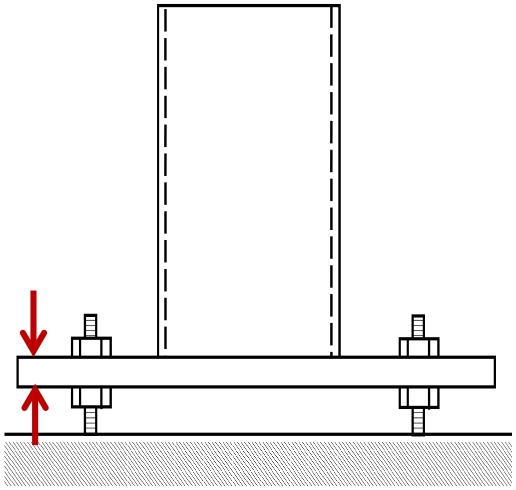




Deflection Curves – Concentric Load

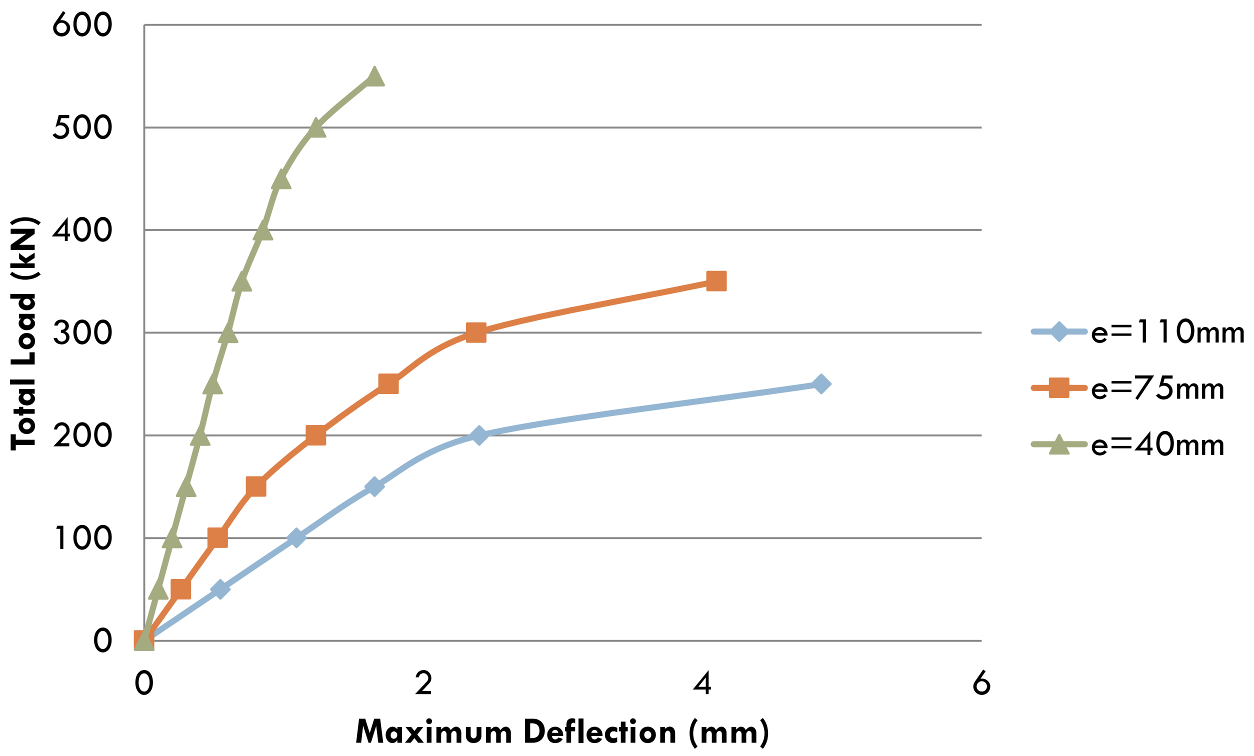
Base Plate Thickness

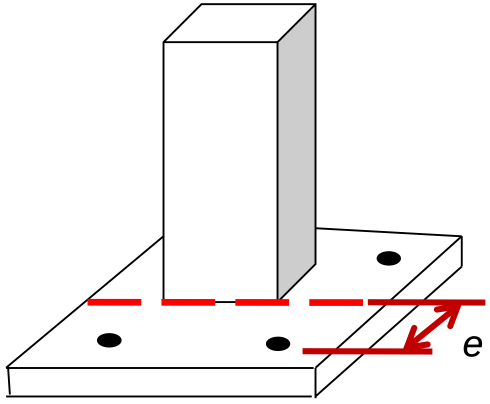




Deflection Curves – Concentric Load

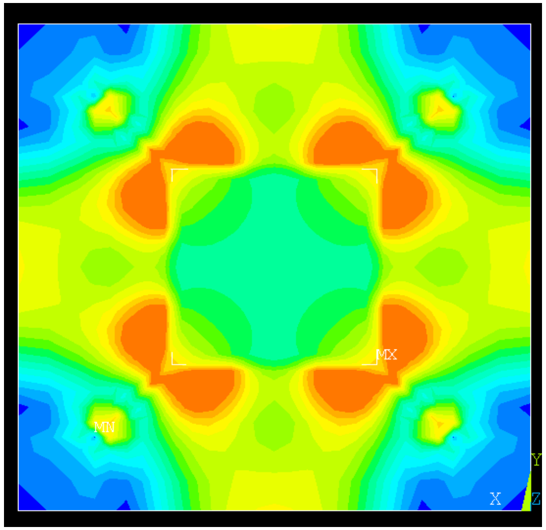
Bolt Eccentricity



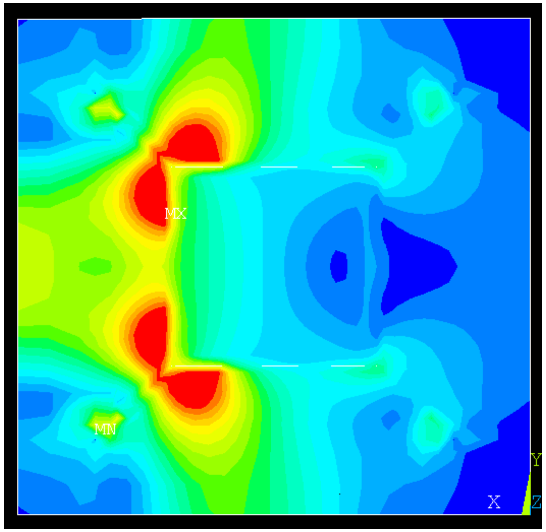


Flexural Stress Contours

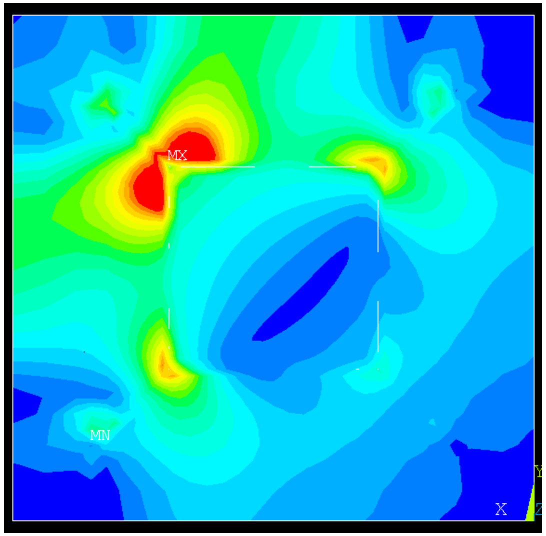
- Effect of Load Type:



Concentric Axial



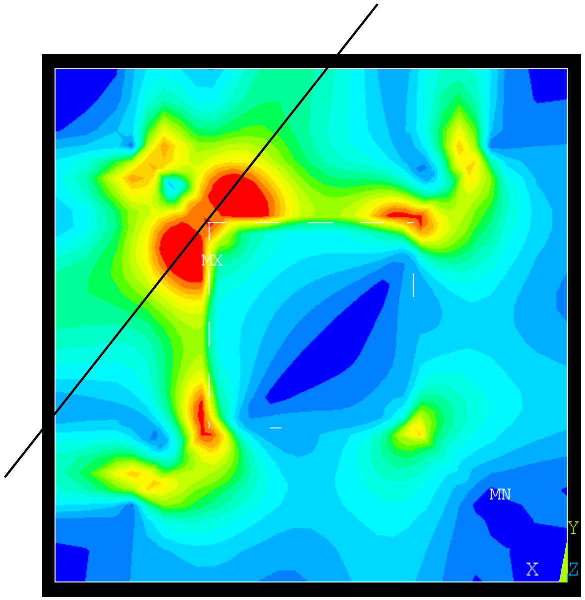
Uniaxial bending



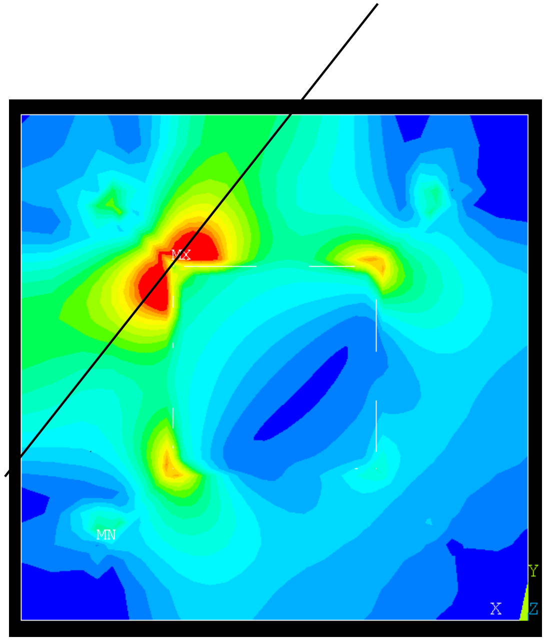
Biaxial Bending

Flexural Stress Contours

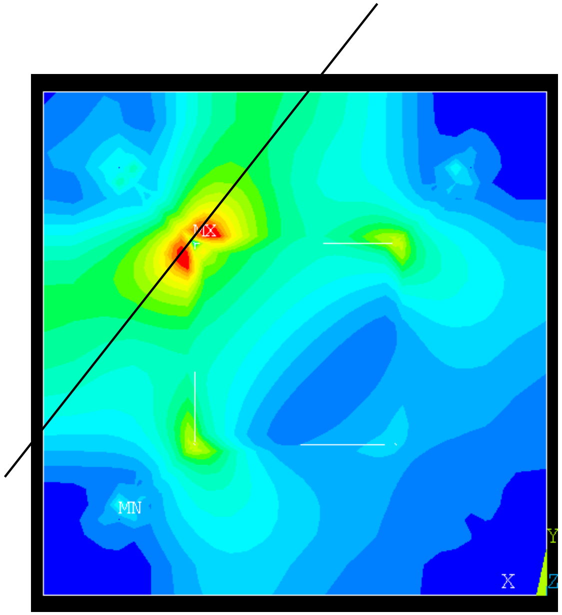
- Effect of Base Plate Thickness:



Thickness = 10 mm



Thickness = 20 mm

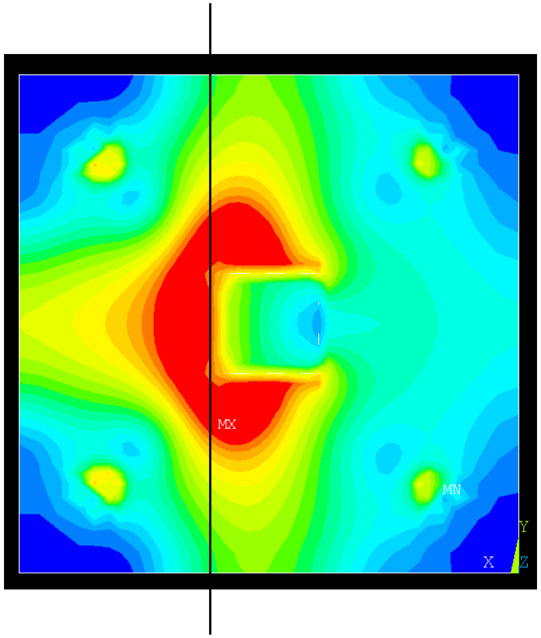


Thickness = 30 mm

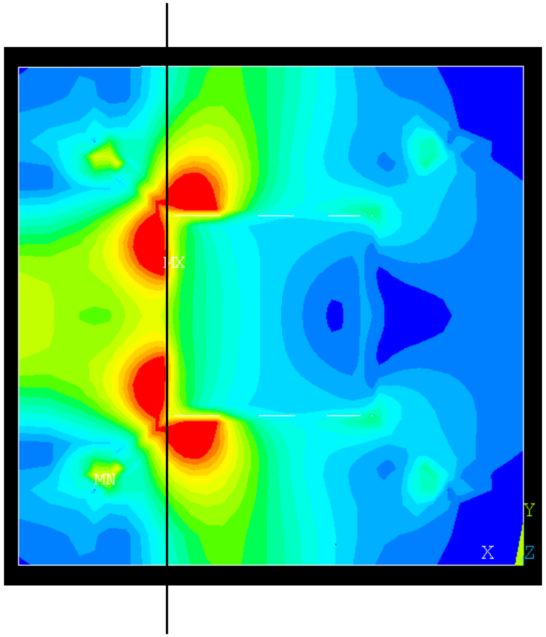
Loading type: Biaxial Bending

Flexural Stress Contours

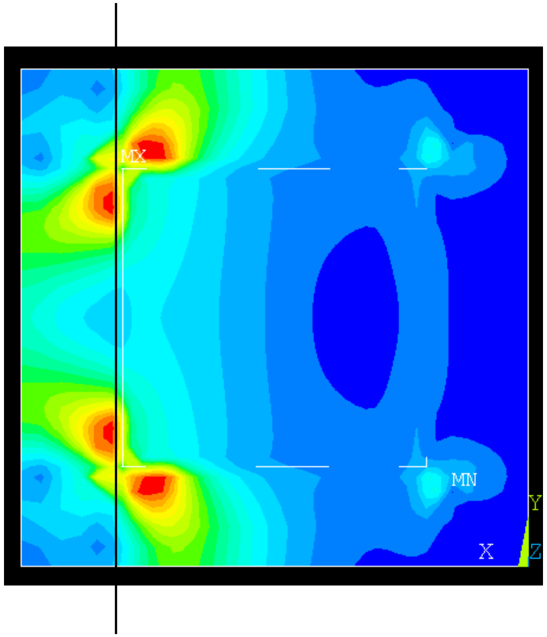
- Effect of Column Size:



100 mm x 100 mm



200 mm x 200 mm

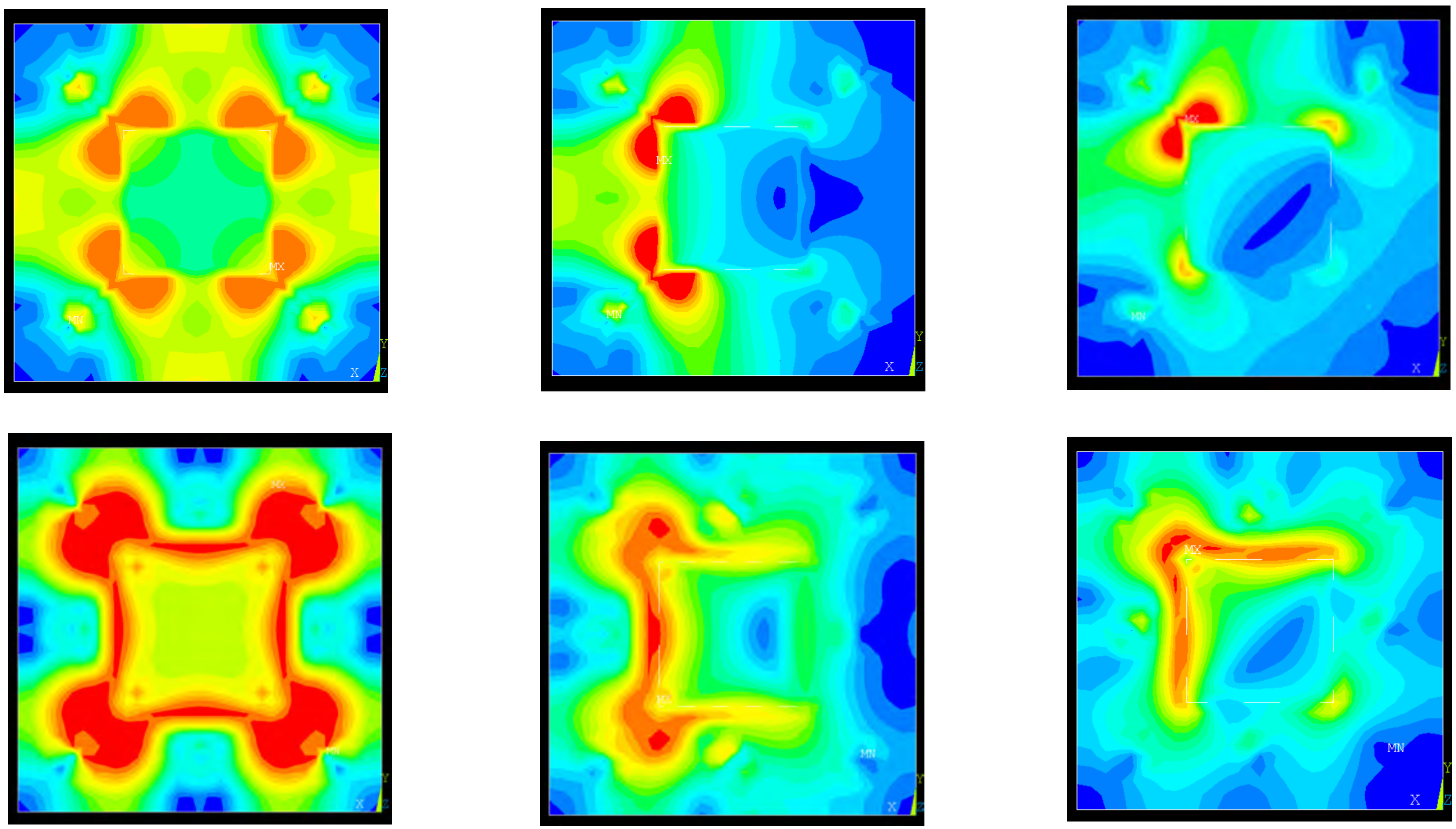


300 mm x 300 mm

Loading type: Uniaxial Bending

Flexural Stress Contours

- Effect of Number of Bolts:



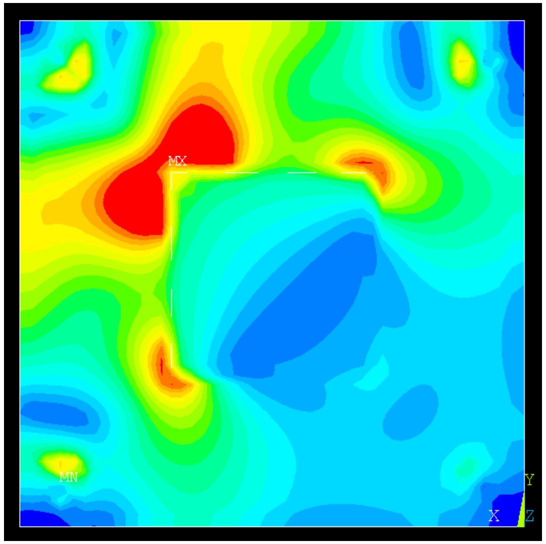
4 bolts

8 bolts

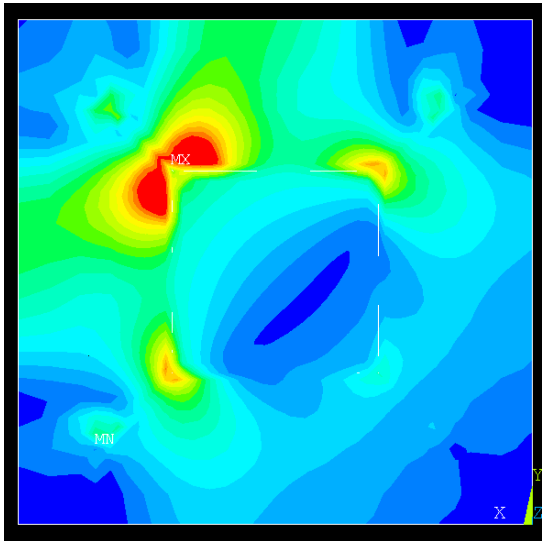
Concentric Axial | Uniaxial bending | Biaxial Bending

Flexural Stress Contours

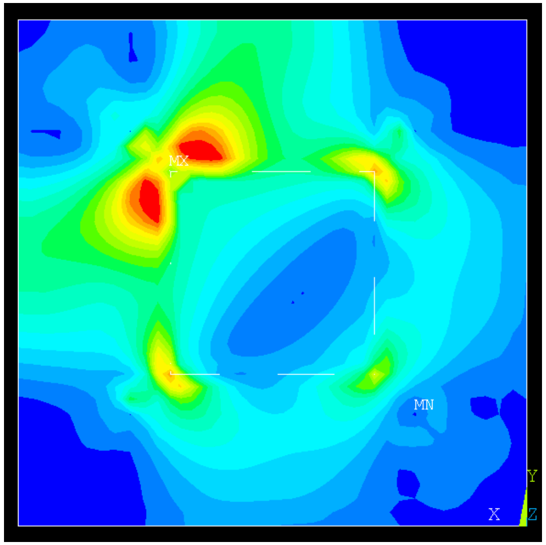
- Effect of Bolt Eccentricity:



e =110 mm



e = 75 mm



e =40 mm

Loading type: Biaxial Bending

Results – Concentric Load Cases

Effect Plate Thickness

Case No.	X	Y	Thk	Cx	Cy	Sx	Sy	CS	e	l	n	Nut Size	Bolt Dia	b
1b	500	500	10	200	200	350	350	75	75	75	4	30 x 30	20	480
1a	500	500	20	200	200	350	350	75	75	75	4	30 x 30	20	450
1c	500	500	30	200	200	350	350	75	75	75	4	30 x 30	20	427
1d	500	500	40	200	200	350	350	75	75	75	4	30 x 30	20	405

Effect of Column Size

Case No.	X	Y	Thk	Cx	Cy	Sx	Sy	CS	e	l	n	Nut Size	Bolt Dia	b
2a	500	500	20	100	100	350	350	75	75	125	4	30 x 30	20	500
1a	500	500	20	200	200	350	350	75	75	75	4	30 x 30	20	450
2b	500	500	20	300	300	350	350	75	75	25	4	30 x 30	20	305
2c	500	500	20	300	200	350	350	75	75	75	4	30 x 30	20	490

Effect of Nut Size

Case No.	X	Y	Thk	Cx	Cy	Sx	Sy	CS	e	l	n	Nut Size	Bolt Dia	b
3a	500	500	20	200	200	350	350	75	75	75	4	20 x 20	10	375
1a	500	500	20	200	200	350	350	75	75	75	4	30 x 30	20	450
3b	500	500	20	200	200	350	350	75	75	75	4	40 x 40	30	500

Effect of clear Spacing under the plate

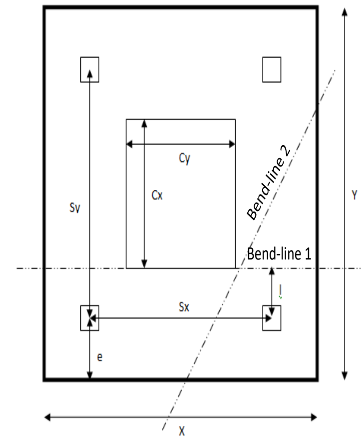
Case No.	X	Y	Thk	Cx	Cy	Sx	Sy	CS	e	l	n	Nut Size	Bolt Dia	b
4a	500	500	20	200	200	350	350	25	75	75	4	30 x 30	20	448
1a	500	500	20	200	200	350	350	75	75	75	4	30 x 30	20	450
4b	500	500	20	200	200	350	350	100	75	75	4	30 x 30	20	452

Effect of Number of Bolts

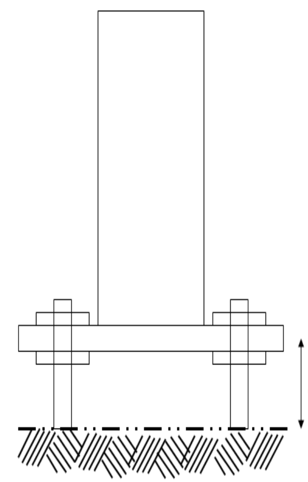
Case No.	X	Y	Thk	Cx	Cy	Sx	Sy	CS	e	l	n	Nut Size	Bolt Dia	b
1a	500	500	20	200	200	350	350	75	75	75	4	30 x 30	20	450
5a	500	500	20	200	200	175	350	75	75	75	6	30 x 30	20	500
5b	500	500	20	200	200	175	175	75	75	75	8	30 x 30	20	480

Effect of Bolt Eccentricity

Case No.	X	Y	Thk	Cx	Cy	Sx	Sy	CS	e	l	n	Nut Size	Bolt Dia	b
6a	500	500	20	200	200	420	420	75	40	110	4	30 x 30	20	500
1a	500	500	20	200	200	350	350	75	75	75	4	30 x 30	20	450
6b	500	500	20	200	200	280	280	75	110	40	4	30 x 30	20	448



(a) Plan



(b) Elevation

Results – Uniaxial Bending Cases

Effect Plate Thickness

Case No.	X	Y	Thk	Cx	Cy	Sx	Sy	CS	e	l	Bolt Dia	n	Nut Size	b avl	b
1b	500	500	10	200	200	350	350	75	75	75	20	4	30 x 30	500	480
1a	500	500	20	200	200	350	350	75	75	75	20	4	30 x 30	500	381
1c	500	500	30	200	200	350	350	75	75	75	20	4	30 x 30	500	327
1d	500	500	40	200	200	350	350	75	75	75	20	4	30 x 30	500	273

Effect of Column Size

Case No.	X	Y	Thk	Cx	Cy	Sx	Sy	CS	e	l	Bolt Dia	n	Nut Size	b avl	b
2a	500	500	20	100	100	350	350	75	75	125	20	4	30 x 30	500	458
1a	500	500	20	200	200	350	350	75	75	75	20	4	30 x 30	500	381
2b	500	500	20	300	300	350	350	75	75	25	20	4	30 x 30	500	261

Effect of Nut Size

Case No.	X	Y	Thk	Cx	Cy	Sx	Sy	CS	e	l	Bolt Dia	n	Nut Size	b avl	b
3a	500	500	20	200	200	350	350	75	75	75	10	4	20 x 20	500	324
1a	500	500	20	200	200	350	350	75	75	75	20	4	30 x 30	500	381
3b	500	500	20	200	200	350	350	75	75	75	30	4	40 x 40	500	425

Effect of clear Spacing under the plate

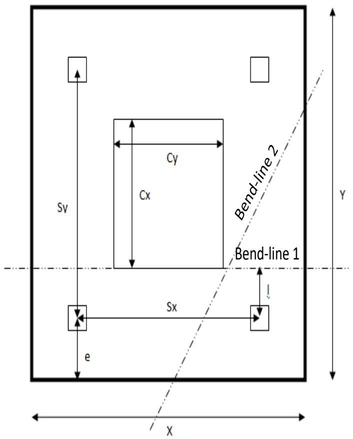
Case No.	X	Y	Thk	Cx	Cy	Sx	Sy	CS	e	l	Bolt Dia	n	Nut Size	b avl	b
4a	500	500	20	200	200	350	350	25	75	75	20	4	30 x 30	500	380
1a	500	500	20	200	200	350	350	75	75	75	20	4	30 x 30	500	381
4b	500	500	20	200	200	350	350	100	75	75	20	4	30 x 30	500	382

Effect of Number of Bolts

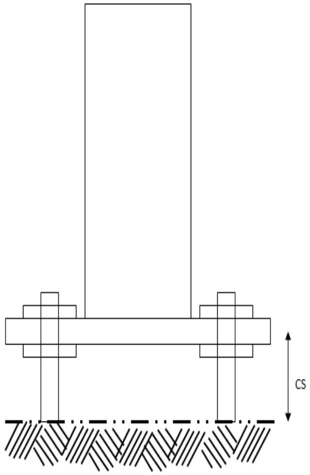
Case No.	X	Y	Thk	Cx	Cy	Sx	Sy	CS	e	l	Bolt Dia	n	Nut Size	b avl	b
1a	500	500	20	200	200	350	350	75	75	75	20	4	30 x 30	500	381
5b	500	500	20	200	200	175	175	75	75	75	20	8	30 x 30	500	480

Effect of Bolt Eccentricity

Case No.	X	Y	Thk	Cx	Cy	Sx	Sy	CS	e	l	Bolt Dia	n	Nut Size	b avl	b
6a	500	500	20	200	200	420	420	75	40	110	20	4	30 x 30	500	420
1a	500	500	20	200	200	350	350	75	75	75	20	4	30 x 30	500	381
6b	500	500	20	200	200	280	280	75	110	40	20	4	30 x 30	500	388



(a) Plan



(b) Elevation

Results – Biaxial Bending Cases

Effect Plate Thickness

Case No.	X	Y	Thk	Cx	Cy	Sx	Sy	CS	e	l	n	Nut Size	Bolt Dia	b avl	b
1b	500	500	10	200	200	350	350	75	75	75	4	30 x 30	20	425	400
1a	500	500	20	200	200	350	350	75	75	75	4	30 x 30	20	425	243
1c	500	500	30	200	200	350	350	75	75	75	4	30 x 30	20	425	177
1d	500	500	40	200	200	350	350	75	75	75	4	30 x 30	20	425	132

Effect of Column Size

Case No.	X	Y	Thk	Cx	Cy	Sx	Sy	CS	e	l	n	Nut Size	Bolt Dia	b avl	b
2a	500	500	20	100	100	350	350	75	75	125	4	30 x 30	20	566	317
1a	500	500	20	200	200	350	350	75	75	75	4	30 x 30	20	425	243
2b	500	500	20	300	300	350	350	75	75	25	4	30 x 30	20	283	148
2c	500	500	20	300	200	350	350	75	75	75	4	30 x 30	20	580	256

Effect of Nut Size

Case No.	X	Y	Thk	Cx	Cy	Sx	Sy	CS	e	l	n	Nut Size	Bolt Dia	b avl	b
3a	500	500	20	200	200	350	350	75	75	75	4	20 x 20	10	425	171
1a	500	500	20	200	200	350	350	75	75	75	4	30 x 30	20	425	243
3b	500	500	20	200	200	350	350	75	75	75	4	40 x 40	30	425	305

Effect of clear Spacing under the plate

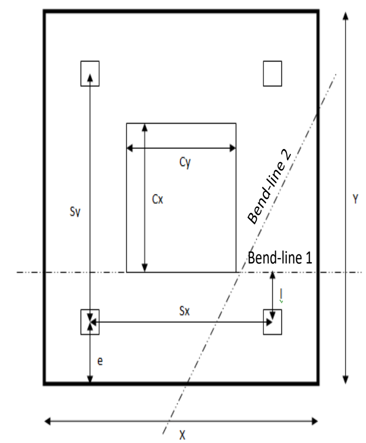
Case No.	X	Y	Thk	Cx	Cy	Sx	Sy	CS	e	l	n	Nut Size	Bolt Dia	b avl	b
4a	500	500	20	200	200	350	350	25	75	75	4	30 x 30	20	425	242
1a	500	500	20	200	200	350	350	75	75	75	4	30 x 30	20	425	243
4b	500	500	20	200	200	350	350	100	75	75	4	30 x 30	20	425	244

Effect of Number of Bolts

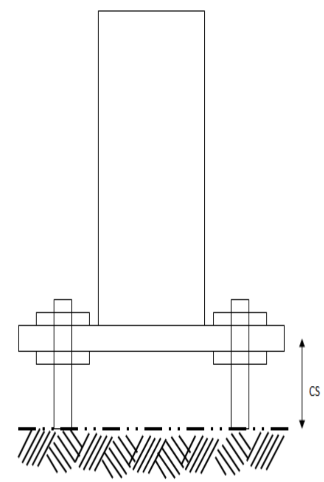
Case No.	X	Y	Thk	Cx	Cy	Sx	Sy	CS	e	l	n	Nut Size	Bolt Dia	b avl	b
1a	500	500	20	200	200	350	350	75	75	75	4	30 x 30	20	425	243
5b	500	500	20	200	200	175	175	75	75	75	8	30 x 30	20	500	391

Effect of Bolt Eccentricity

Case No.	X	Y	Thk	Cx	Cy	Sx	Sy	CS	e	l	n	Nut Size	Bolt Dia	b avl	b
6a	500	500	20	200	200	420	420	75	40	110	4	30 x 30	20	425	325
1a	500	500	20	200	200	350	350	75	75	75	4	30 x 30	20	425	243
6b	500	500	20	200	200	280	280	75	110	40	4	30 x 30	20	425	235



(a) Plan



(b) Elevation

Results

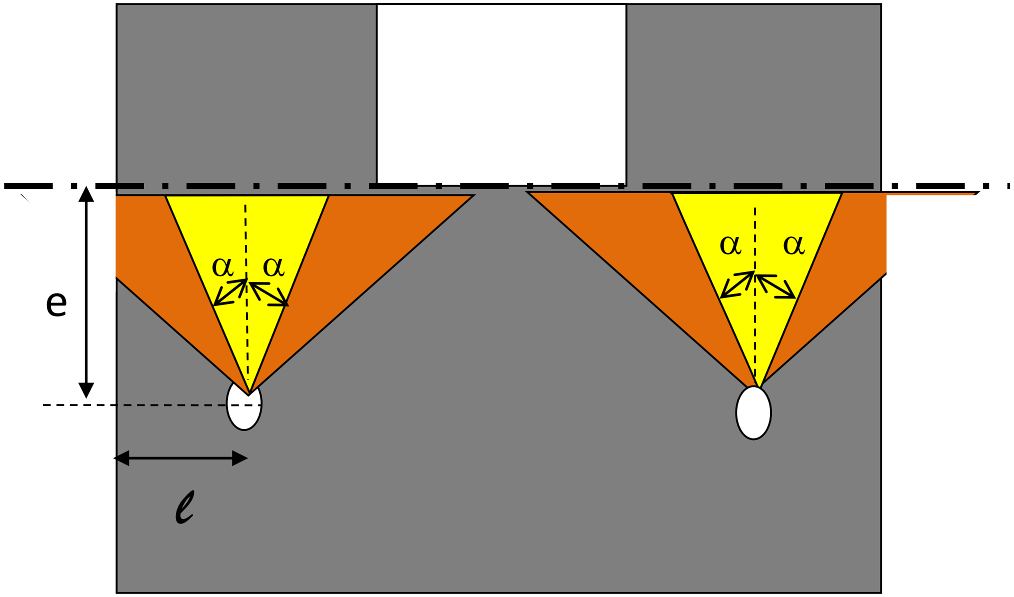
Calculation of Angles

$$\alpha > \tan^{-1}\left(\frac{l}{e}\right)$$

$$\alpha = \tan^{-1}\left[\frac{\left(\frac{b}{2} - l\right)}{e}\right]$$

$$\alpha < \tan^{-1}\left(\frac{l}{e}\right)$$

$$\alpha = \tan^{-1}\left[\frac{b}{(4 * e)}\right]$$



Results

Base Plate Thickness Parameter

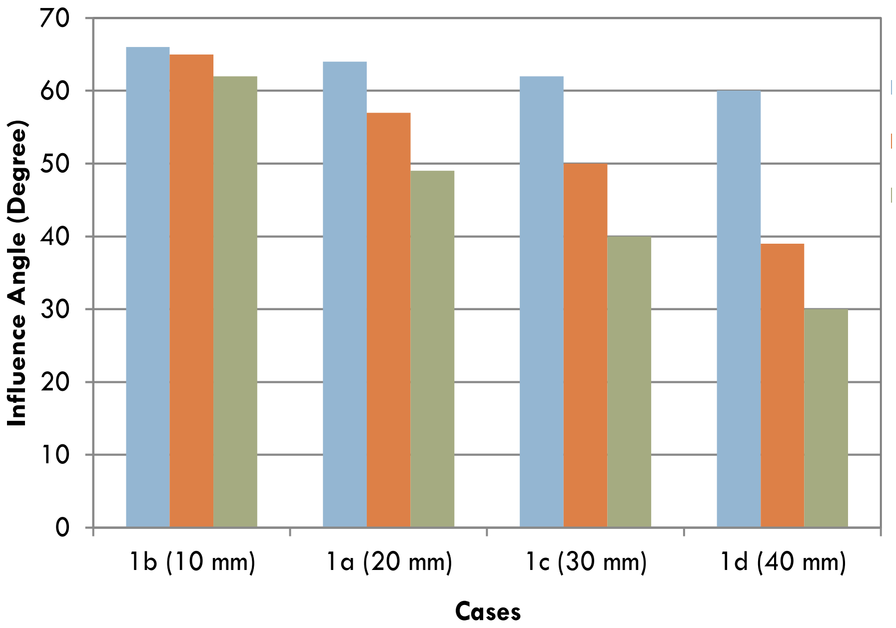
LOAD/ CASE	Concentric	Uniaxial Bending	Biaxial Bending
1b (10 mm)	66^{o}	67^{o}	62^{o}
1a (20 mm)	64^{o}	57^{o}	49^{o}
1c (30 mm)	62^{o}	50^{o}	40^{o}

Column Size Parameter

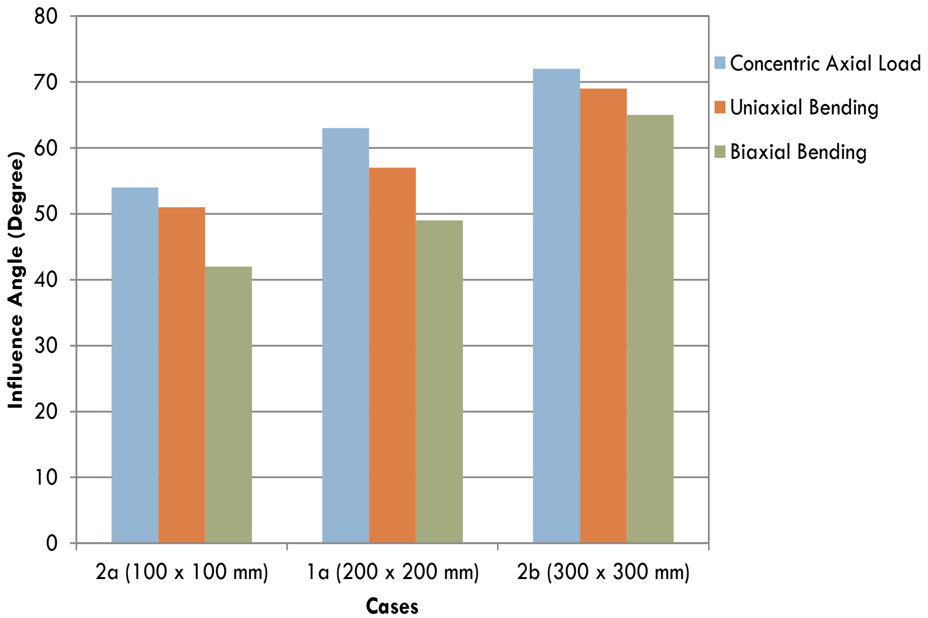
LOAD/ CASE	Concentric	Uniaxial Bending	Biaxial Bending
2a (100 mm x100 mm)	54^{o}	51^{o}	42^{o}
1a (200 mm x 200 mm)	64^{o}	57^{o}	49^{o}
2b (300 mm x 300 mm)	72^{o}	69^{o}	65^{o}

Results

- Influence Angles



Effect of Base Plate Thickness



Effect of Column Size

Results

No. of bolts parameter

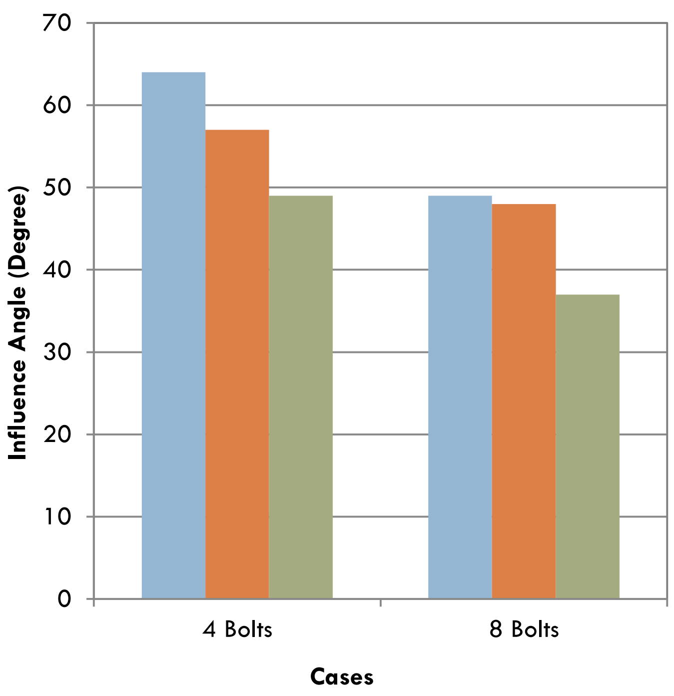
LOAD/ CASE	Concentric	Uniaxial Bending	Biaxial Bending
1a (4 Bolts)	64°	57°	49°
5b (8 Bolts)	49°	48°	37°

Bolt Eccentricity from the column

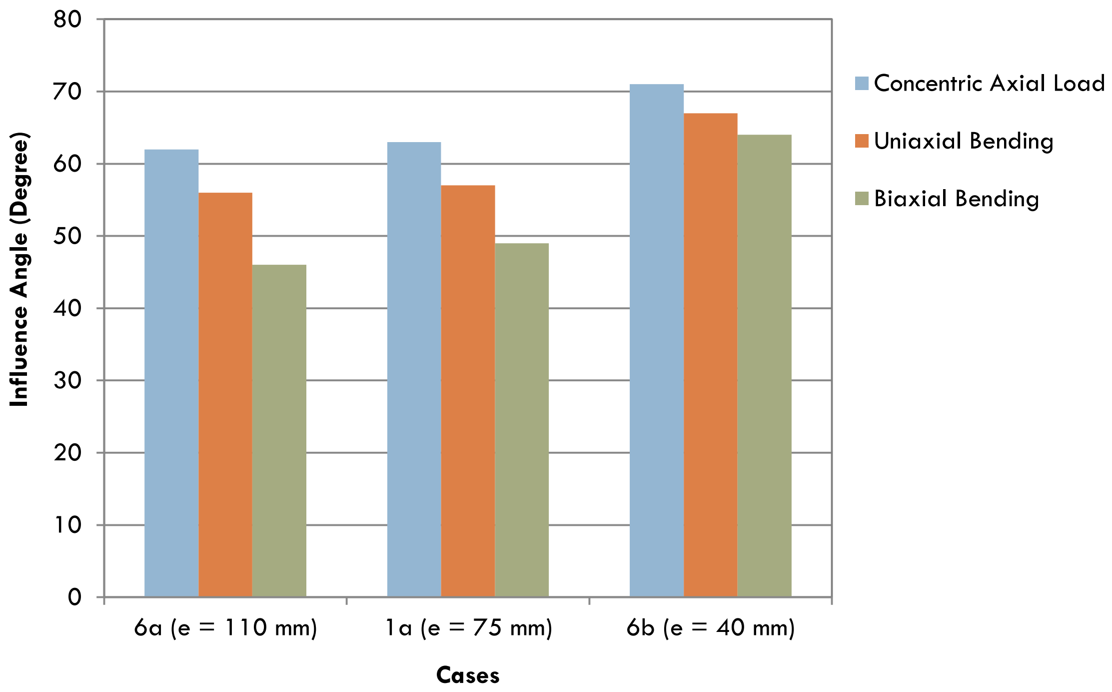
LOAD/ CASE	Concentric	Uniaxial Bending	Biaxial Bending
6a (110 mm)	62°	56°	46°
1a (75 mm)	64°	57°	49°
6b (40 mm)	71°	67°	64°

Results

- Influence Angles



Effect of No. of bolts



Effect of Bolt eccentricity

Influence Angles Equations

For Concentric Loading Case

$$\alpha = (67° - 2t) * (1.2 - 0.003e)$$

For Uniaxial Bending Case

$$\alpha = (75° - t) * (1.25 - 0.003e)$$

For Biaxial Bending Case

$$\alpha = (70° - t) * (1.25 - 0.003e)$$

where t = plate thickness (mm) & e = bolt eccentricity (mm)

Conclusions

- Not all of the base plate width contributes to resisting the applied moment within the plate.
- Regions of local flexural stresses within the base plate are always generated, even when the applied load is symmetrical.
- The most heavily stressed regions are at the corners of the column within the base plate.
- The nature of loading (whether concentric or eccentric) greatly affects the extent of the effective width of the base plate, which consequently dictates the required base plate thickness.

Conclusions

- For Concentric loads and Uniaxial bending, the maximum flexural stress regions start originating opposite to anchor bolts next to the column edges and continue increasing along the column face with increase in loads.
- For Biaxial bending, the failure line is usually along a tangent to the column corner and the plastic hinge develops along this bend-line.
- The location of anchor bolts and the width of column are the most important factors to influence the flexural stress distribution in the base plate.

Conclusions

- The clear spacing under the base plate and the size of nuts and bolts do not greatly affect the flexural stresses.
- Preliminary sizing of base plates using simple equations that are based on finite element results is possible.
- The equations derived in this study give adequate results if all possible failures at bend-lines are investigated.

Future Work

Future research in the area of base plates on leveling nuts may consider the effects of:

- Various shapes of columns
- Effect of stiffeners
- Dynamic loads
- Fatigue strength

Questions?