Stability of Bridge Column Rebar Cages during Construction

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Outline

- Background on Reinforcement Bars and Rebar Cages
- Loads on Rebar Cages and Who Design them?
- Collapse of Rebar Cages and Causes
- Current Research on Rebar Cage Stability
- Best Practices on Improving Rebar Cage Stability during Construction
- Research Needs on Rebar Cages

Background

Structural Engineers:

- Design reinforcement bars inside concrete elements to resist code **permanent** loadings.
- Specify bar reinforcement details (cover, spacing, and splice type).
- Pepare contract document (Drawing and Special Provisions) for the reinforced concrete elements.

Background

Contractors:

- Must build the reinforced concrete elements according to the contract drawings, special provisions and State Standard Specifications.
- Choose Methods and Means on how to build the reinforced concrete elements.
- Utilize steel fabricators and detailer to furnish and assembly reinforcement bars.

Reinforcement Bar Assembly

- Steel Detailer prepare shop plans according to the contract drawings (bar schedule: size length, spacing, splice details).
- Structural Engineers approve shop plans.
- Steel Fabricators assemble bar reinforcement and build **rebar cages** using their expertise and CRSI “Placing Reinforcing Bars” document.
- Steel Fabricator transport rebar cages to site.

Erecting Rebar Cages

- Contractors choose how to erect rebar cages: number of cranes, concrete forms, type of bracing system.
- Rebar cages are now part of a **temporary structure** that includes: guy wires and their connection devices and anchor blocks.
- Construction engineer design and seal temporary structure drawings.

Caltrans Standard Specifications CT Section 52-1.01C(3)-2010

52-1.01C(3) Shop Drawings

52-1.01C(3)(a) General

Shop drawings and calculations must be sealed and signed by an engineer who is registered as a civil engineer in the State.

52-1.01C(3)(b) Temporary Support System

If a portion of an assemblage of bar reinforcing steel exceeds 20 feet in height and is not encased in concrete, submit shop drawings and design calculations for a temporary support system.

The temporary support system must be designed to:

1. Resist all expected loads
2. Prevent collapse or overturning of the cage

If form installation or other work requires changes to or the temporary release of any part of the temporary support system, the shop drawings must show the support system to be used during these changes or the temporary release.

The minimum horizontal wind load to be applied to the reinforcing steel assemblage or to a combined assemblage of reinforcing steel and forms must be the sum of the products of the wind impact area and the applicable wind pressure value for each height zone.

Caltrans Requirements

1. Temporary structure shall be designed to resist all expected loads.
2. Temporary structure shall be adequate to prevent collapse or overturning.
3. Requires checking to any temporary release of any portions of the support system.
4. Specify minimum wind load.

Current Practice

- Construction engineers analyze and design for wind loading only.
- Size guy wires and their connections and determine the required anchor weights.
- Caltrans False Work Manual requires guy wires to be pre-tensioned so they become effective in resisting loads.
- Construction workers P/T wires using turn-buckle or come-along.

Internal Forces in Rebar Cages

- Rebar cage is part of the temporary structure.
- The rebar cage has structural boundary conditions at the base (fixity, pin, lap-splice) and along it height (guy wires)
- The cage has structural section properties: area (A), moment of inertia (I_x, I_y, J)
- The cage material has Young's Modulus, E
- Loads will create axial forces, bending moments and shear forces in the rebar cage.

What are Loads on Rebar Cages?

1. Self Weight
2. Construction Loads
   - P/T Wire forces
   - Live Load (construction workers)
3. Environmental Loads
   - Wind

- These loads are not similar to the permanent loads that the reinforced concrete element was designed for!

Engineering Analysis and Design

- Structural engineer designed the bar reinforcements and approved the shop plans.
- Construction engineers designed the guying plan for the temporary structure.
- So <u>**who**</u> analyzed, designed and checked the rebar cages to the construction loads that are subjected to?

NO ONE!


Belt



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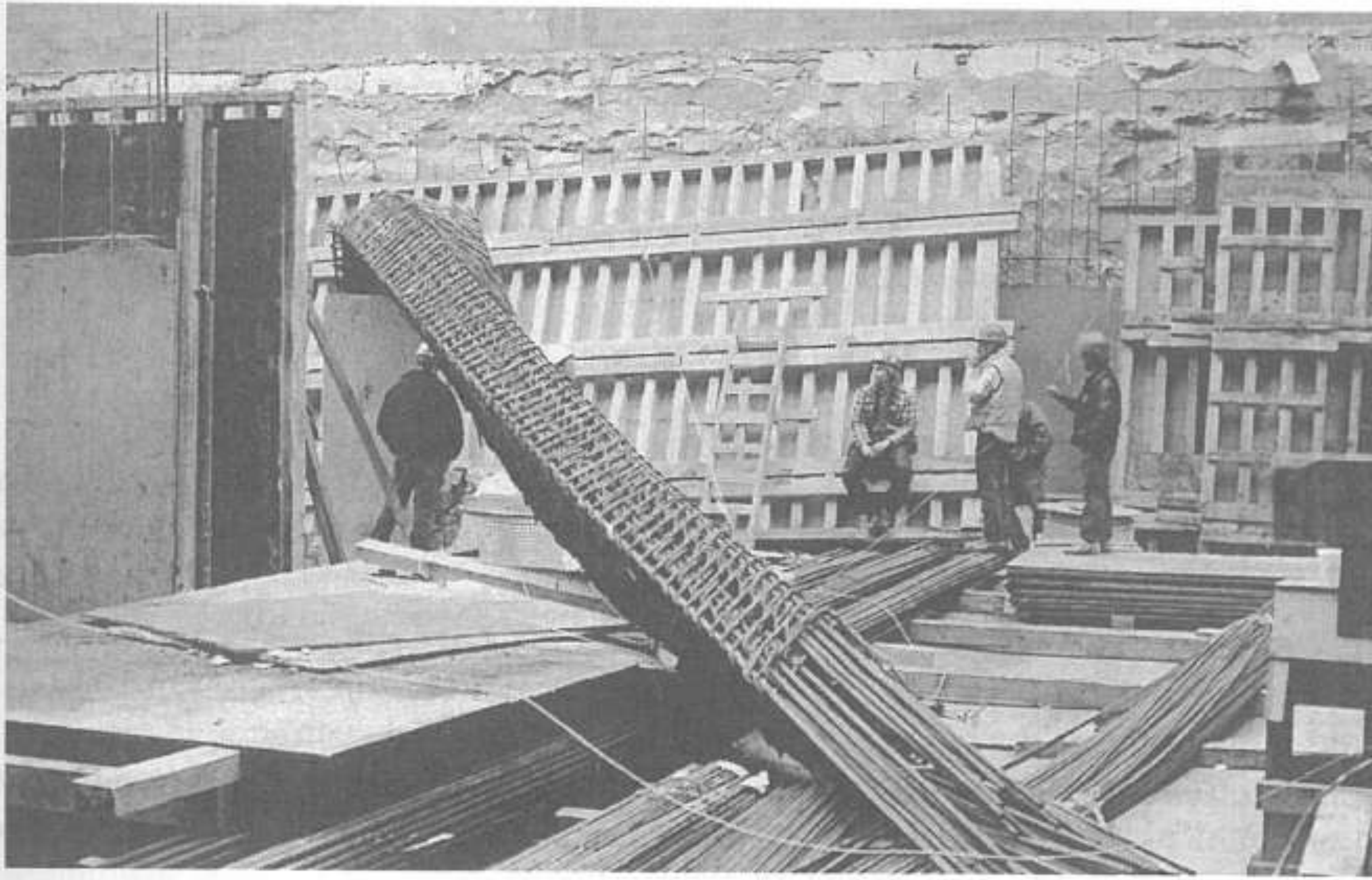
VICON



(a)

FIGURE 10.11 Column reinforcing steel. (a) Tall reinforcing steel cage collapsed before erecting formwork. (*From Jozef Jakubowski, Workers' Compensation Board of British Columbia, Vancouver, BC, Canada.*)

Ironworker Killed When Rebar Cage Collapses*

Industry: Structural Steel and Precast Concrete Contractors
Task: Installing rebar cage
Occupation: Journey level ironworker
Type of Incident: Struck by falling object

Release Date: April 12, 2011
Incident Date: February19, 2009
Case No.: 09WA01101
SHARP Report No.: 71-100-2011

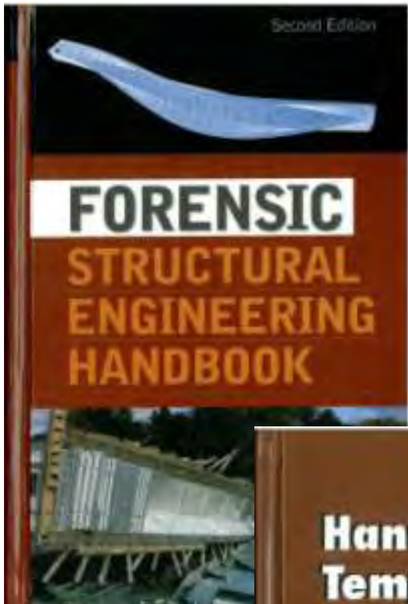
On February 19, 2009, a 23-year-old journey level ironworker died when a rebar cage collapsed. The victim worked for a structural steel erection contractor. The contractor was hired to perform steel rebar assembly and installation on the site of a new commercial office building. The job site work crew was erecting a steel rebar cage weighing about 5,600 lbs as part of a column structure. It measured 20x56 inches and 30 feet tall. They had previously erected 11 similar cages. The rebar cage was braced using 2x4's nailed together and attached to the building floor. A tower crane placed the cage into position and then released the cage. The victim and another crew member were climbing the cage to make adjustments to the rebar and set the braces. Both workers had fall protection gear and were working on the same side of the cage when the crew noticed the cage began to lean. The crew attempted to reconnect the crane to the cage, but before they were able to one of the 2x4 braces failed and the cage collapsed. The victim was struck by the falling rebar cage and died of blunt force injury of the head at the scene. The other worker escaped without injury.

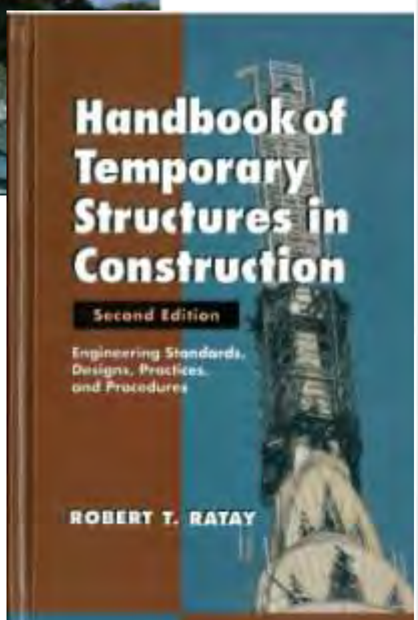
Collapse of Rebar Cages

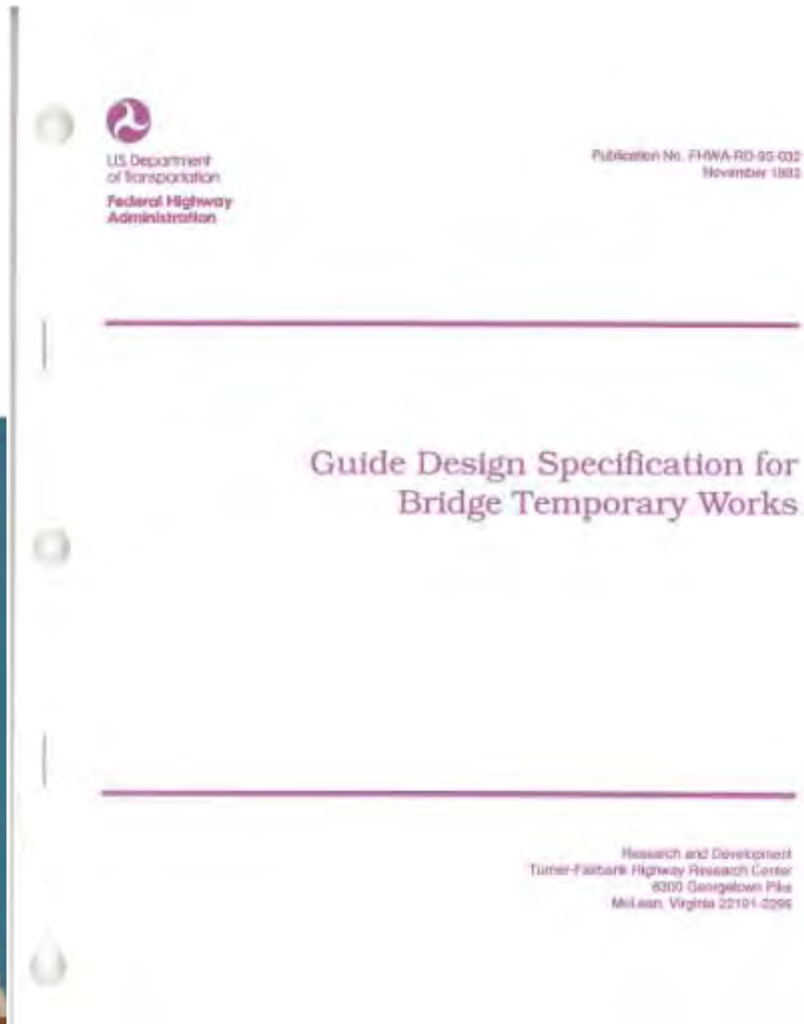
- Collapse of rebar cages is a rare incidence.
  - In California around 60 bridge cages collapsed during last 15 years.
- Collapse is associated with
  - Life safety: injury or death
  - Litigation
  - Schedule delay
  - Repair
- Lack of information on collapse cases due to legal issues.

What Causes Rebar Cages to Collapse?

- Lack of knowledge and no National Standards







Why Rebar Cages Collapse?

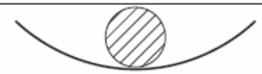
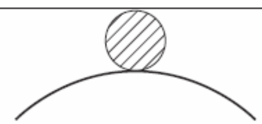
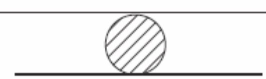
1. Rebar Cage Construction Methods and Means
   - Crane use and number of cranes
   - Decision on using rebar cage to part of temporary structure
2. Lack of Rebar Cage Analysis and Design
   - Cage Axial Resistance
   - Cage own weight
   - Effect of pre-tensioning of guy wires
3. Geometrical Disturbance
   - Asymmetrical Guy Wires
   - Guy wire release sequence
   - Accidental load-Crane hit

Collapse of Rebar Cages

- Instability: Loss of Stiffness
  - Axial Instability
  - Lateral Torsional Instability
- Base Boundary Condition
  - Pin or lap splice at base
- Guy Wires
  - Insufficient Stiffness to brace rebar cage
  - Insufficient Strength to resist lateral loads
  - Asymmetrical configuration

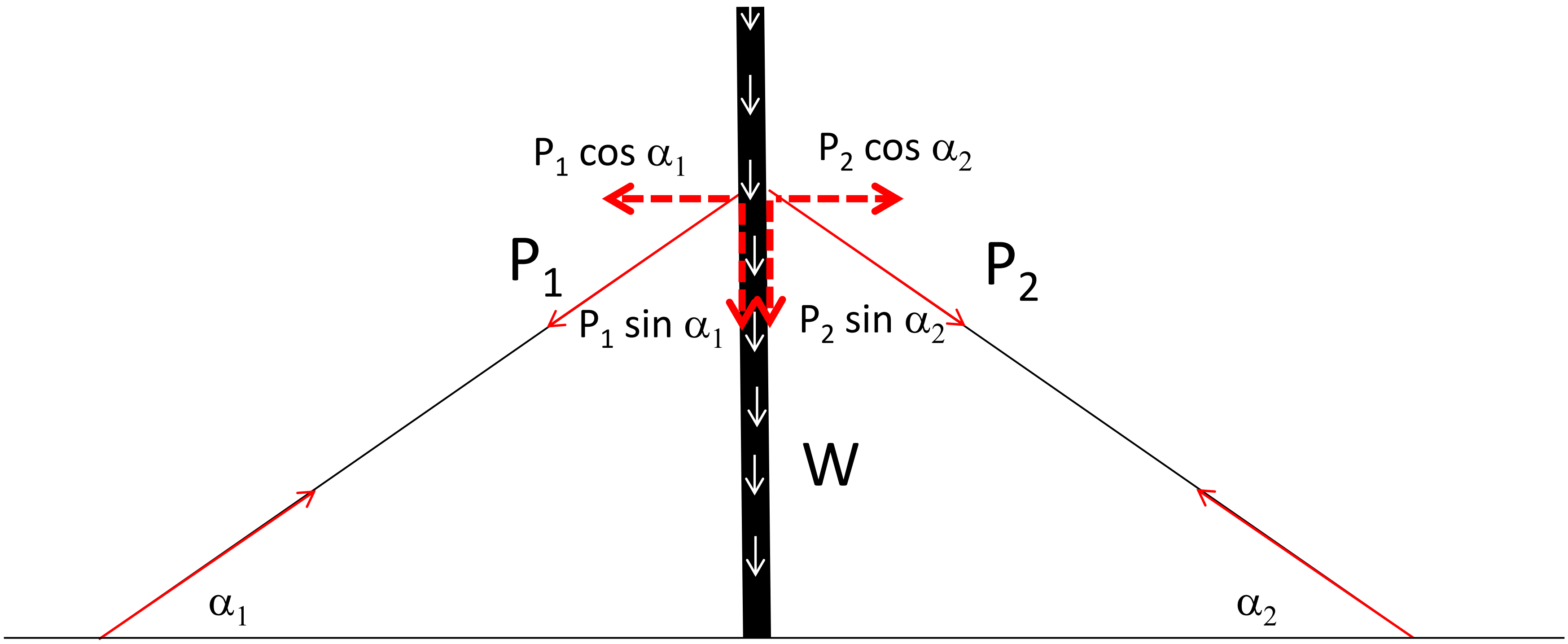
Instability of Rebar Cages

- Instability is a loading condition in which slight disturbance in load or geometry cause large displacements.

• *Minimum of* Π • ***Stable equilibrium*** • *Energy must be added to change configuration.*	$\frac{d^2\Pi}{d\theta^2} > 0$		*Ball in cup can be disturbed, but it will return to the center.*
• *Maximum of* Π • ***Unstable equilibrium*** • *Energy is released as configuration is changed.*	$\frac{d^2\Pi}{d\theta^2} < 0$		*Ball will roll down if disturbed.*
• *Transition from minimum to maximum* • ***Neutral equilibrium*** • *There is no change in energy.*	$\frac{d^2\Pi}{d\theta^2} = 0$		*Ball is free to roll.*

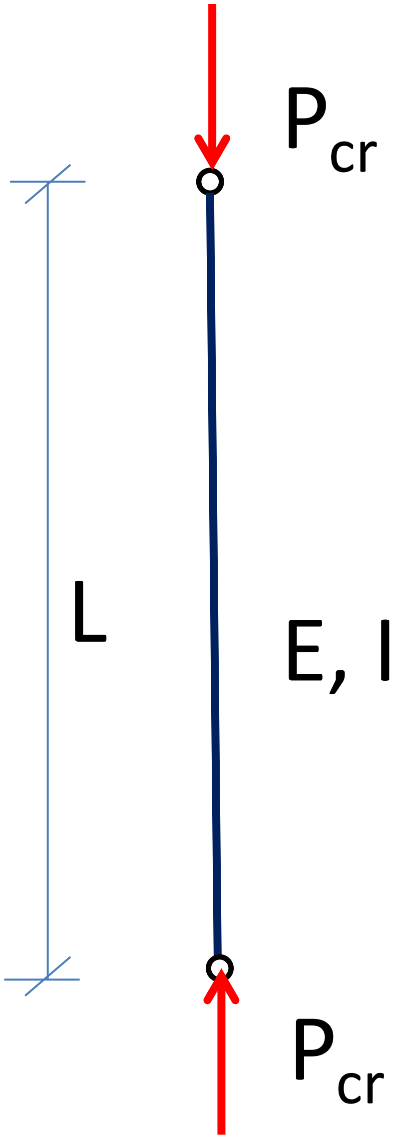
Axial Stability of Rebar Cages

Axial Resistance > Axial Load Demand



Axial Load Demand= $W+\Sigma P_i \sin \alpha_i$

Axial Resistance



Resistance Based Axial Stability

Euler Critical Load

- Perfect Straight Member
- Elastic Behavior
- First Buckling Mode

Critical Load

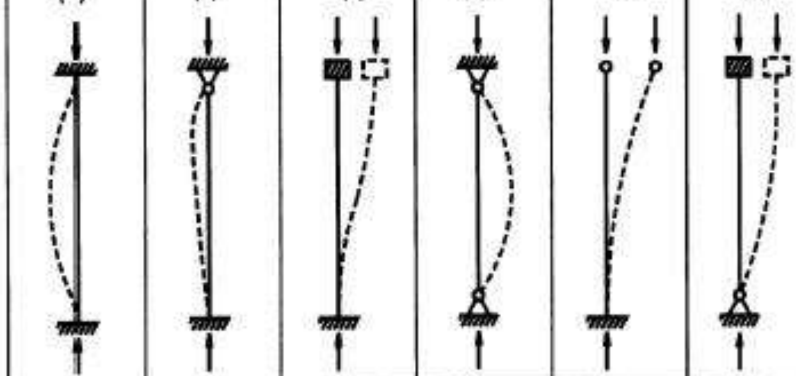
Axial Critical Load

$$P_{cr} = \frac{\pi^2 EI}{(KL)^2}$$

1. E: Material Young's Modulus
2. I: Section Moment of Inertia
3. L: Height
4. K: Effective Length Factor-Boundary Conditions

Effective Length Factor

Approximate Values of Effective Length Factor, *K*

	(a)	(b)	(c)	(d)	(e)	(f)
Buckled shape of column is shown by dashed line.						
Theoretical *K* value	0.5	0.7	1.0	1.0	2.0	2.0
Recommended design value when ideal conditions are approximated	0.65	0.80	1.2	1.0	2.10	2.0
End condition code	 *Rotation fixed and translation fixed* *Rotation free and translation fixed* *Rotation fixed and translation free* *Rotation free and translation free*					

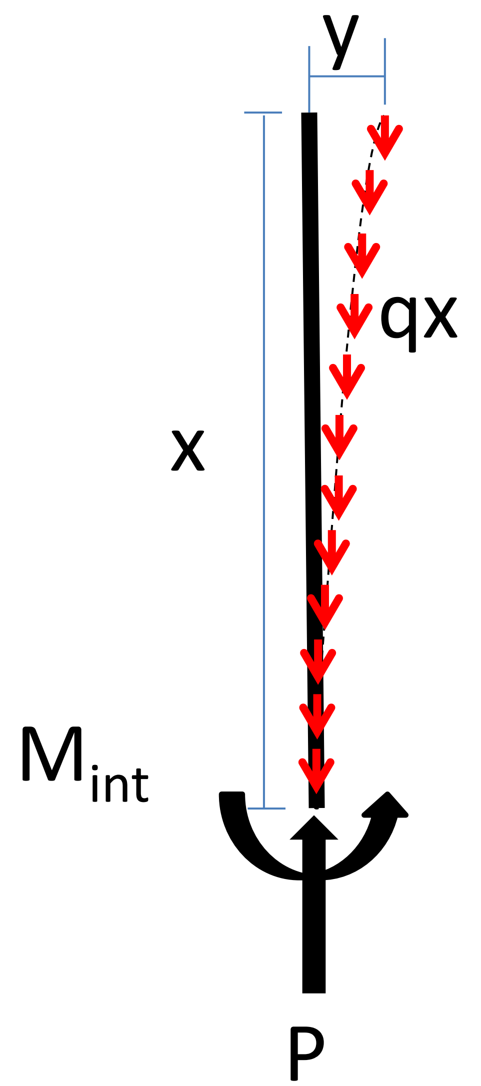
Axial Stability under Own Weight

- Internal Moment

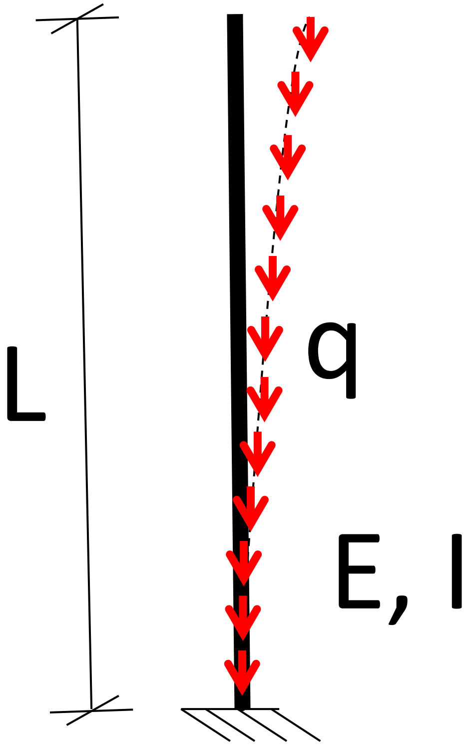
$$M_{int} = -\frac{E}{R}\int_A y^2 dA = -EI\varphi$$

- Section Moment of Inertia

$$I = \int_A y^2 dA$$

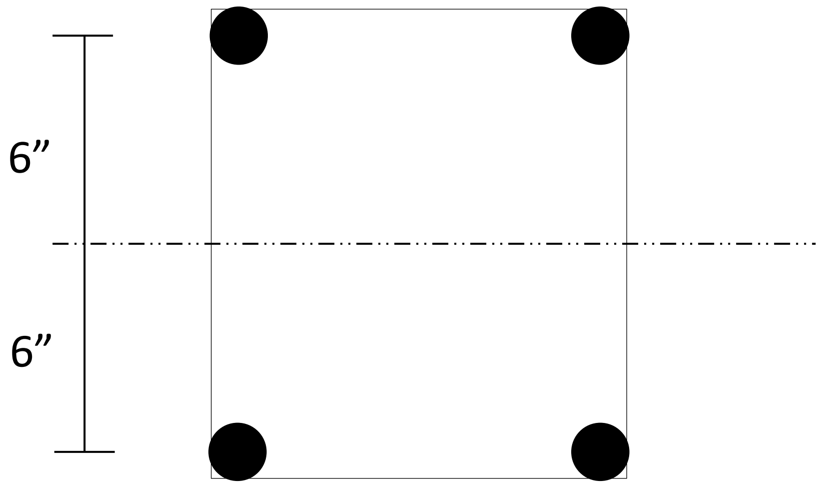


Column Under Own Weight



$$(qL)_{cr} = \frac{\pi^2 EI}{(1.22L)^2}$$

Example of Axial Stability



- 12”x12” Section
- Height 30’-0”
- Longitudinal 4#8 bars
- Transverse Ties #4@6”
- Cage Weight: 520 lb

Limit State Axial Resistance

- $I = \Sigma Ad^2 = 4x0.79x6^2 = 114$ in^4

$$P_{cr} = \frac{\pi^2 EI}{(1.22L)^2} = 168 \text{ kip} \qquad P_y = Af_y = 182 \text{ kip}$$

- The section moment of inertia equation can be used when section area can be fully **developed** 0.79x2x60=95 kips.
- Bars are attached to stirrups by tie wire connections
- Tie wire connections need to develop 95 kips!

Limit State Axial Resistance

- Assuming tie wire connections cannot develop 95 kips.
- Section moment of inertia will be the summation of individual bars
  - $I = \Sigma I_o = 4x0.05 = 0.2\ in^4$

$$P_{cr} = \frac{\pi^2 EI}{(1.22L)^2} = 300 \text{ lb vs } 168 \text{ kips!}$$

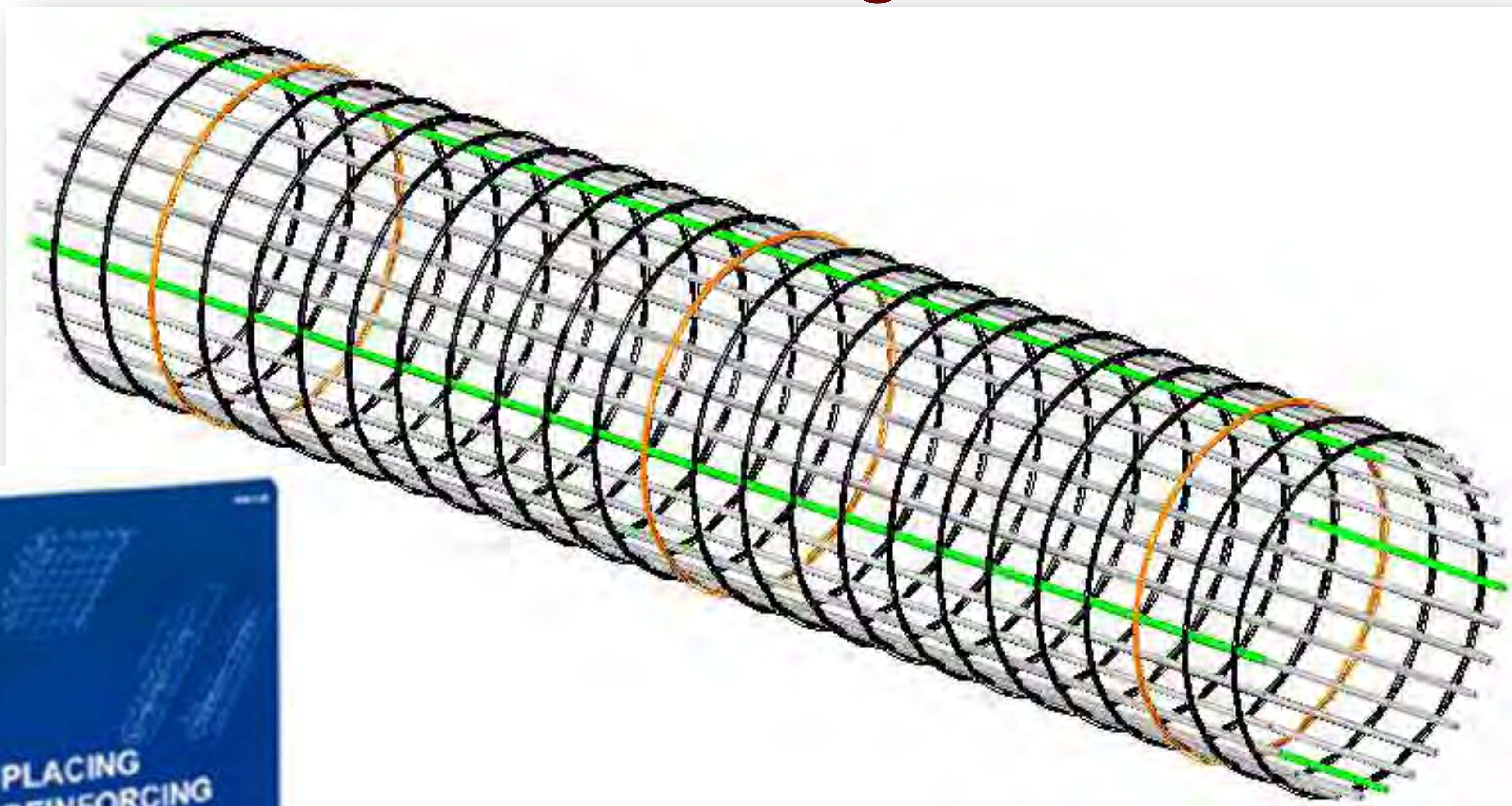
- Which section moment of inertia should be used!

Rebar Cage Section Moment of Inertia

$$I = \Sigma I_o + \beta \Sigma A d^{2}$$

- β is a reduction factor
  - Ratio depends on how much area can be developed in one side of the section to its yield strength.
  - Depends on tie wire connection
    - Connection Strength
    - Number and Type

Reinforcement Placement and Assembly
Rebar Cage



Tie Wires for Rebar Cages

Material and Gauge No.

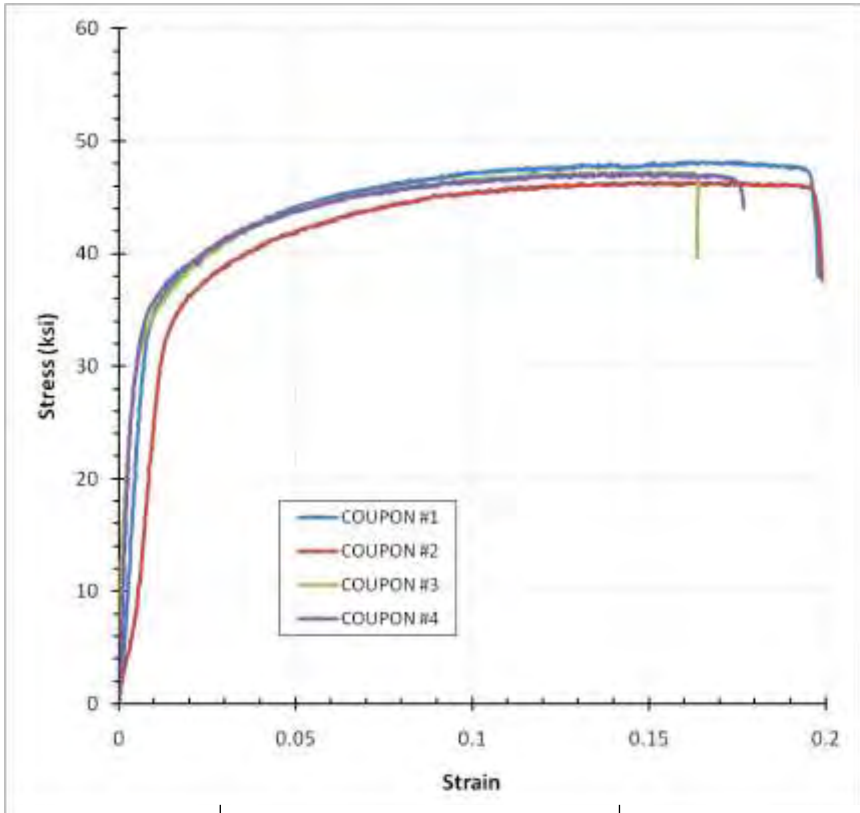
- Black Annealed Wire for General Purpose
  - Imported form China
  - Low carbon soft annealed steel

    F_u min =40 ksi
- #15 Gauge
  - Diameter = 0.072 in
  - Area = 0.004in^2
- Site Visits
  - # 16 gauge Black Wire
  - White Wires!

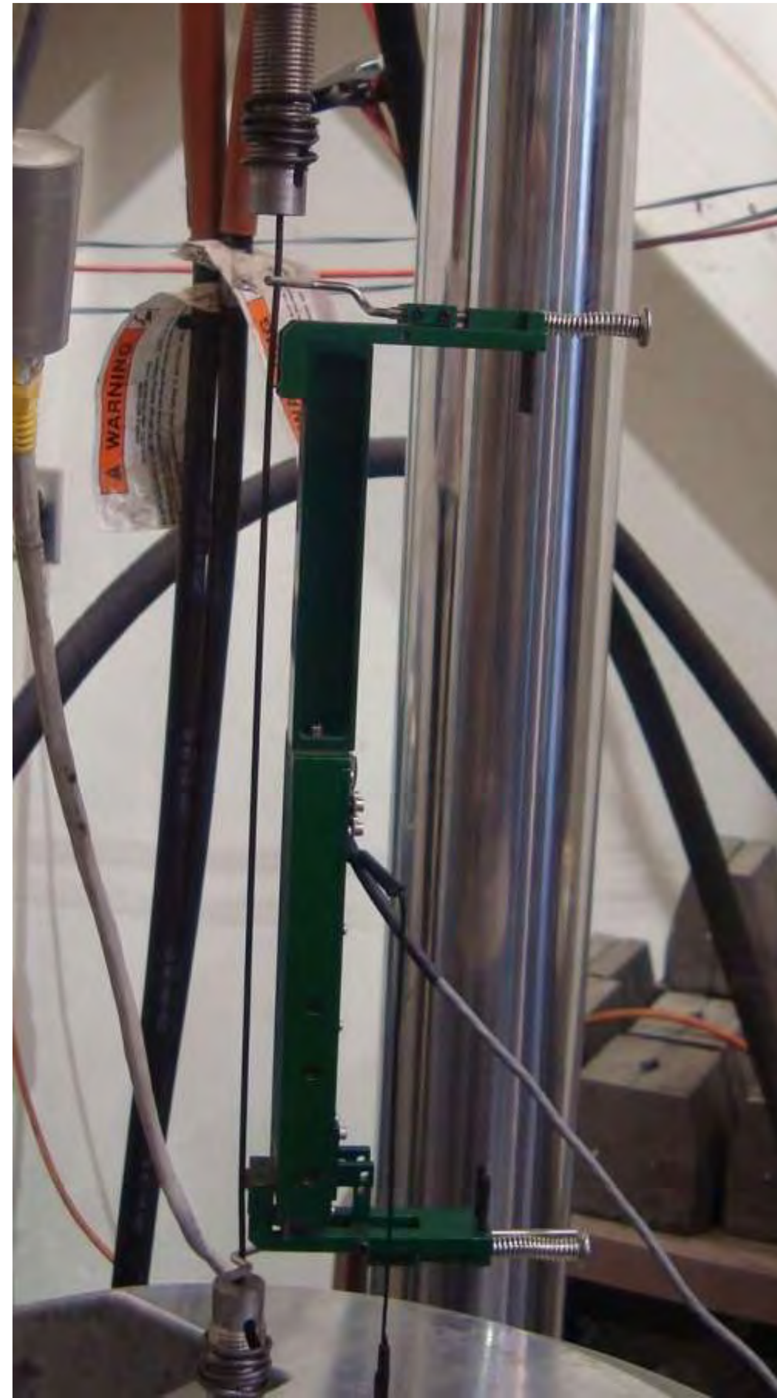
Nominal Ultimate Tensile Axial Force

- #15 gauge, $A=0.004\ in^2$
- F_u=40,000 psi
- $P_{nominal}$ =160 lb

Tie Wire Tensile Tests



TEST #	MAX. FORCE (lb)	STRESS (ksi)
1	196	48.2
2	189	46.4
3	193	47.3
4	192	47.2
AVRG	**192**	**47.3**



Tie Wire Connections-CRSI

Single Snap Tie

Double Snap tie

Single U-Tie

Double U-Tie

Column Tie

Wrap and Saddle

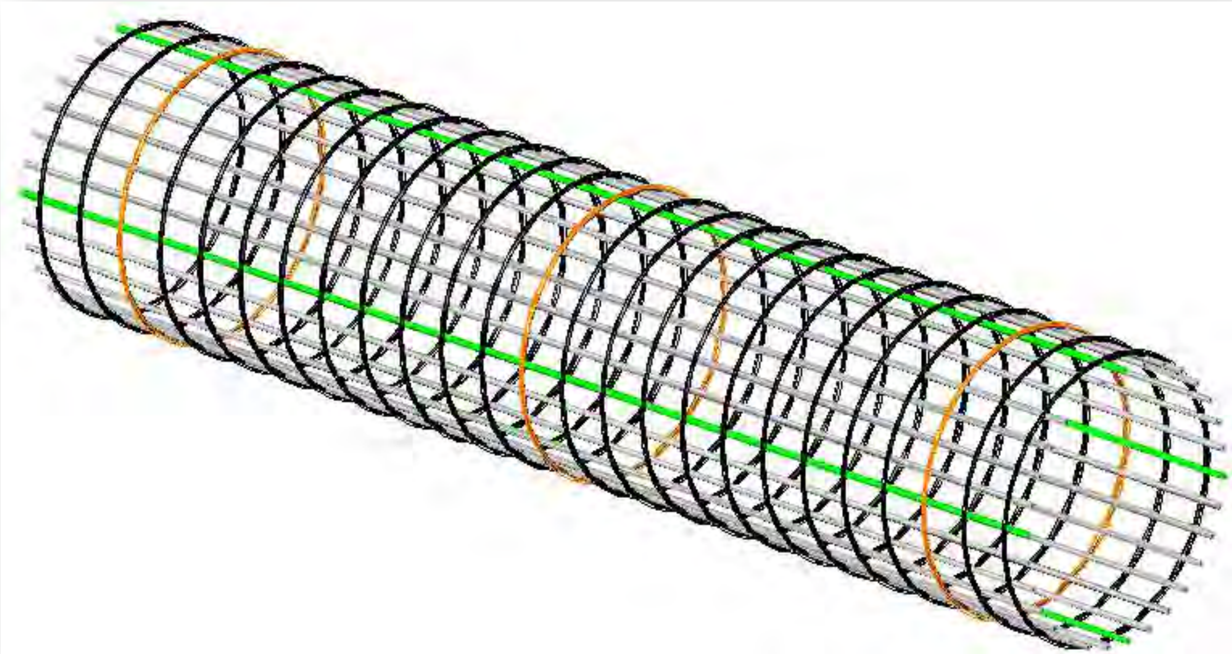
Single Snap

Single-U Connection

Double-U Connection

Wrap and Saddle Connection

Rebar Cage Assembly

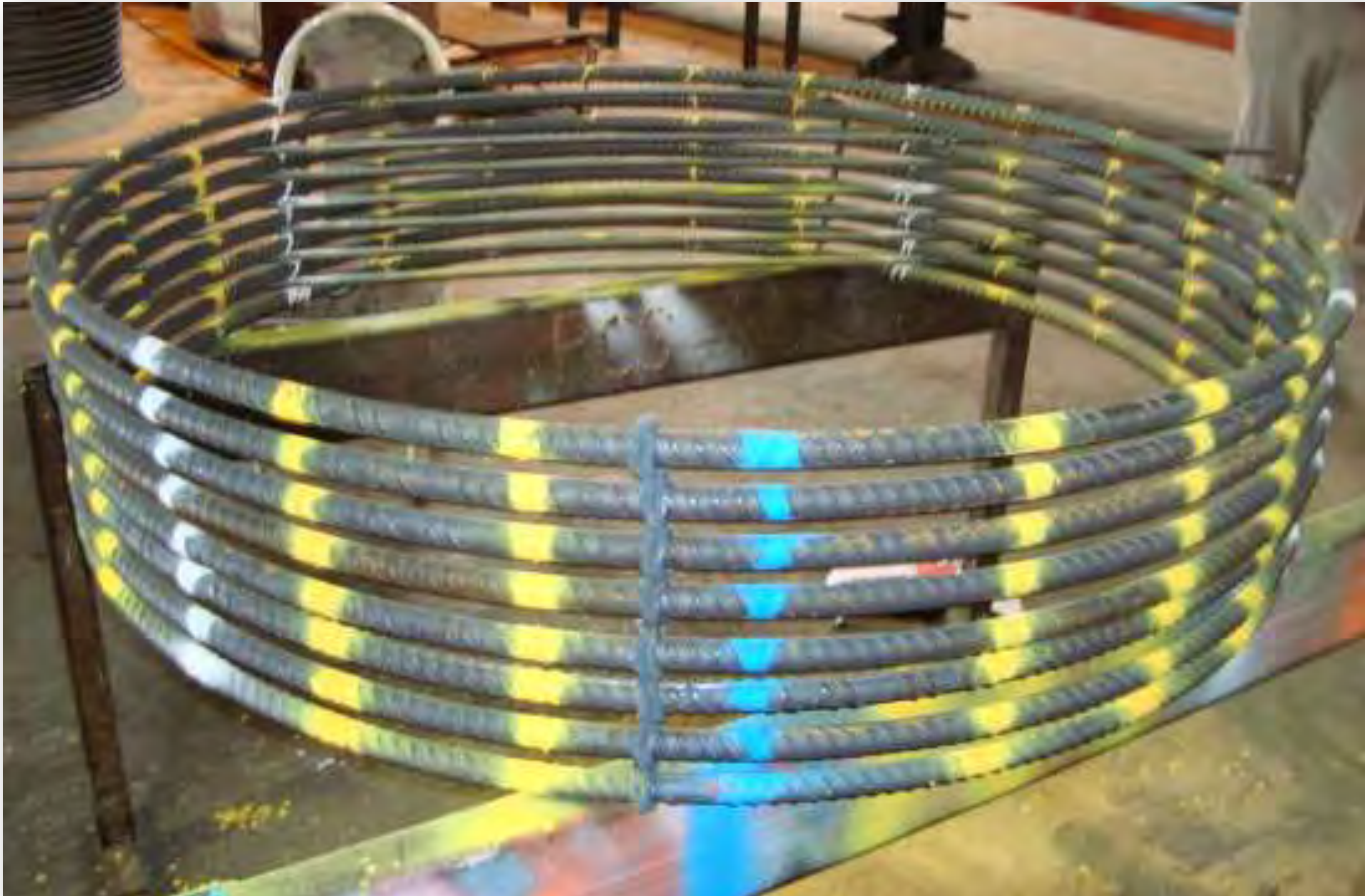


Main Cage Components

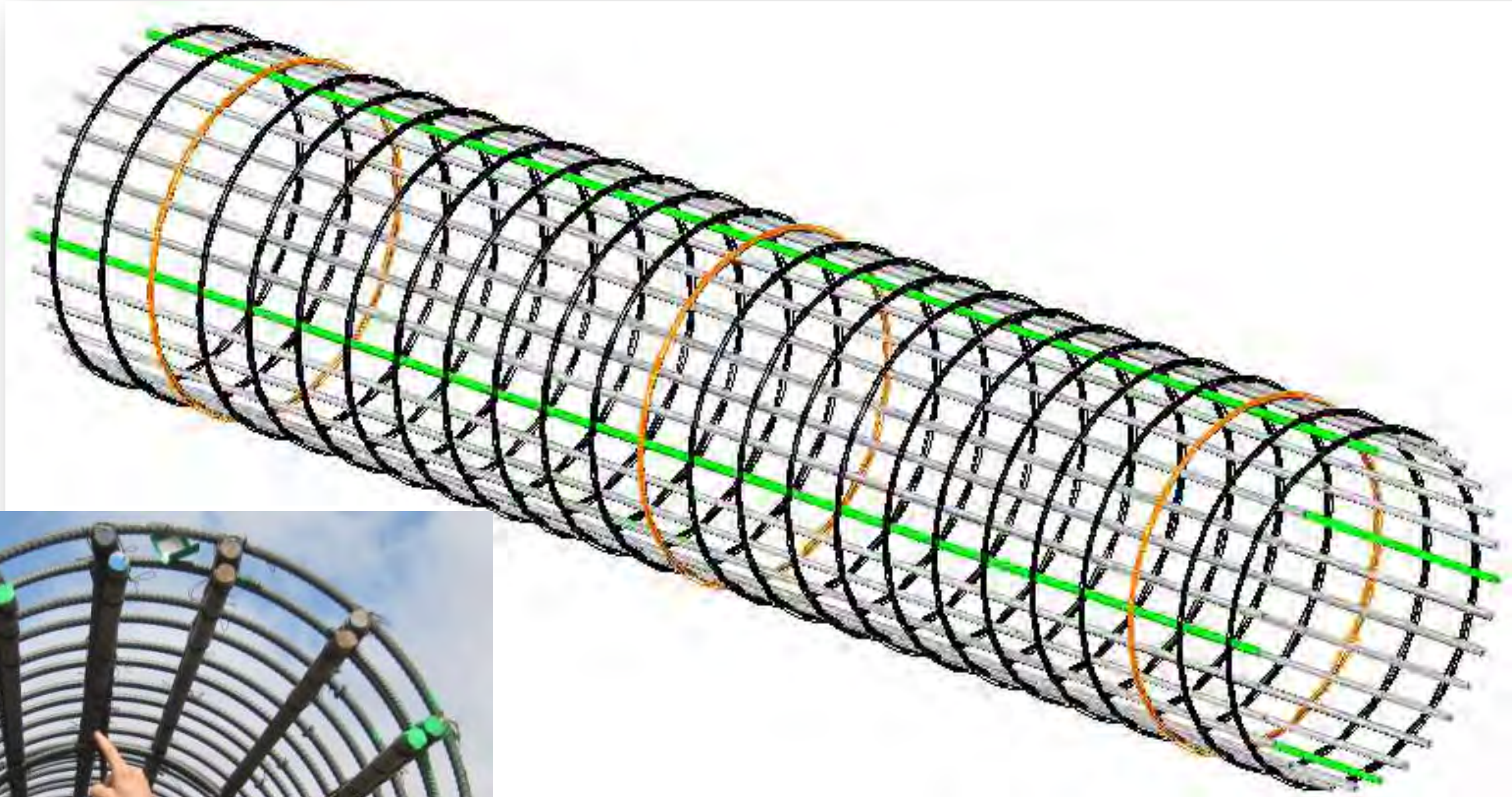
- Template Hoops (Orange Color)
- Pick Up Bars (Green Color)

Joint Connection

- Tie wire material and gage #
- Types of tie wire connections
- Number of Connections
- Workmanship



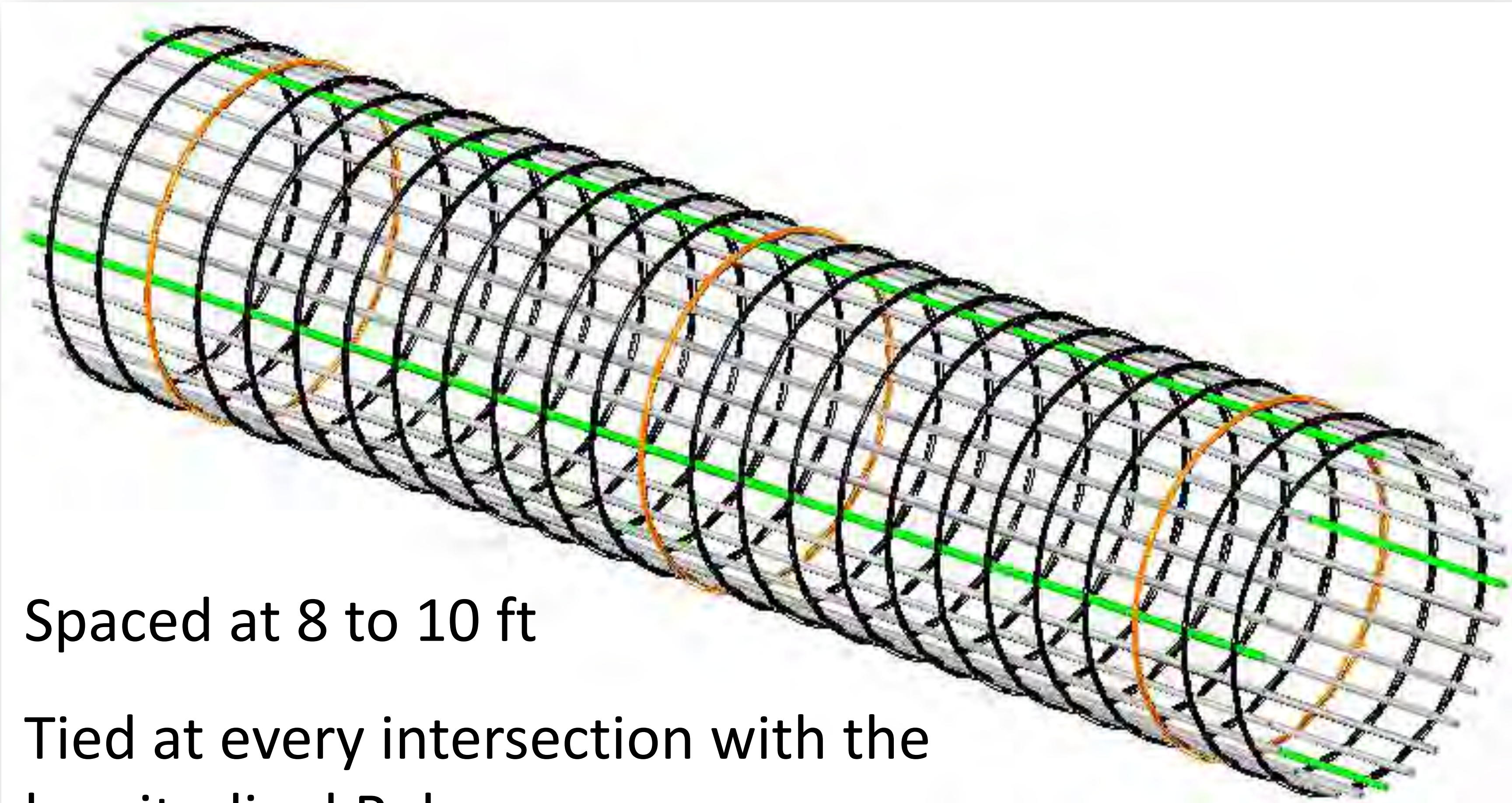
PICK UP BARS



- Four longitudinal bars that form a square
- Tie at every intersection
- Double snap tie, Quadruple snap tie

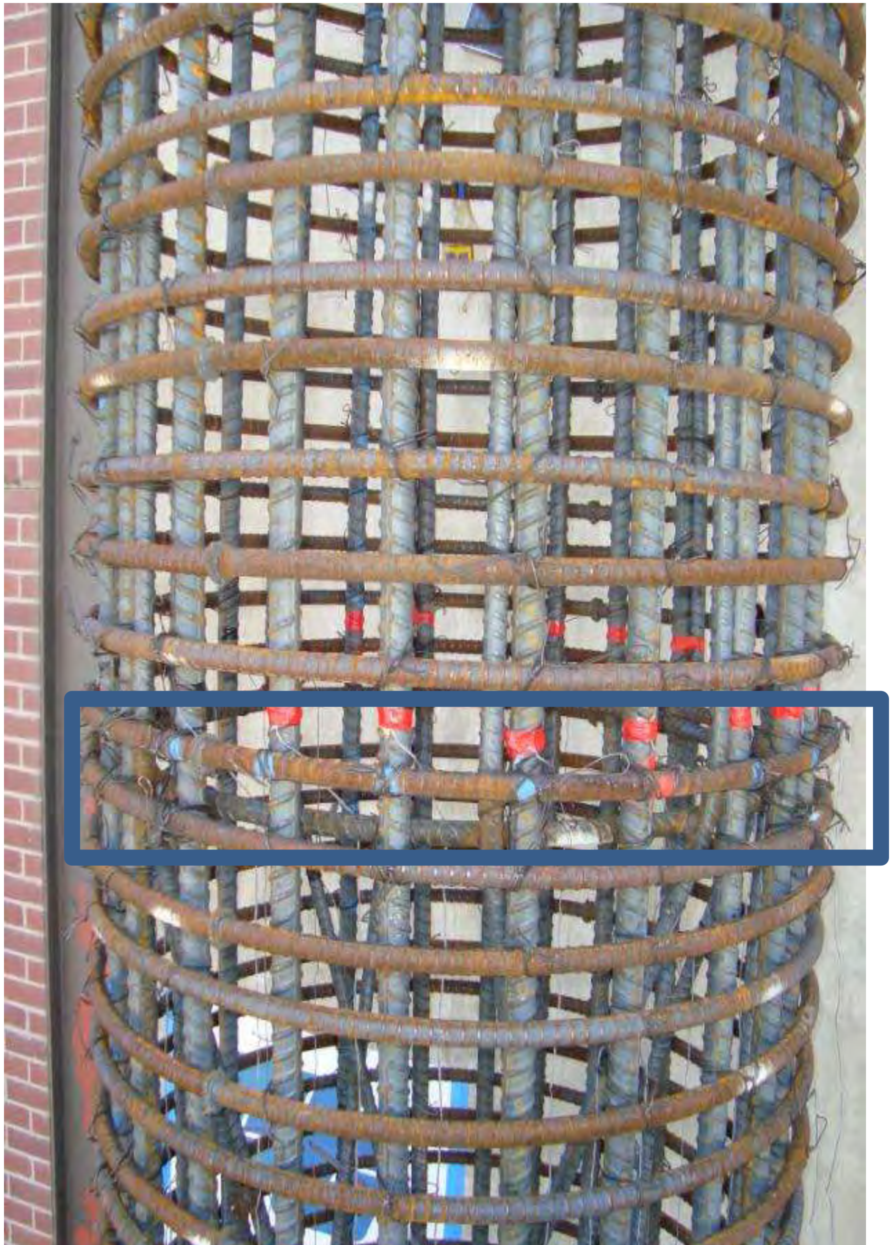
Pick-Up Bar Tying

TEMPLATE HOOPS



- Spaced at 8 to 10 ft
- Tied at every intersection with the longitudinal Rebar
- Double U-Tie, Wrap-and-Saddle

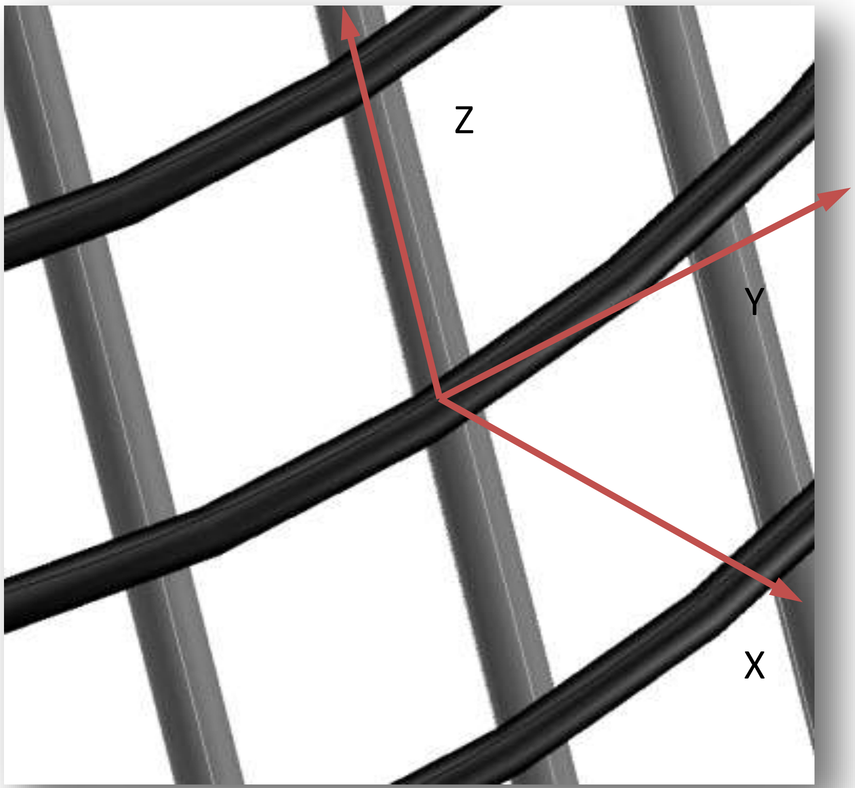
Template Hoops Tying



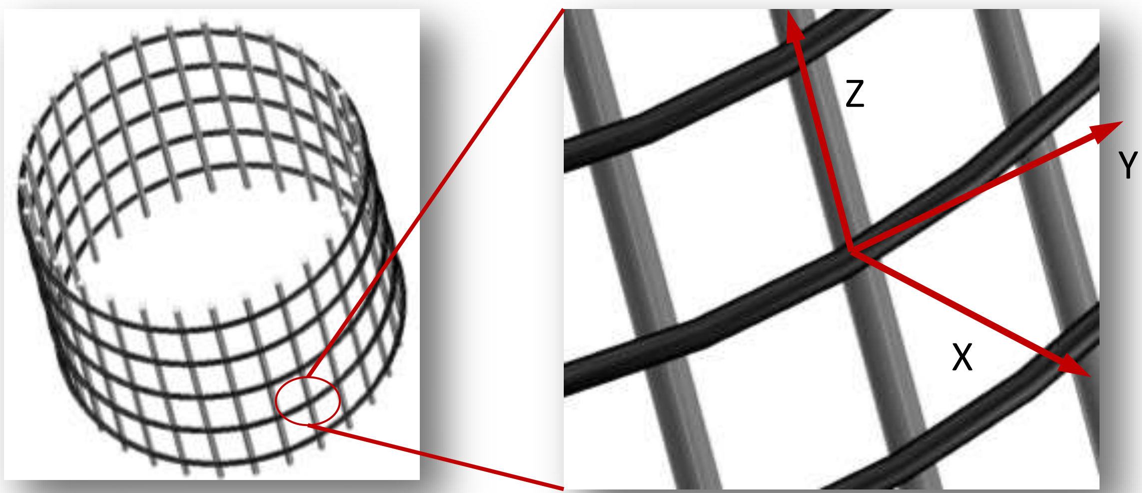
FIELD ZONE TYING

- Zone between template hoops: Field Zone
- Tie 20% to 30% alternating joints
- Single Snap

Tie Wire Connection Restraints Strength and Stiffness



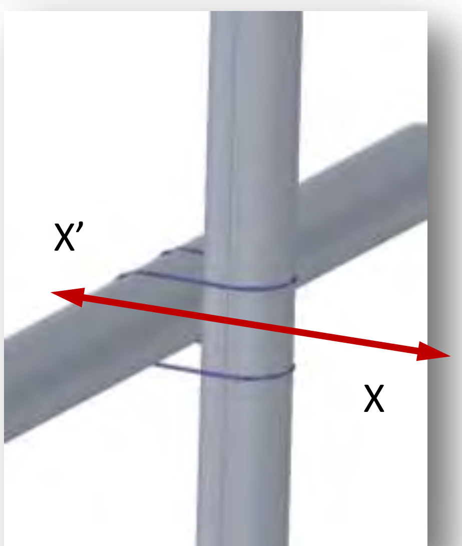
Nonlinear Translational Springs (P-Δ)



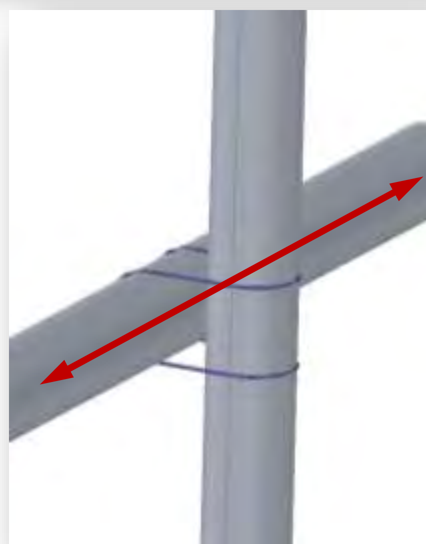
X: normal direction

Y: tangential direction

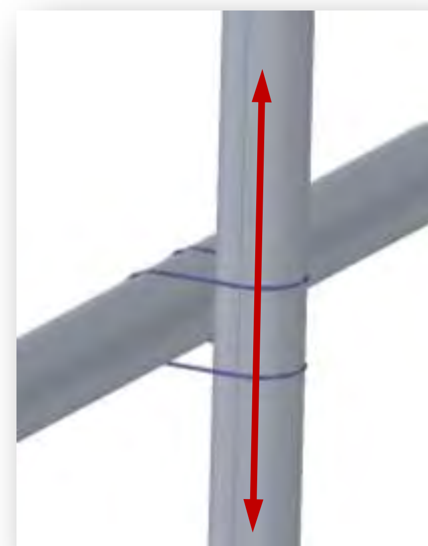
Z: vertical direction



Normal strength

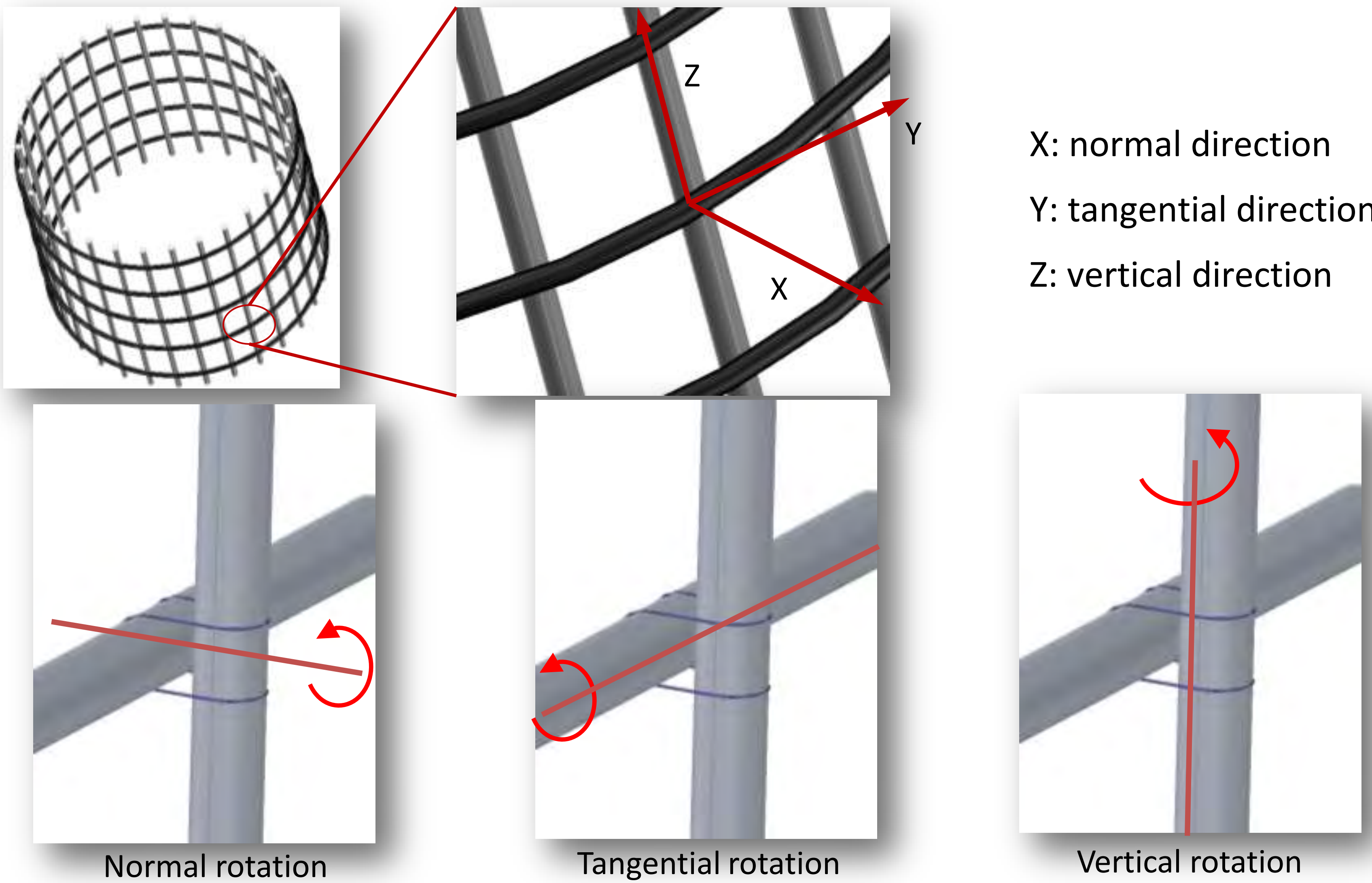


Tangential strength

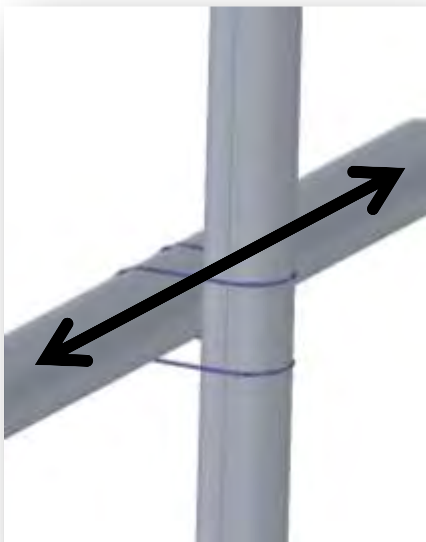


Vertical strength

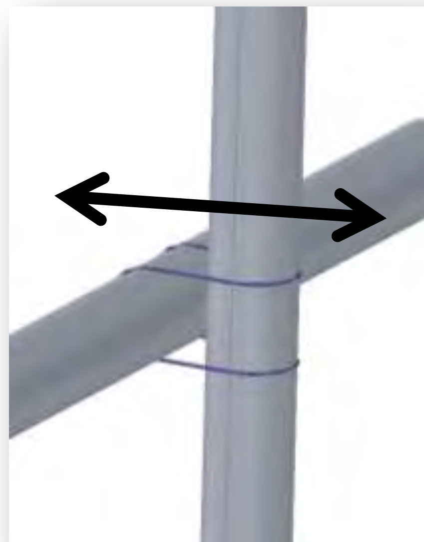
Nonlinear Rotational Springs (M-θ)



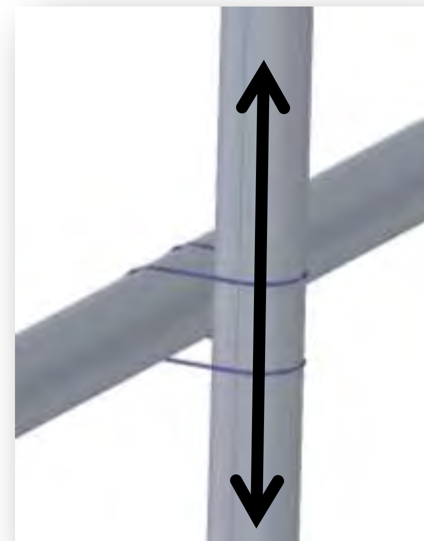
Loading Direction on Tie Wire Connections



Tangential



Normal



Vertical

Experimental Investigation

1. Six Types of Tie Connections

- Single-Snap
- Double-Snap
- Single-U
- Double-U
- Column-tie
- Wrap-and-Saddle

2. Workmanship

   – Experience vs Inexperience Ironworker

152 Experiments

Tie Wire Connection Specimens

SNAP TIE

DOUBLE SNAP TIE

U-TIE

DOUBLE U-TIE

WRAP AND SADDLE

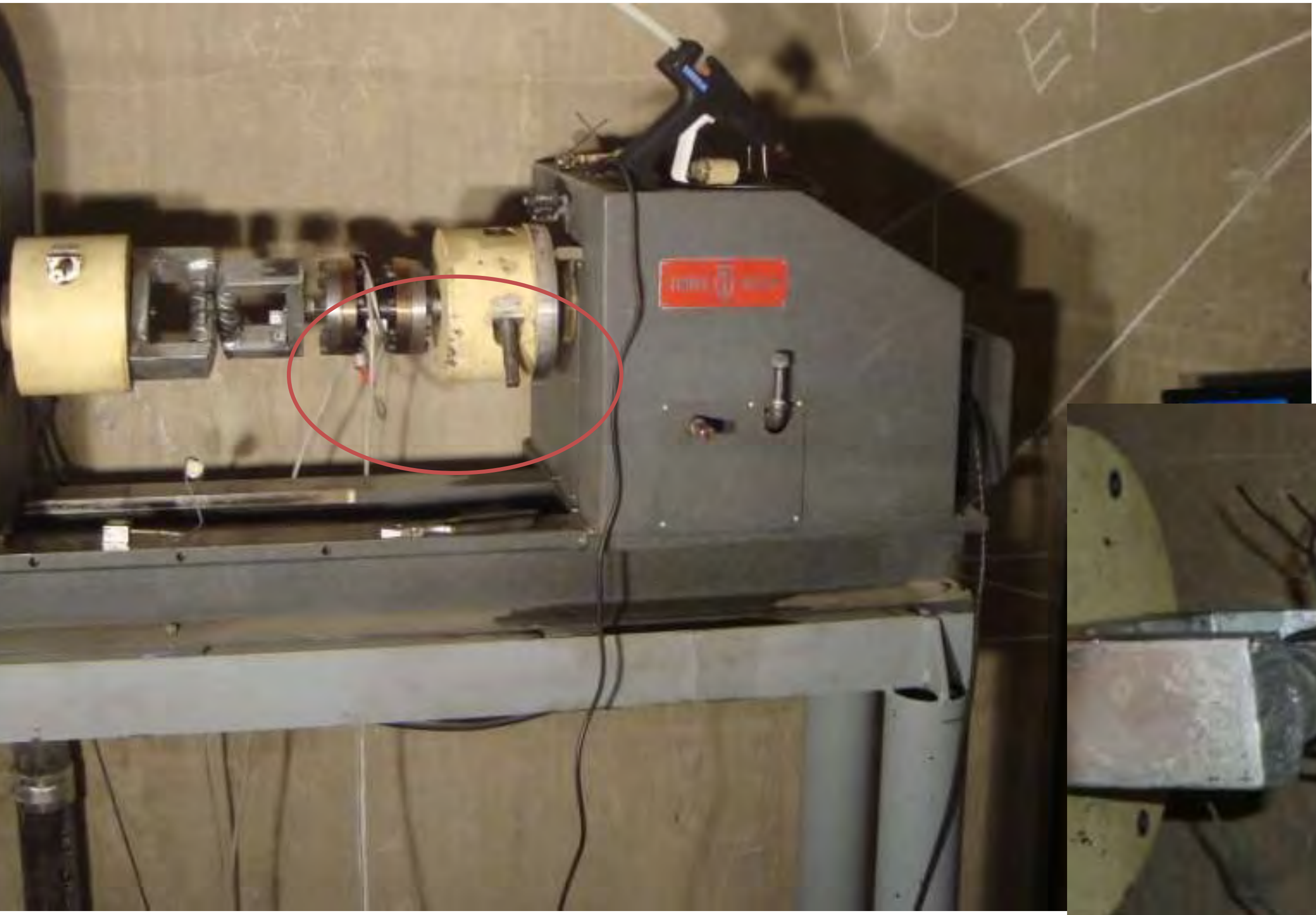
COLUMN TIE

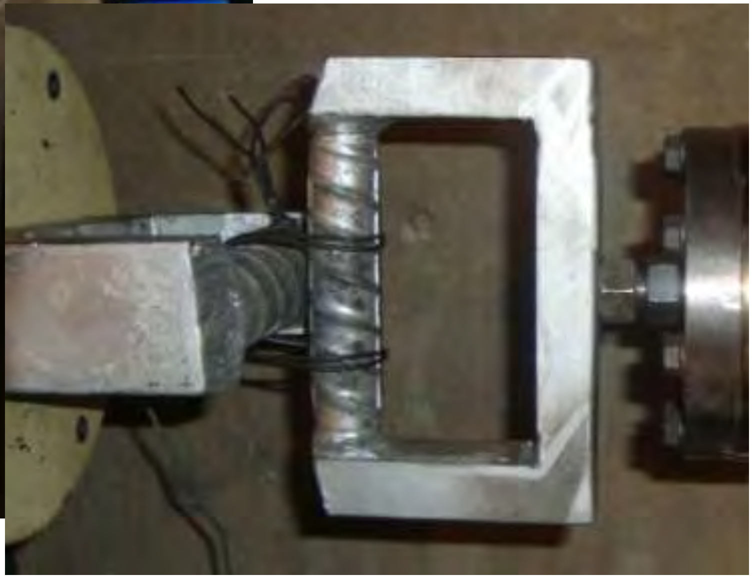
Test Set-up for Nonlinear P-Δ Response

Translation in the normal direction

Translation in the tangential and vertical direction

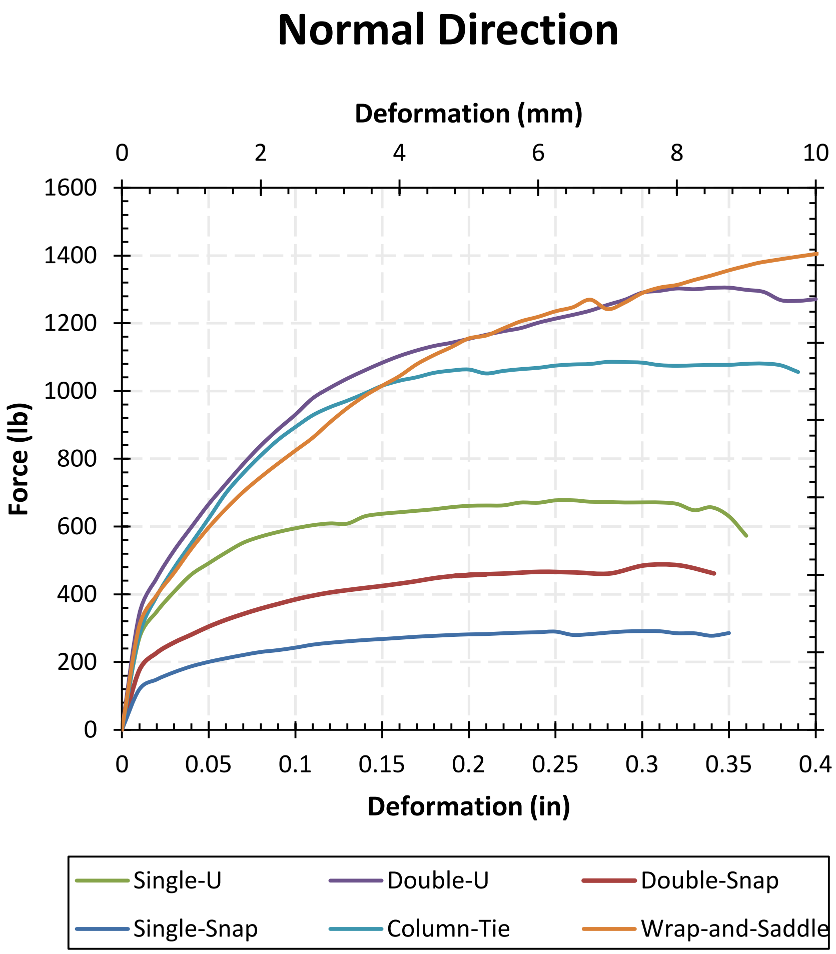
Test Set-up for Nonlinear M-θ

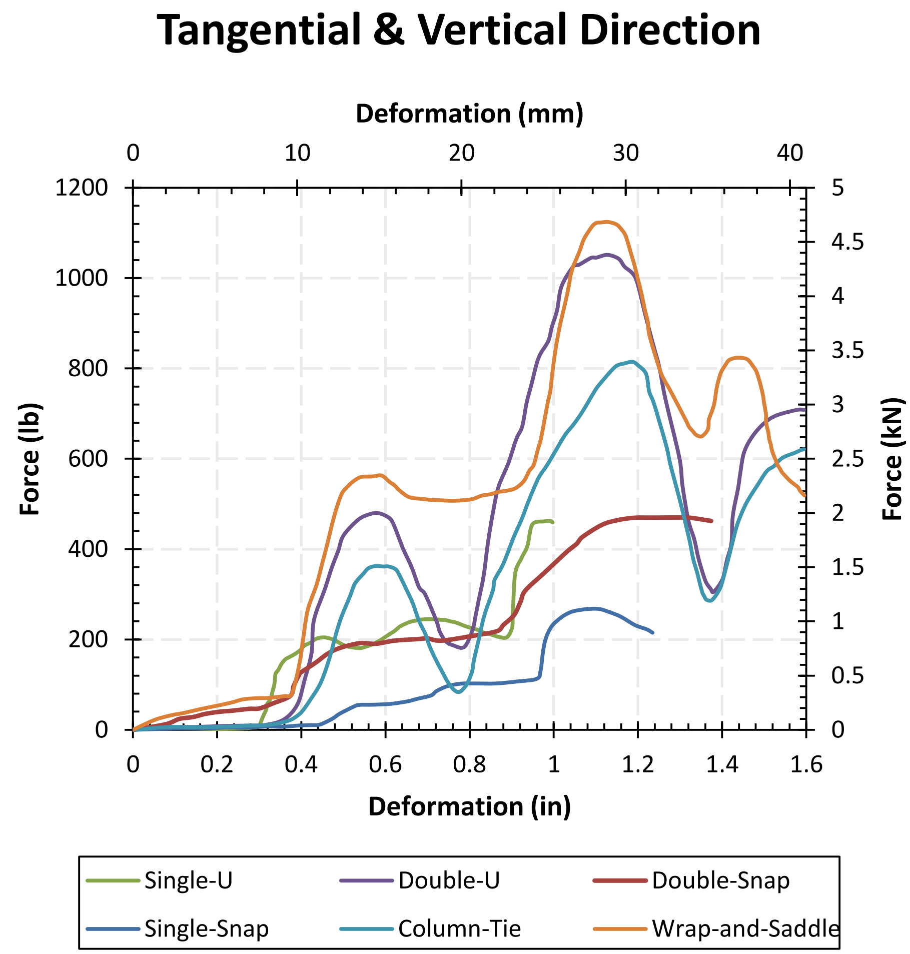




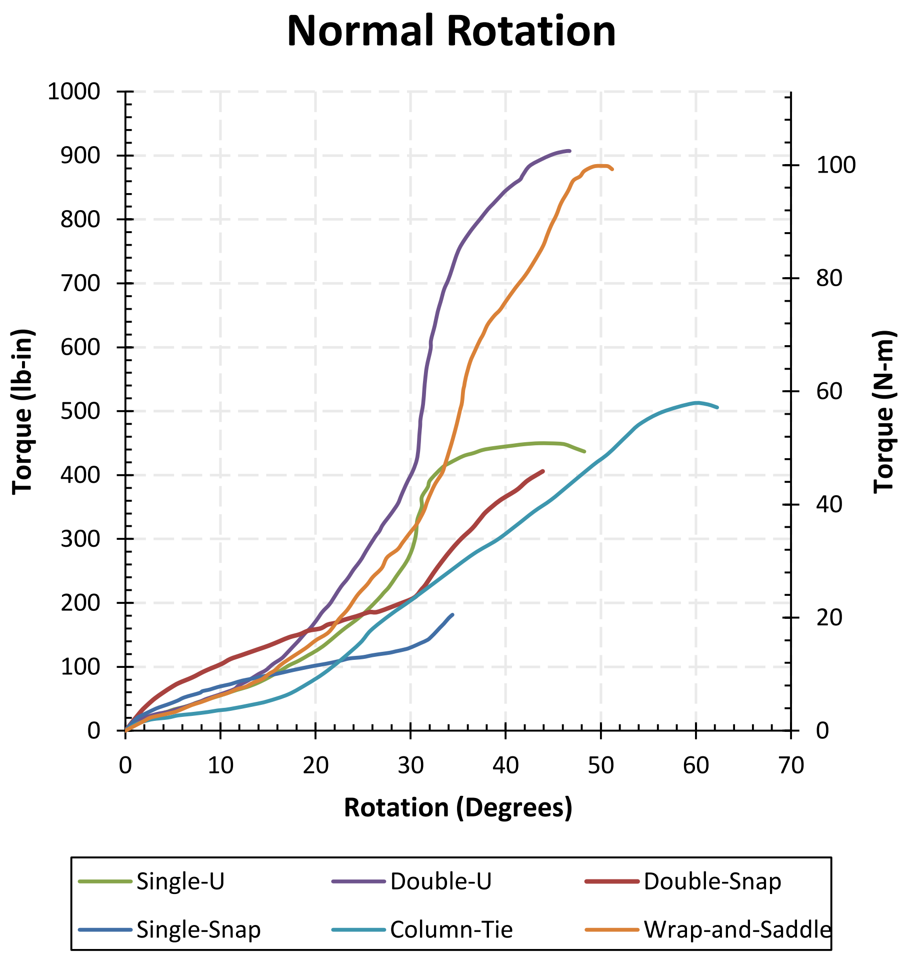
Rotation about the normal direction

P-Δ Nonlinear Response
Experienced Iron Worker





M-θ Nonlinear Response Experienced Worker



Ultimate Strength of Tie Wire Connections

Connection Ultimate Strength						
Connection Type	**Experienced Iron Worker**			**Inexperienced Iron Worker**		
	N (lb)	**T (lb)**	**R (lb-in)**	**N (lb)**	**T (lb)**	**R (lb-in)**
Single Snap	305	269	223	281	186	198
Double Snap	465	506	469	403	313	510
Single-U	681	469	479	541	544	448
Double-U	1310	1034	912	1025	721	845
Column Tie	1101	810	518	972	608	513
Wrap-and Saddle	1393	1139	865	1235	999	692

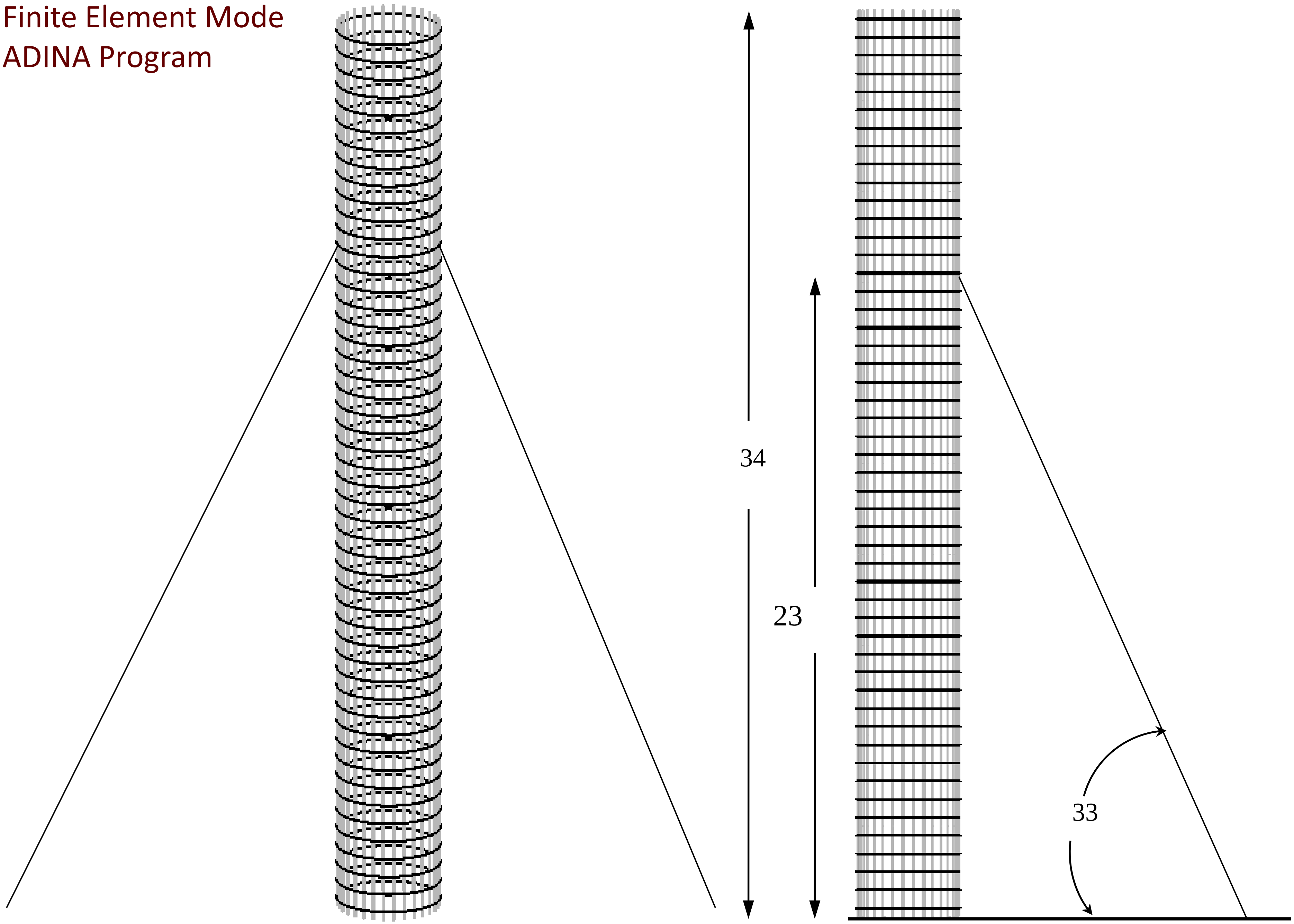
Reflections on Tie Wire Connection Tests

- Established nonlinear response of P-Δ and M-θ
- Tie wire connections are soft and weak.
- Best tie wire connection cannot develop 1% of the bar area.
- Caution when determining section moment of inertia of rebar cages.

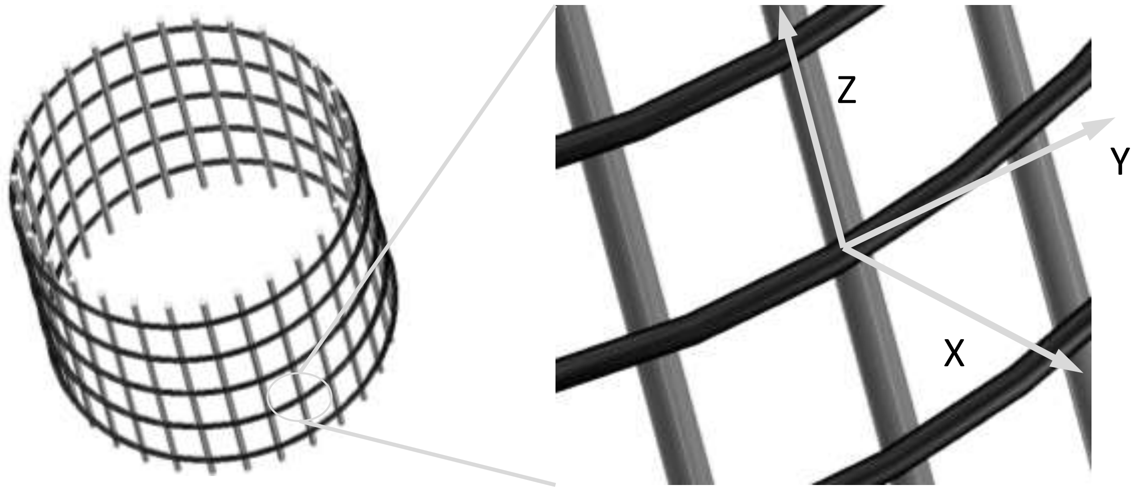
Lap Splice in Reinforcement Bars and Rebar Cages

- Lap splice lengths were determined for R/C elements
  - Length will develop bar area through concrete bond stresses.
- Rebar cages are subjected to construction loads.
  - Lap splice strength depends on number and strength of tie wire connection.

Finite Element Mode
ADINA Program



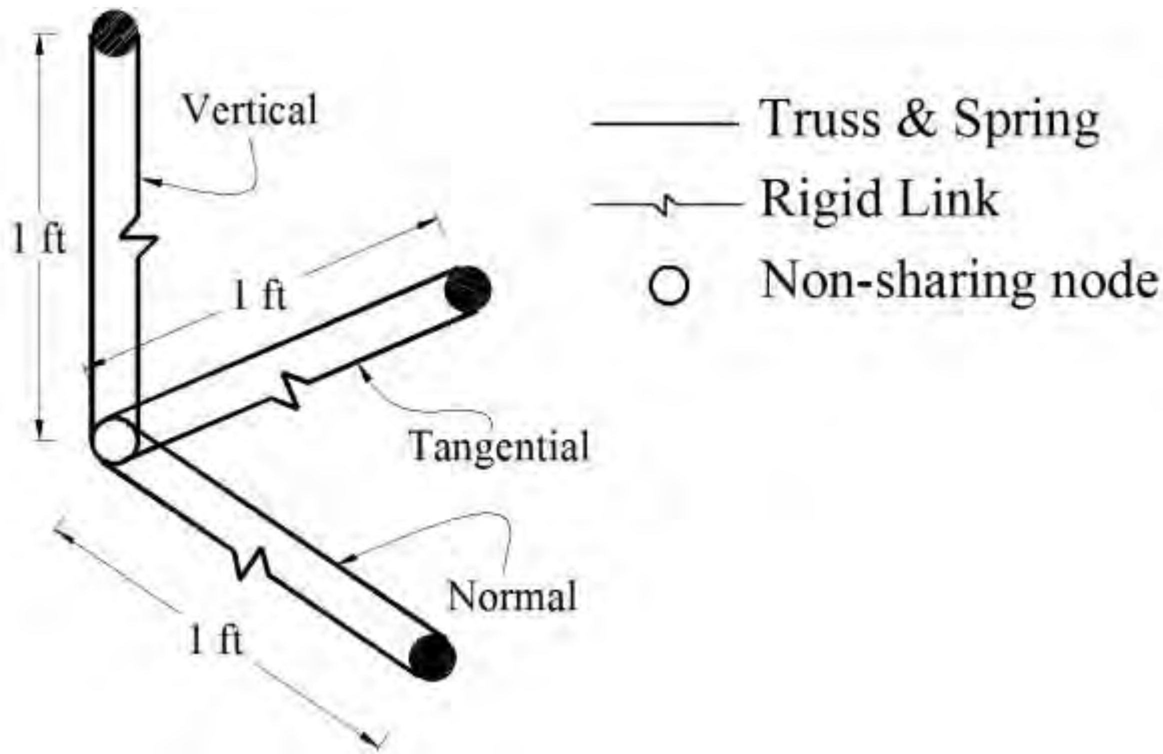
Model of Tie Wire Connections



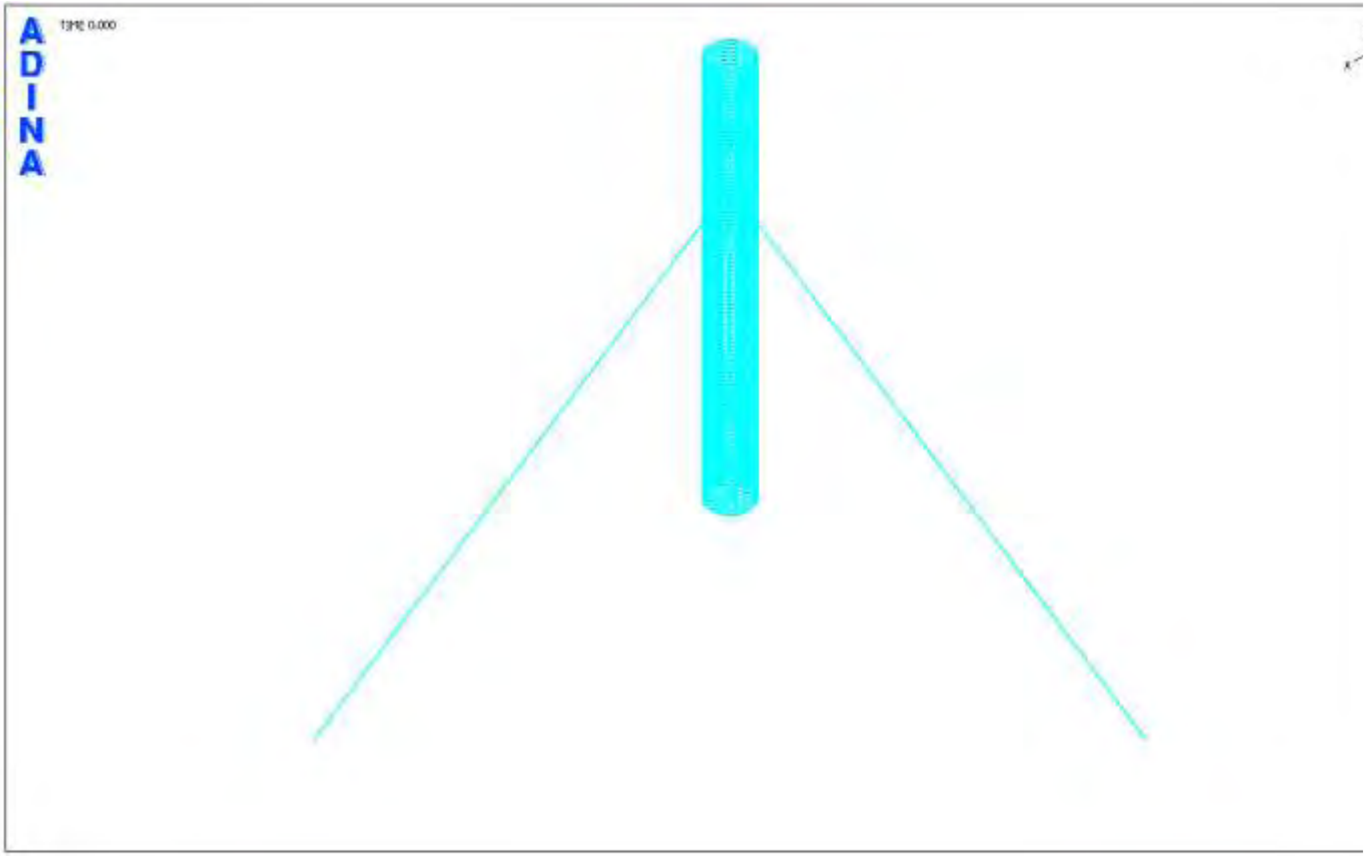
X: normal direction

Y: tangential direction

Z: vertical direction

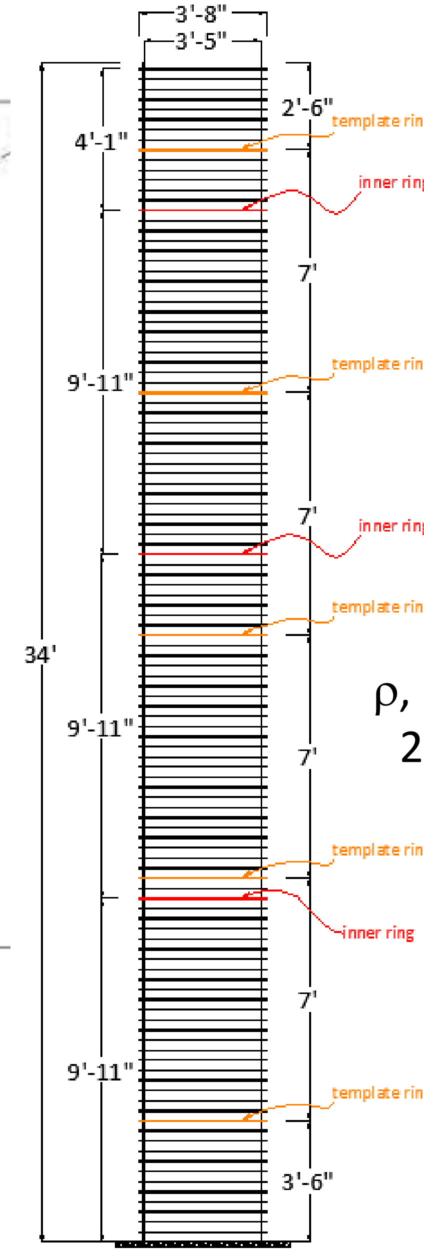


Nonlinear Finite Element Analysis



Tie Wire Connections

1. Min Tie: Template Hoops and Pick-up Bars
2. Max Tying –Every Joint



ρ, ρ_s= 2%

Nonlinear FEA Results

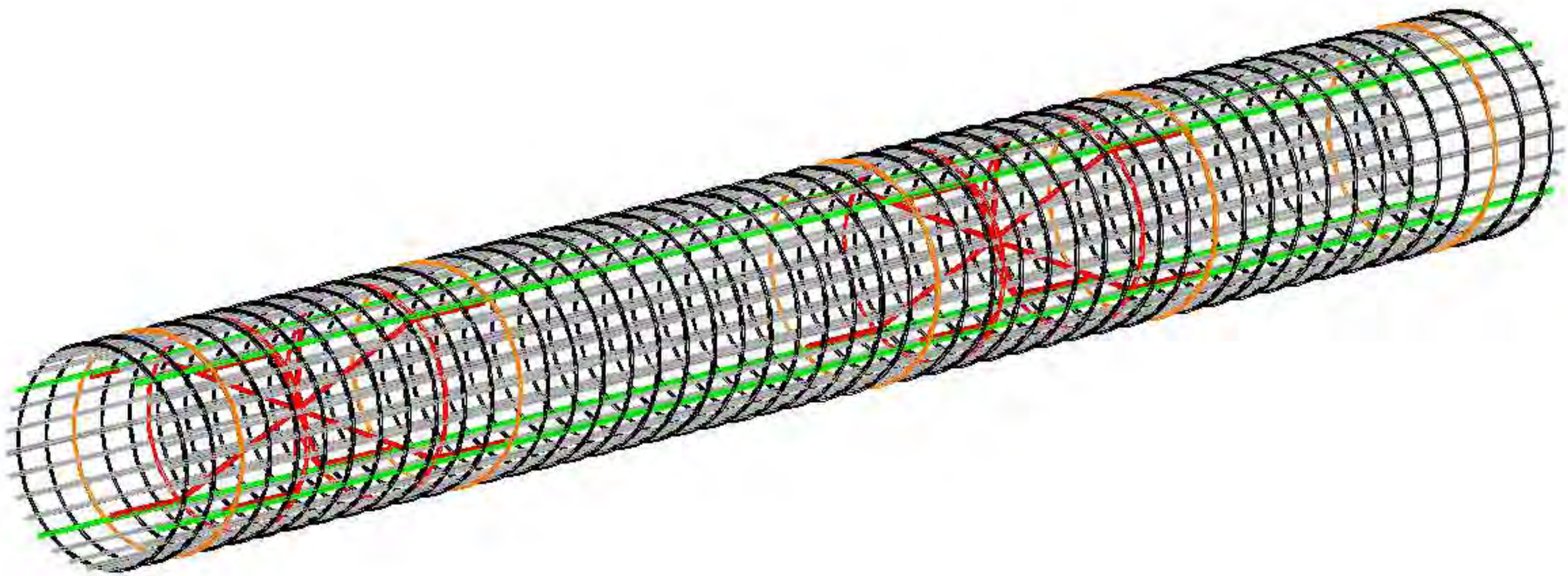
FE Model		Elastic Stiffness (lb/in)	Max Lateral Load (lb)	Stiffness Ratio	Load Ratio
Tying	No. of Ties				
Min	620	511	1,160	1	1
Max	3140 (5xMin)	1,600	4,750	3.1	4.1

Tie wire connections **<u>are not</u>** effective in increasing the strength and stiffness

Reflections on FE Analysis Results

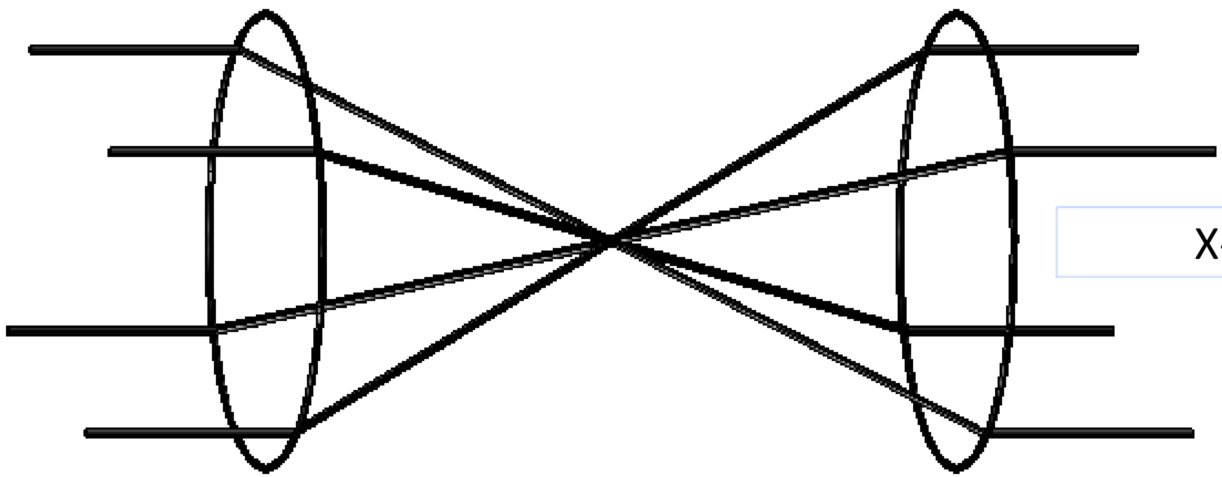
1. Cages are dominated by **shear flexibility** (GA_s) and not by flexure (EI).
2. β factor is almost zero for minimum tying.
3. Tie wire connections **are not** effective in increasing the strength and stiffness.
4. Need to significantly increase the cage stiffness.
5. Investigate effect of internal braces

Rebar Cage Internal Braces

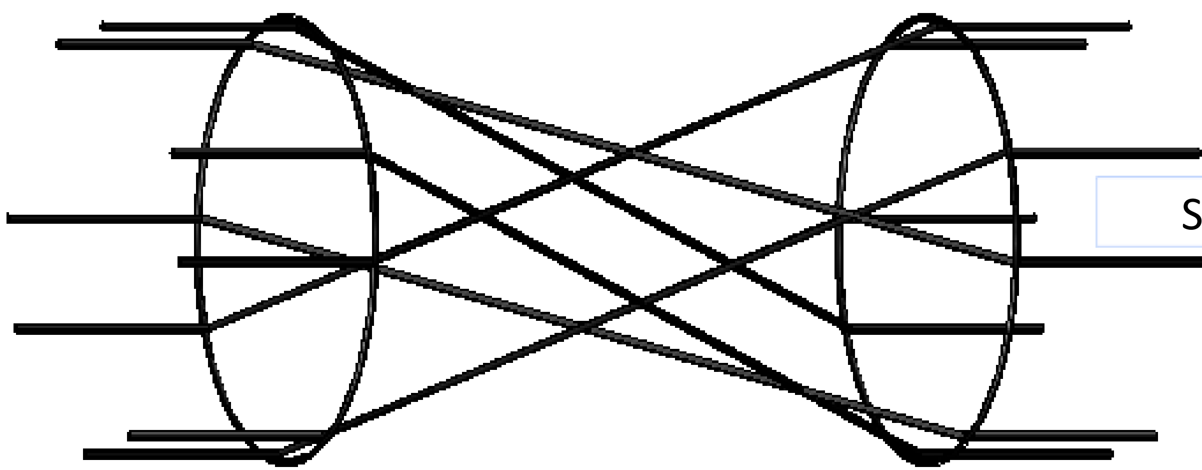


- Two Types: X-Type or Square
- #8 bars welded in the middles and spaced @ 10 ft
- Tied to longitudinal bars and to end rings

Cage Internal Braces



X-Brace

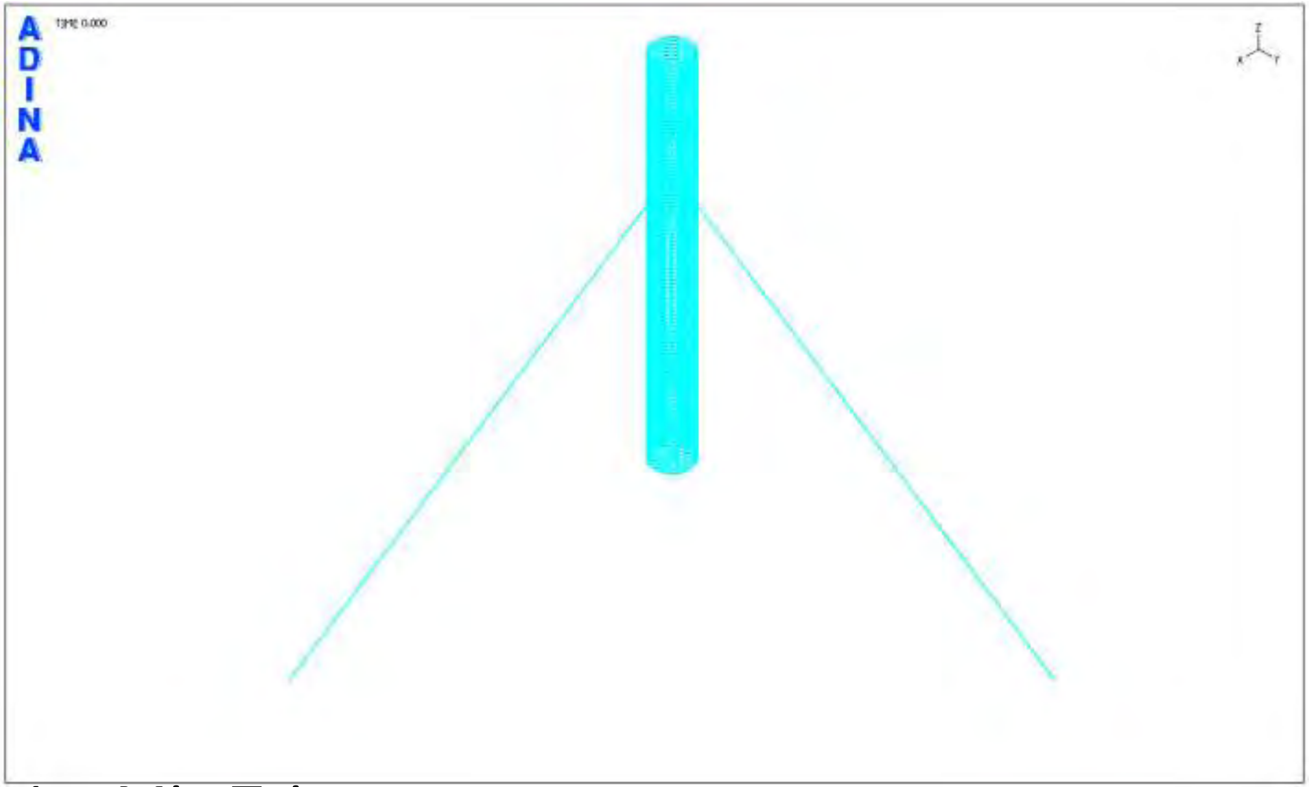


Square Brace

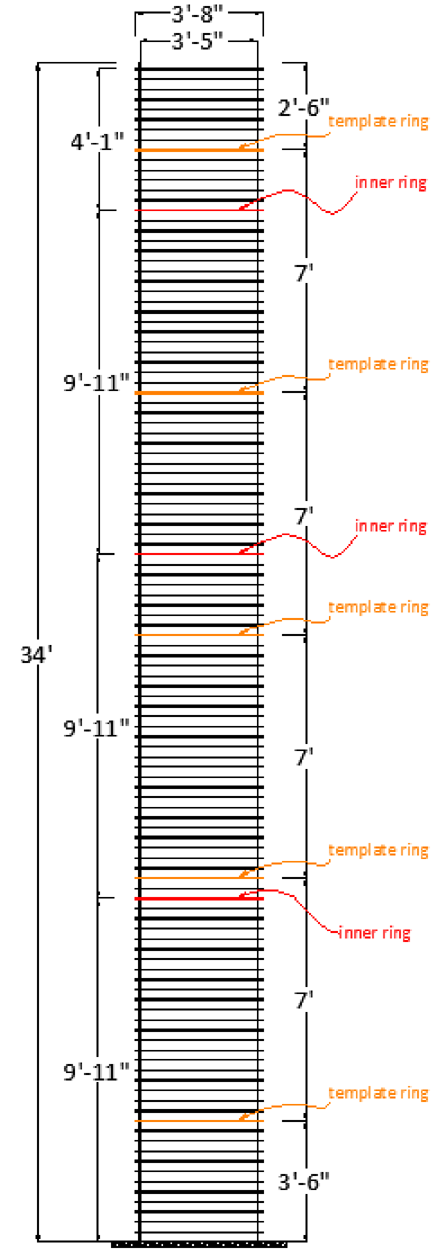
Internal Braces
X Type

Internal Braces
Box Type


Nonlinear Finite Element Analysis



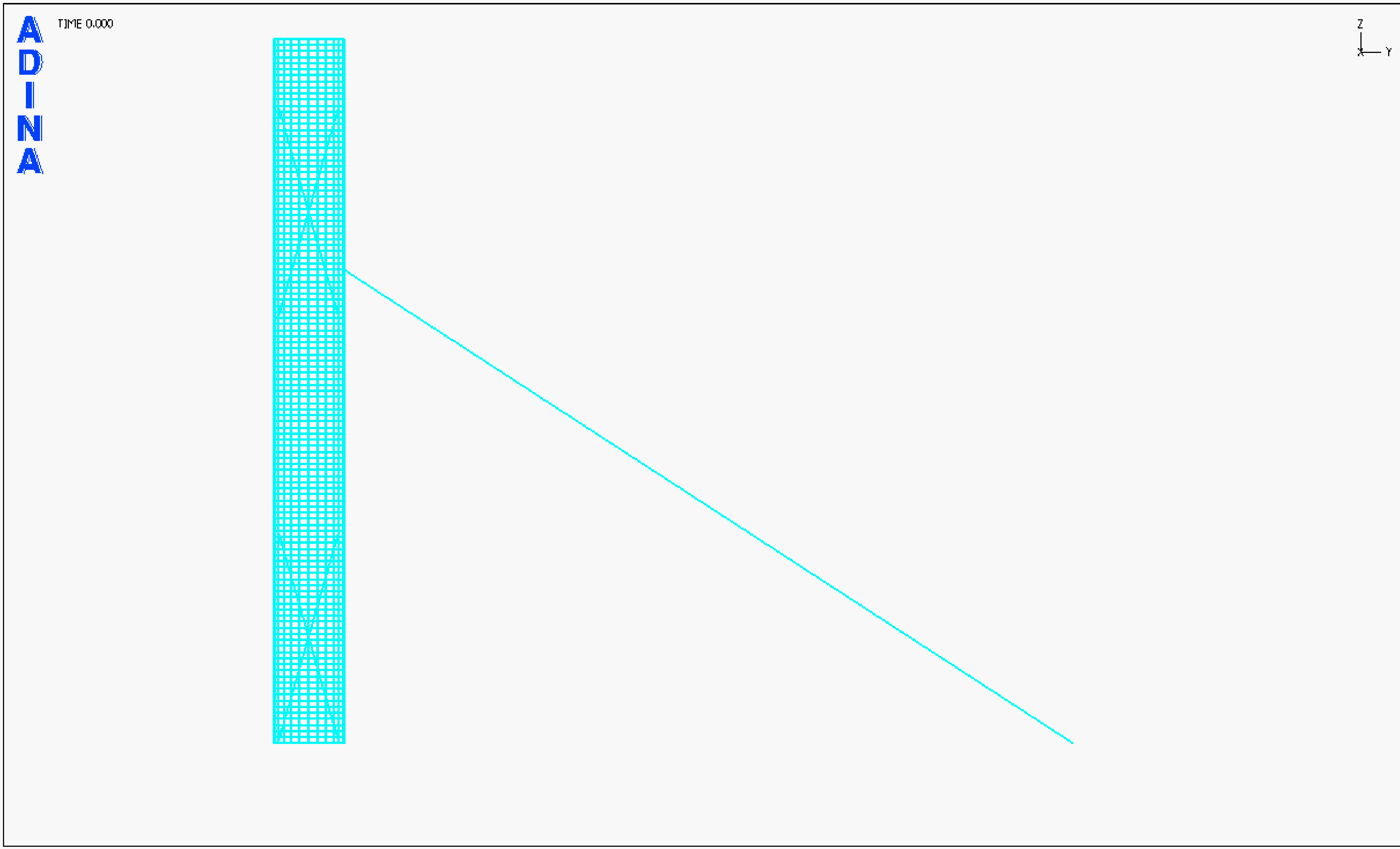
1. Min Tying
2. Max Tying
3. Min Tying with X-Braces
4. Min Tying with Box Braces



Nonlinear FEA Results

Model		Elastic Stiffness (lb/in)	Max Lateral Load (lb)	Stiffness Ratio	Load Ratio
Tying	Brace Type				
Min	00	511	1,160	1	1
Max	00	1600	4,750	3.1	4.1
Min	Box	5370	6,230	10.5	5.4
Min	X	5170	7,140	10.1	6.2

FEA Results



Reflections on FEA Results

- Internal Braces increased the strength and stiffness of rebar cage.

- Rebar cages without internal braces are very flexible.

- Rebar cages must have internal braces.

Rebar Cage Full Scale Experiments

Need to determine information on rebar cage collapse under controlled environment to:

- Determine Lateral Strength and Stiffness
- Progression of Collapse
- Calibrate Analytical Models

Rebar Cage Experiments

- Two Full Scale Specimens
- Fabricated at Pacific Coast Steel similar to Caltrans cage assembly
- Cage Height 34 ft, Cage Dia 3’-8”, H/D=34’-0”/3’-8”=9.3

Specimen	Longitudinal Bars		Transverse Bars		Brace Type	Weight
I	12#11	ρ=1%	#8@7”	ρ_s=1%	X 4#8	4,100 lb
2	24#11	ρ=2%	#8@3.5”	ρ_s=1%	Square 8#8	8,200 lb


Caltrans

Reinforcement Placing

- Four pick-up bars tied at every Joints
- Five template hoops tied at every joint

Specimen	Bar Type	Tie Wire Connection Types			
		2-Snap	4-Snap	Column-tie	Wrap & Saddle
I	Pick-up	20%	70%	4%	6%
	Template	0%	33%	33%	33%
II	Pick-up	90%	5%	0%	5%
	Template	5%	0%	0%	95%

Number and Type of Tie Wire Connections

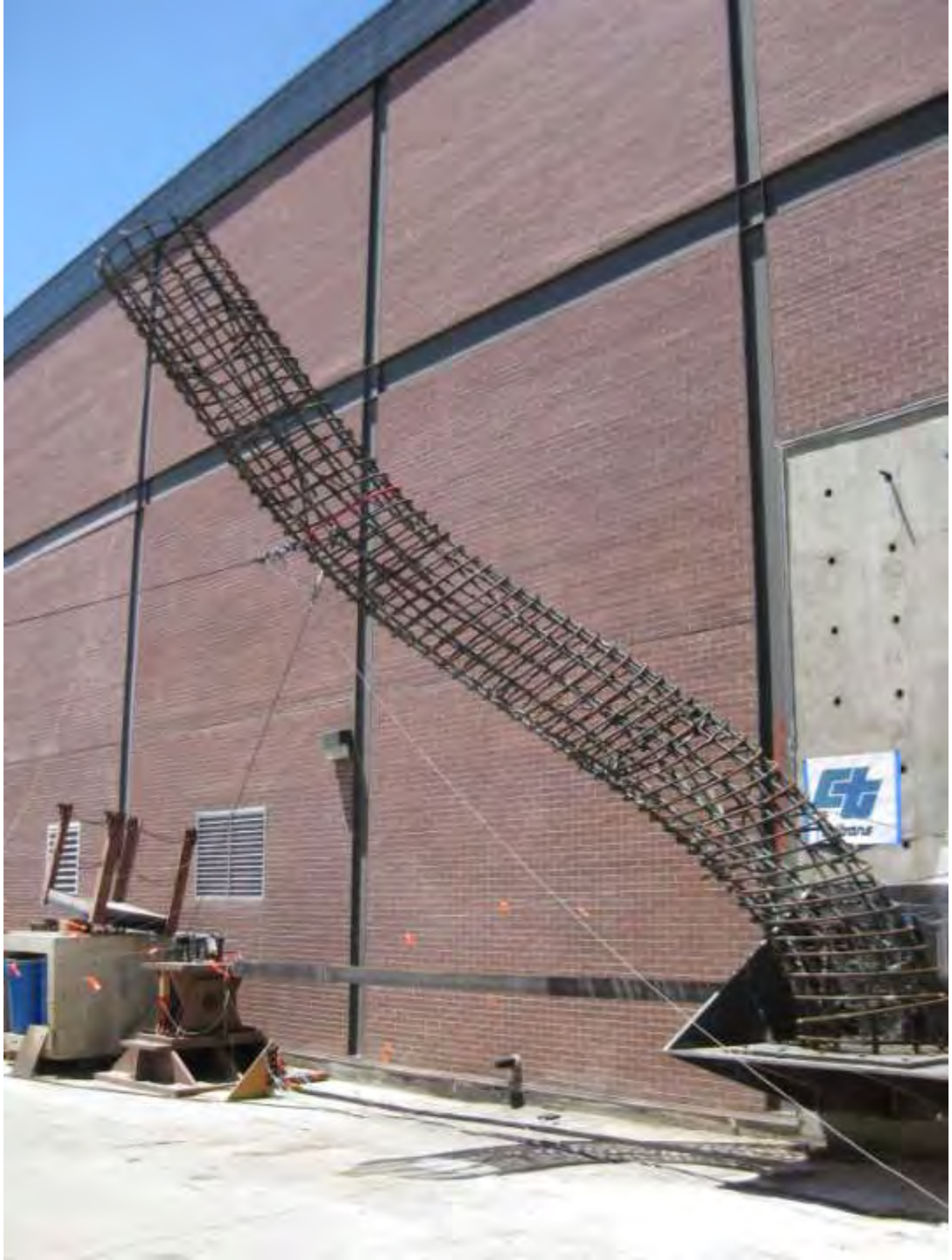
Specimen	# Joint	%Tied Joints				No Ties
		2-snap	4-Snap	Column Tie	Wrap & Saddle	
I	708	21%	41%	2%	4%	28%
II	2808	33%	10%	1%	4%	52%

Test Set-up

- Fixity at the base of the cage
- Load applied at 23 ft high through two 7/16”-dia guy wires @ N-S and E-W directions
- Guy wire inclination 33 degrees
- Load applied through hydraulic wench with displacement control at the two locations


Link-Belt


ASYM
BLOCK
ASYM

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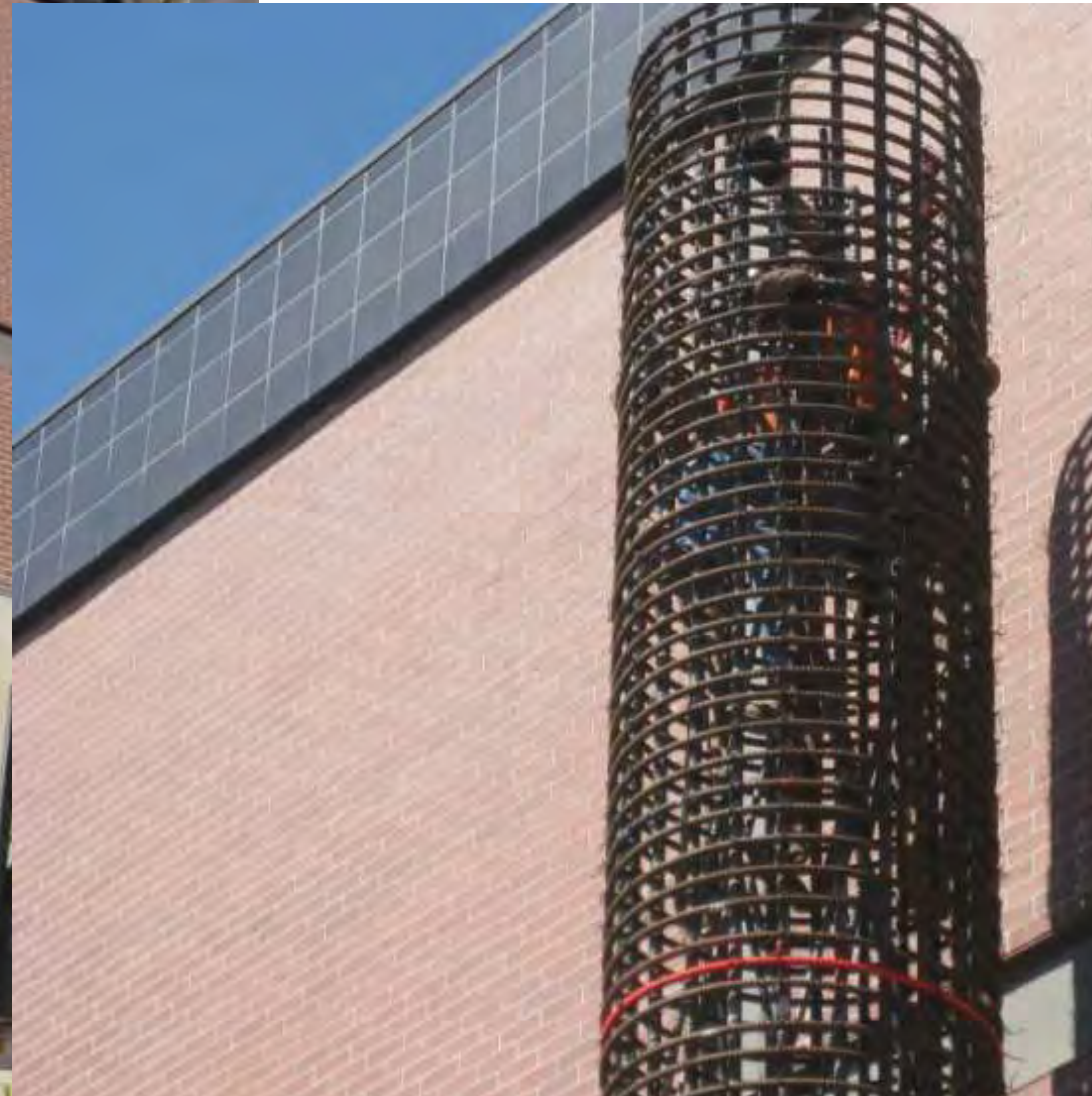
- Specimen II
  - ρ = 2% (24 #11 rebar)
  - ρ_s=2% (#11@3.0 in)
  - Square braces
  - Weight 8,200 lb



Link-Belt

Link-Belt



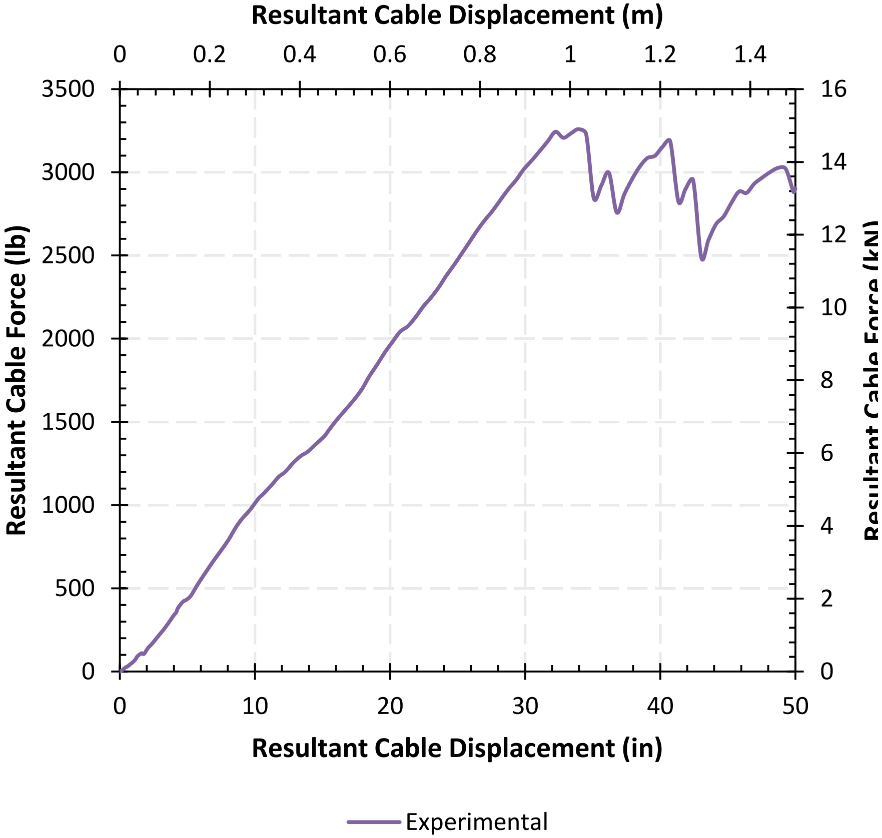

Testing Specimen II


Caltrans

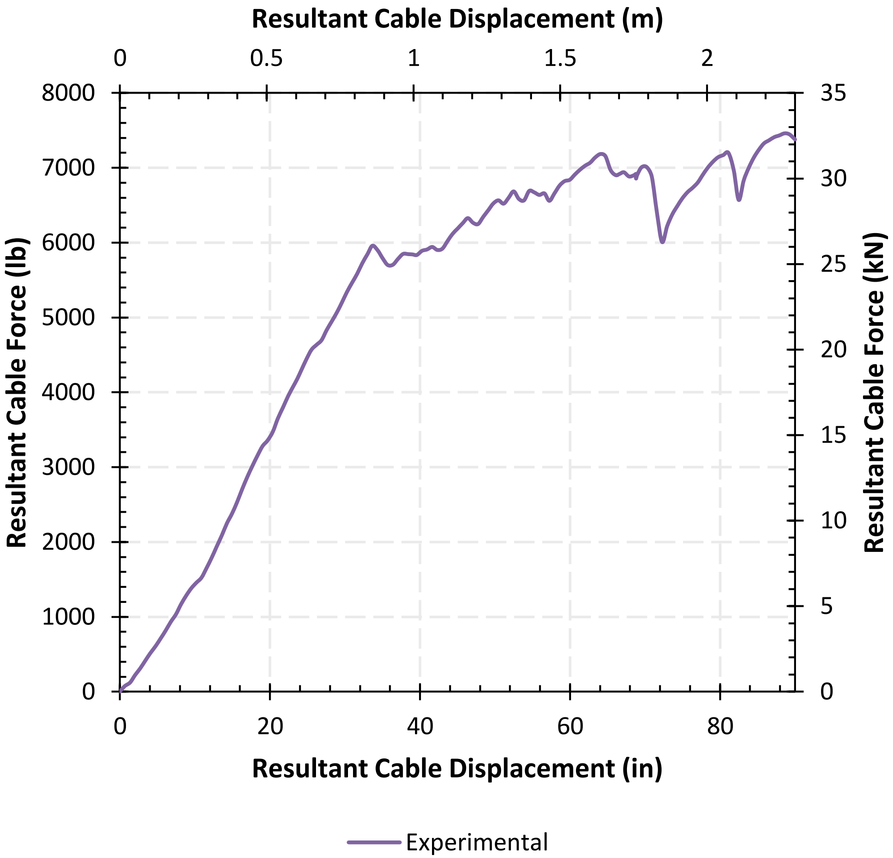

Caltrans

Experimental Results

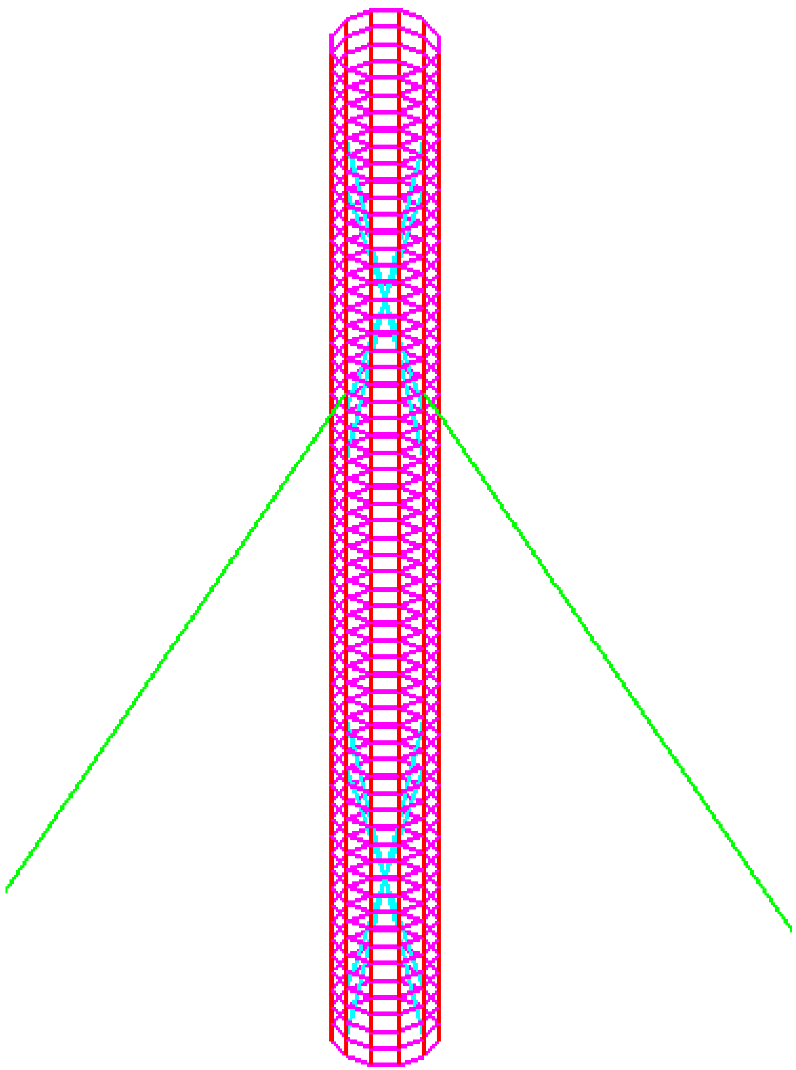
Specimen I



Specimen II



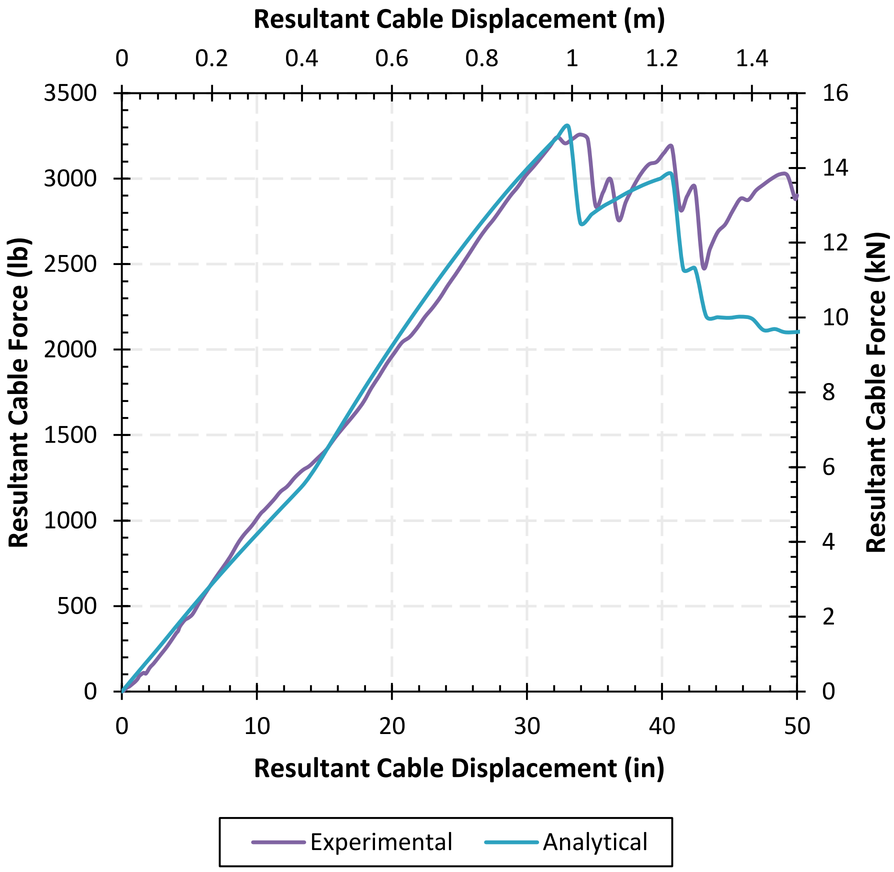
Calibration of Computational Model



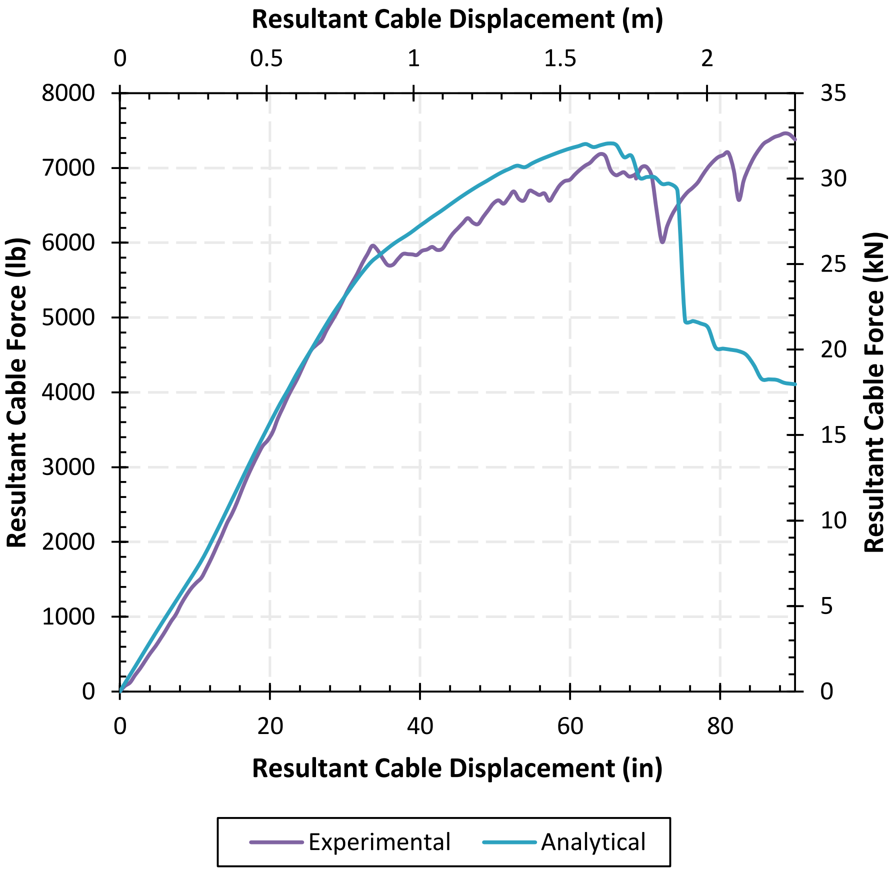
- ADINA v.8.6
- Tie Wire Connections
  - Strength
  - Stiffness
- Longitudinal bars
  - Axial
  - Flexure
  - Torsion
- Bracing Element
  - Boundary Conditions and Buckling

Calibrated Computational Model Analysis Results

Specimen I

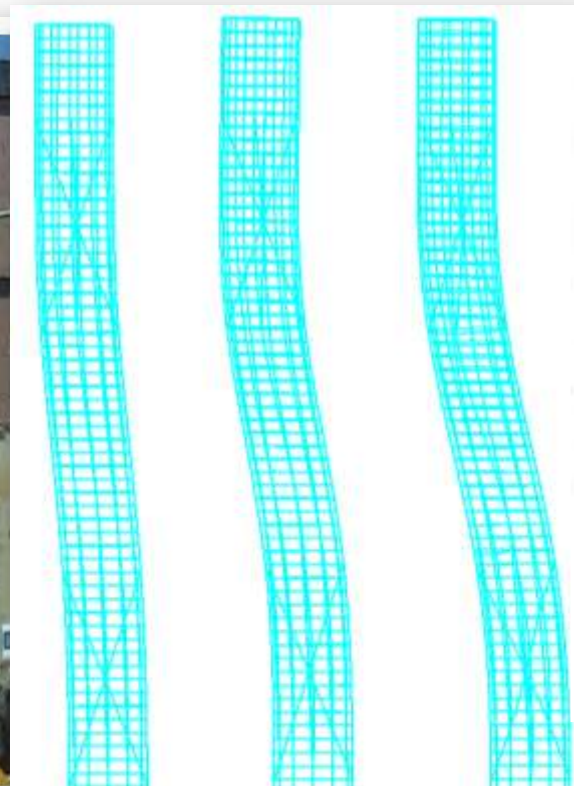


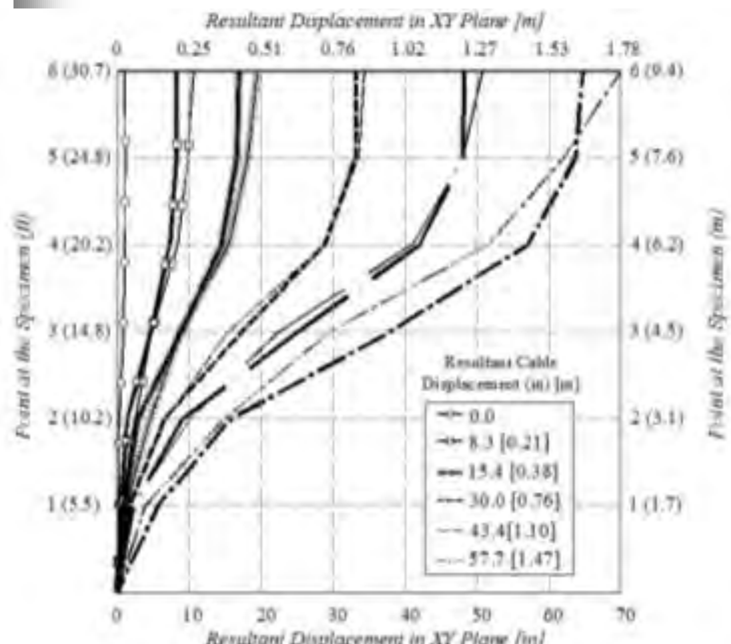
Specimen II



Calibrated Computational Model Results

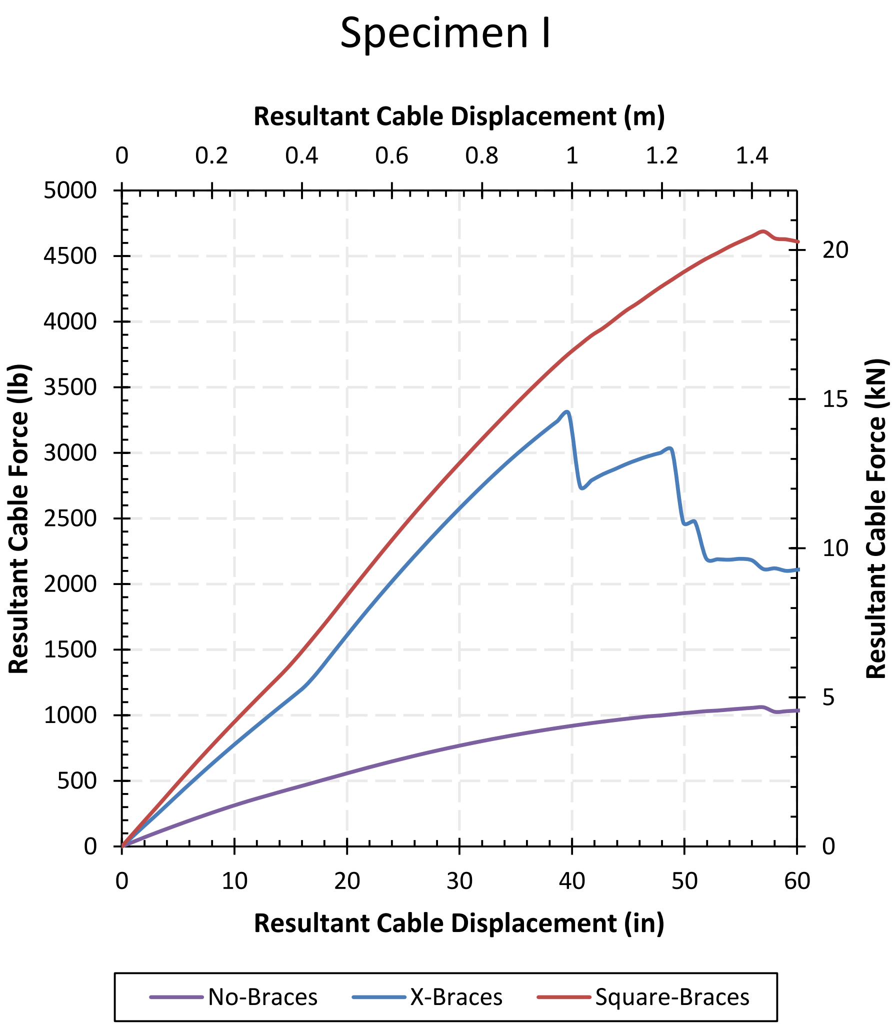
Deformed Shape of Specimen I

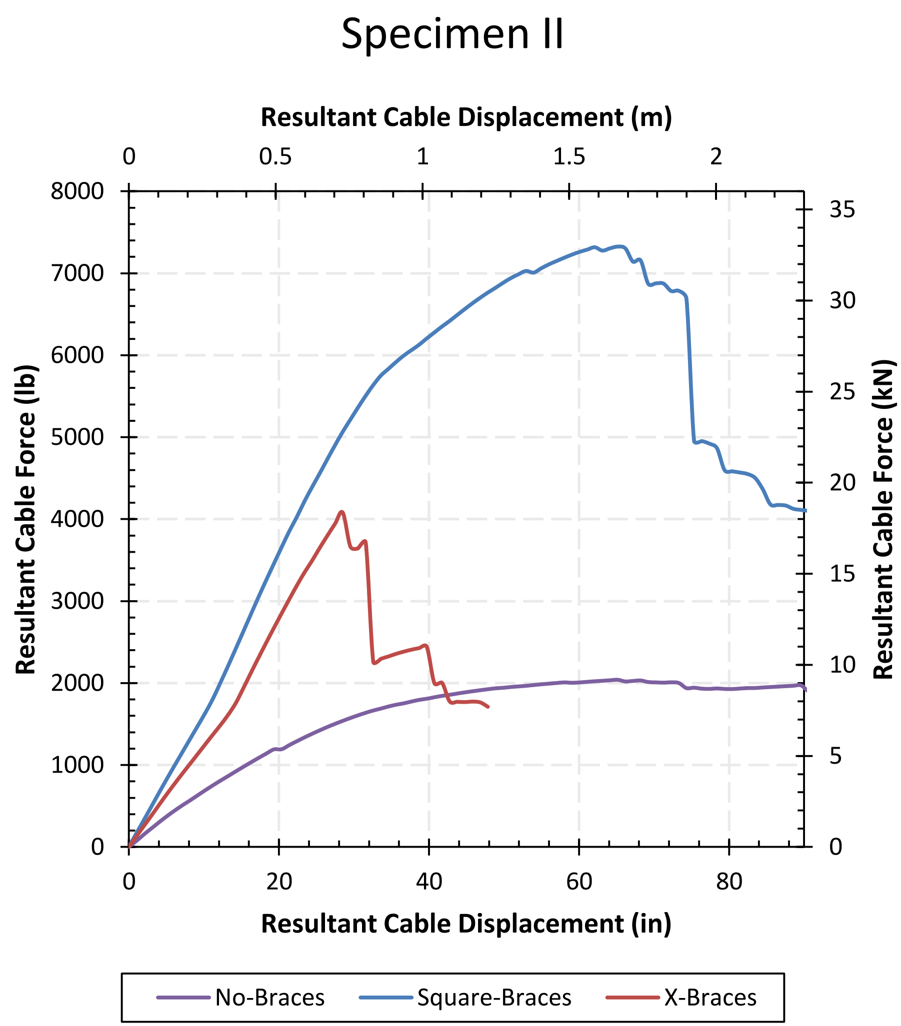




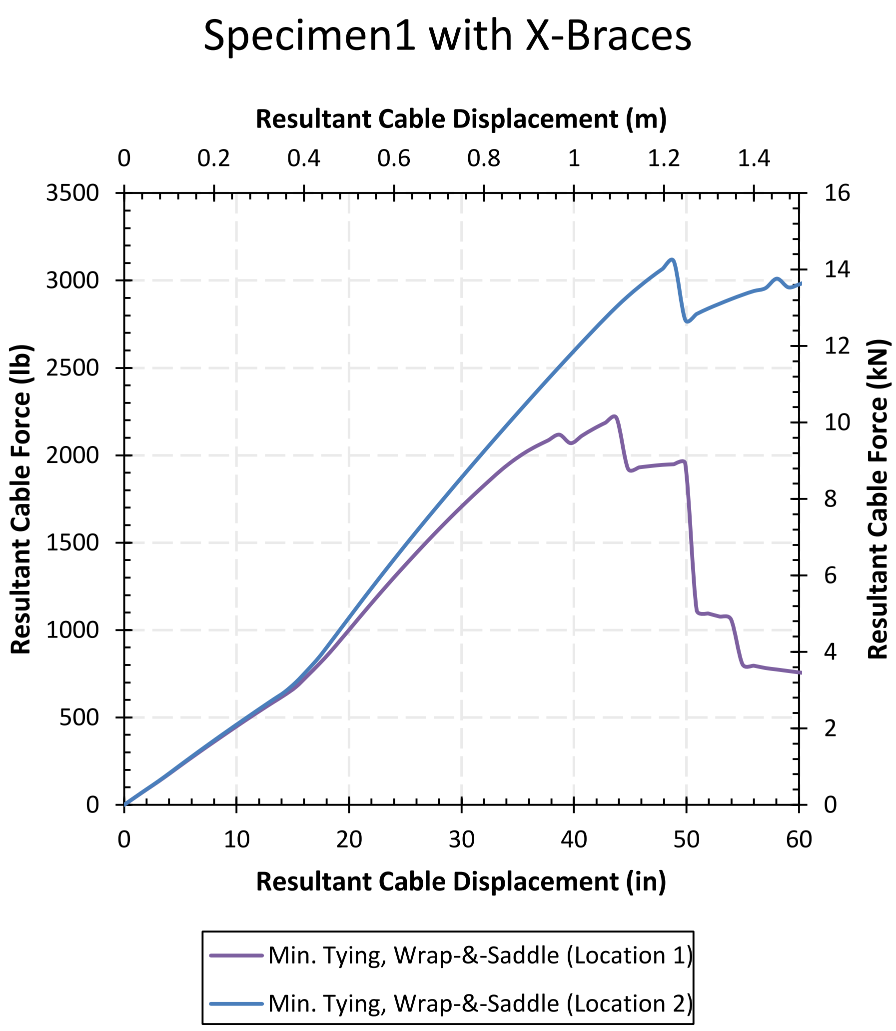
Measured (Dark)
Analytical (Light)

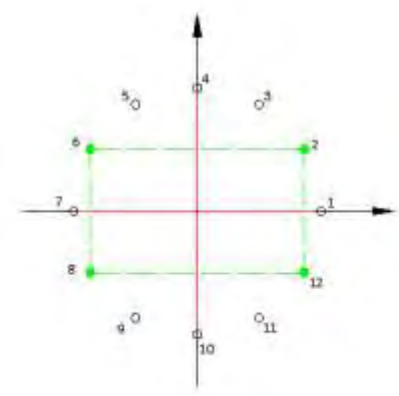
Effect of Presence and Type of Internal Braces



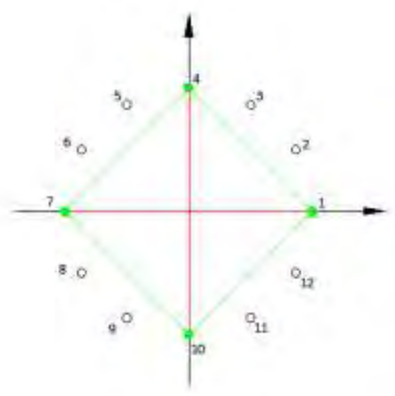


Effect of Connecting the Braces to Pick-Up bars



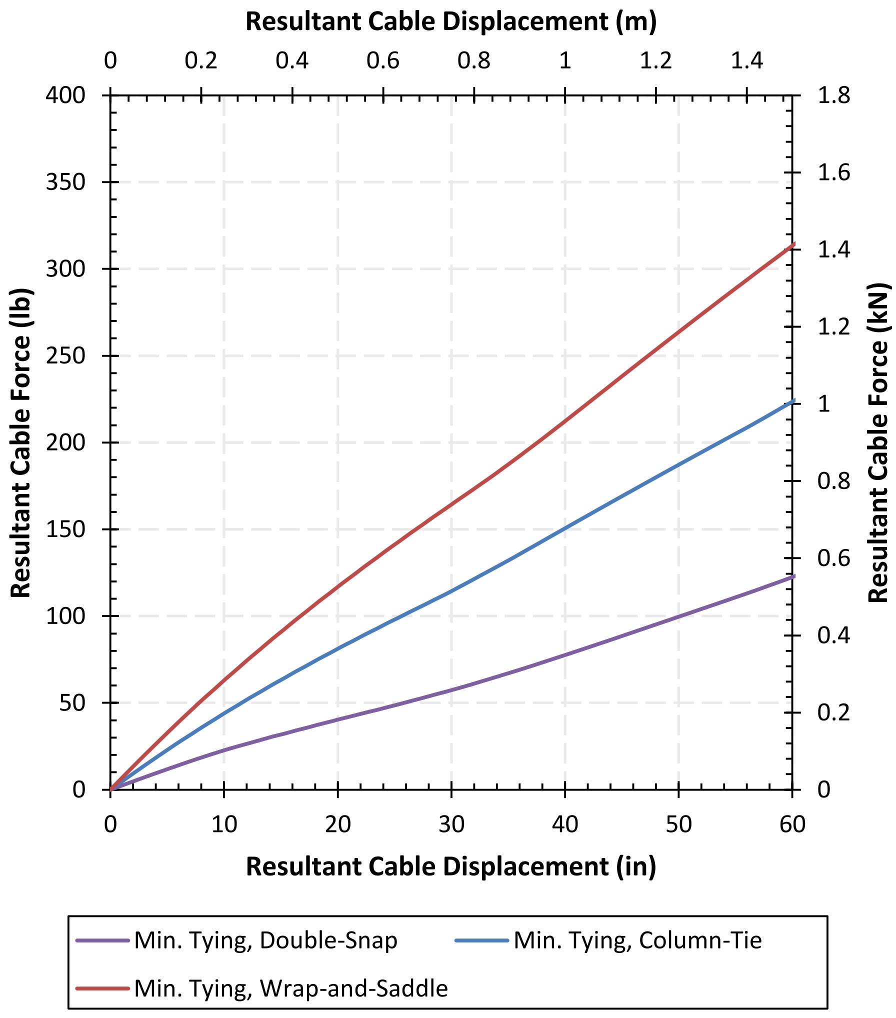


Location 1

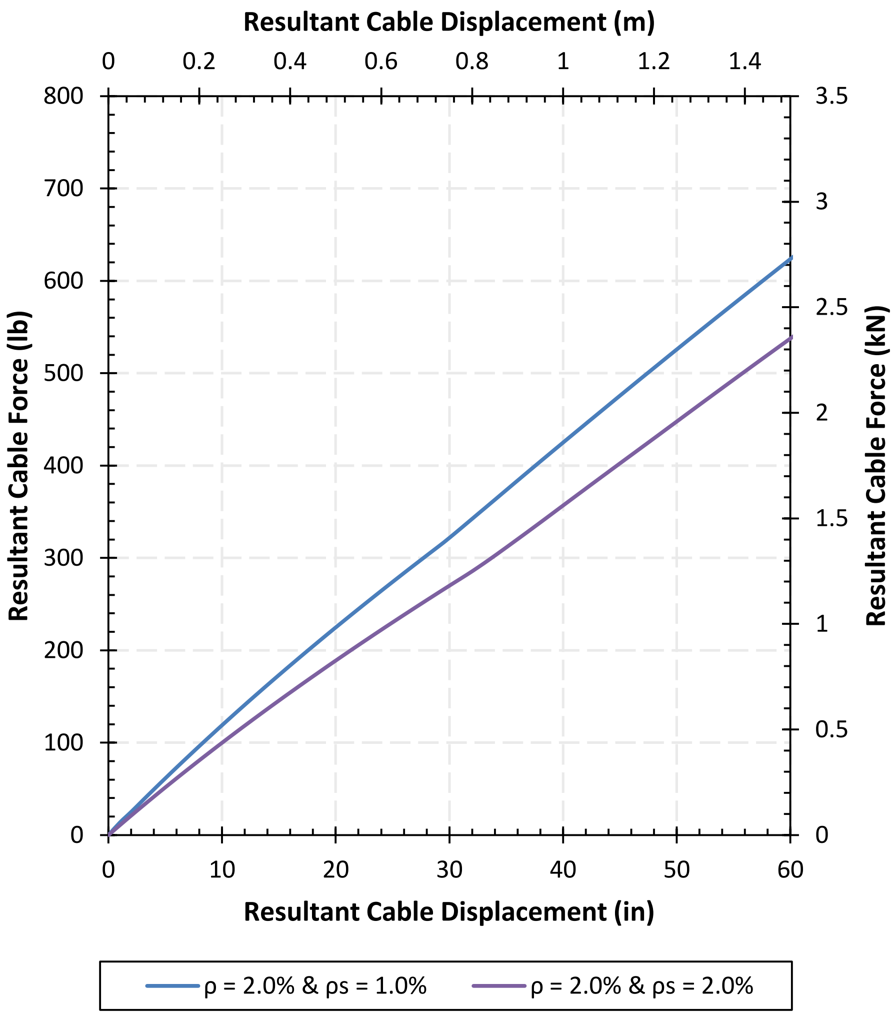


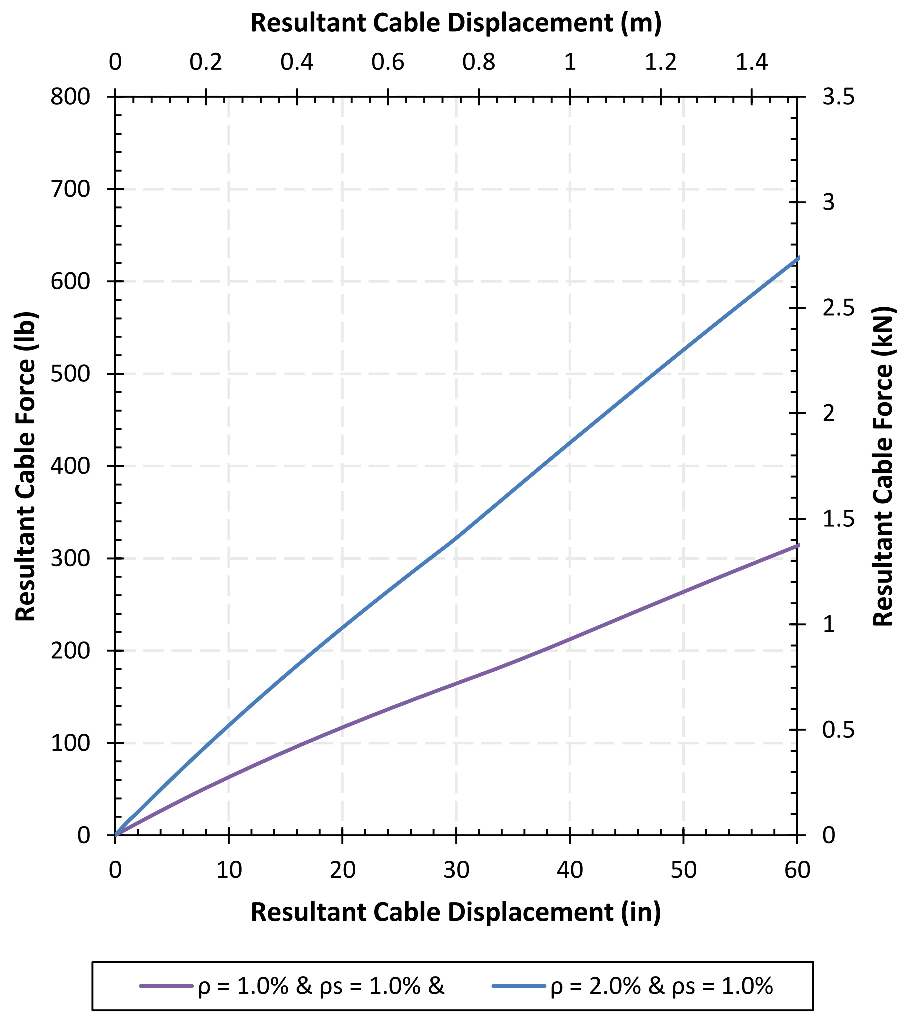
Location 2

Effect of Tie Wire Connection Types
No Braces

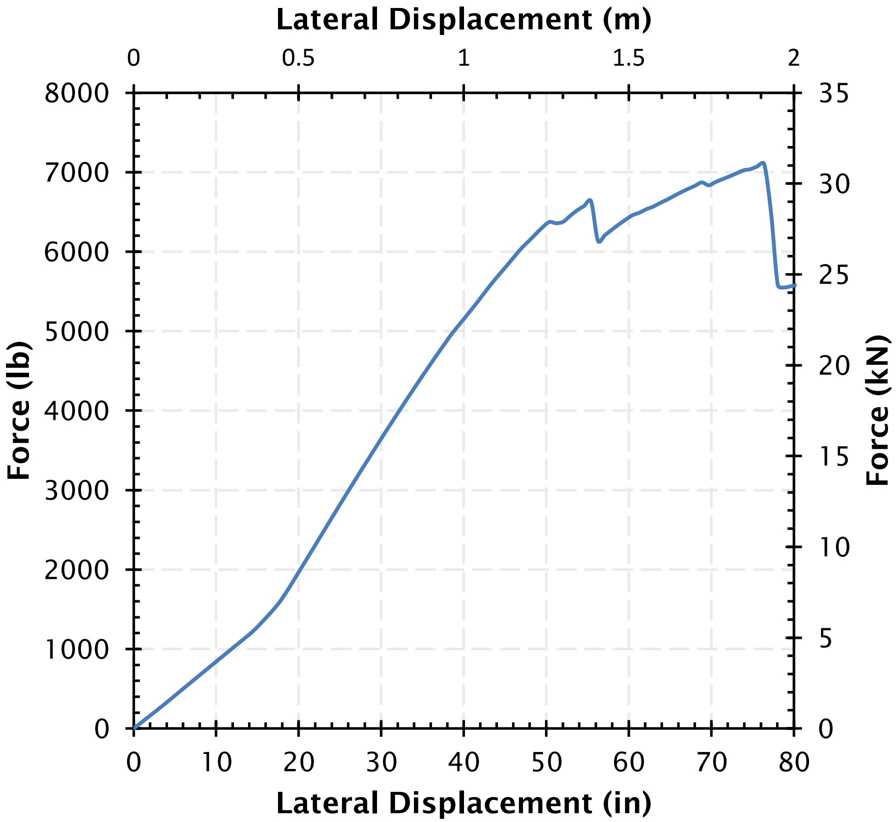


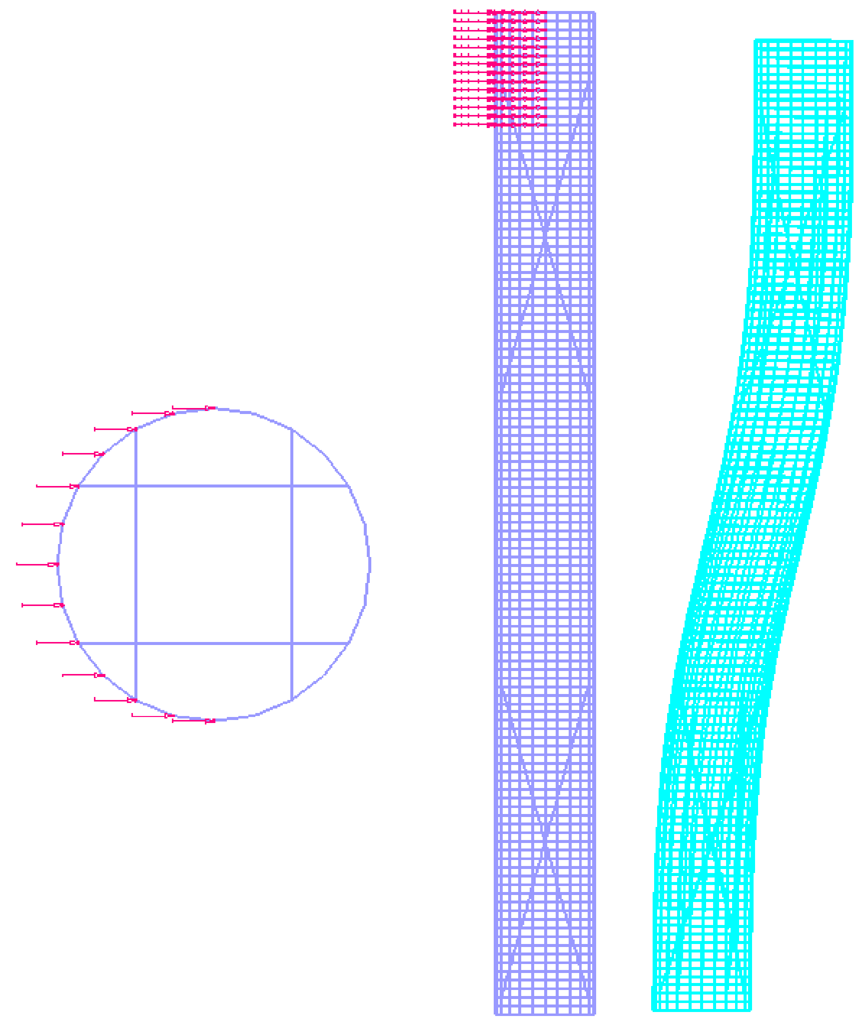
Effect of Transverse and Longitudinal Reinforcement Ratios
No Internal Braces



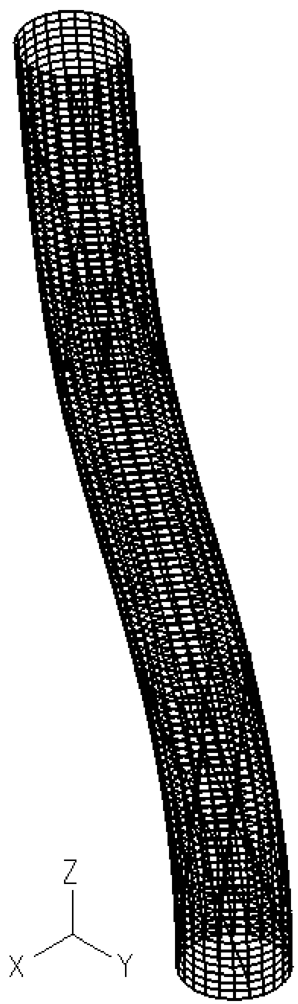


Static Response under Accidental Loading With Square Braces

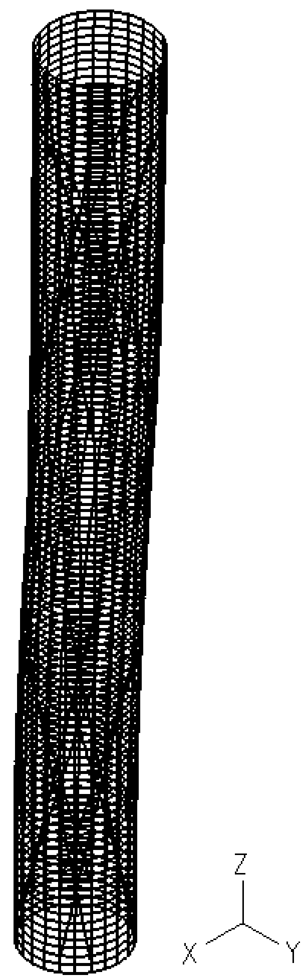




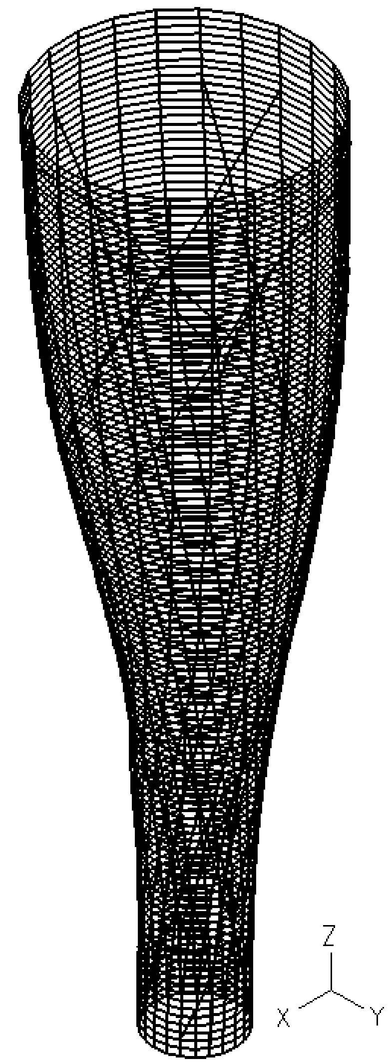
Dynamic Characteristics-Mode Shapes of Specimen II



T1 = 2.13 sec

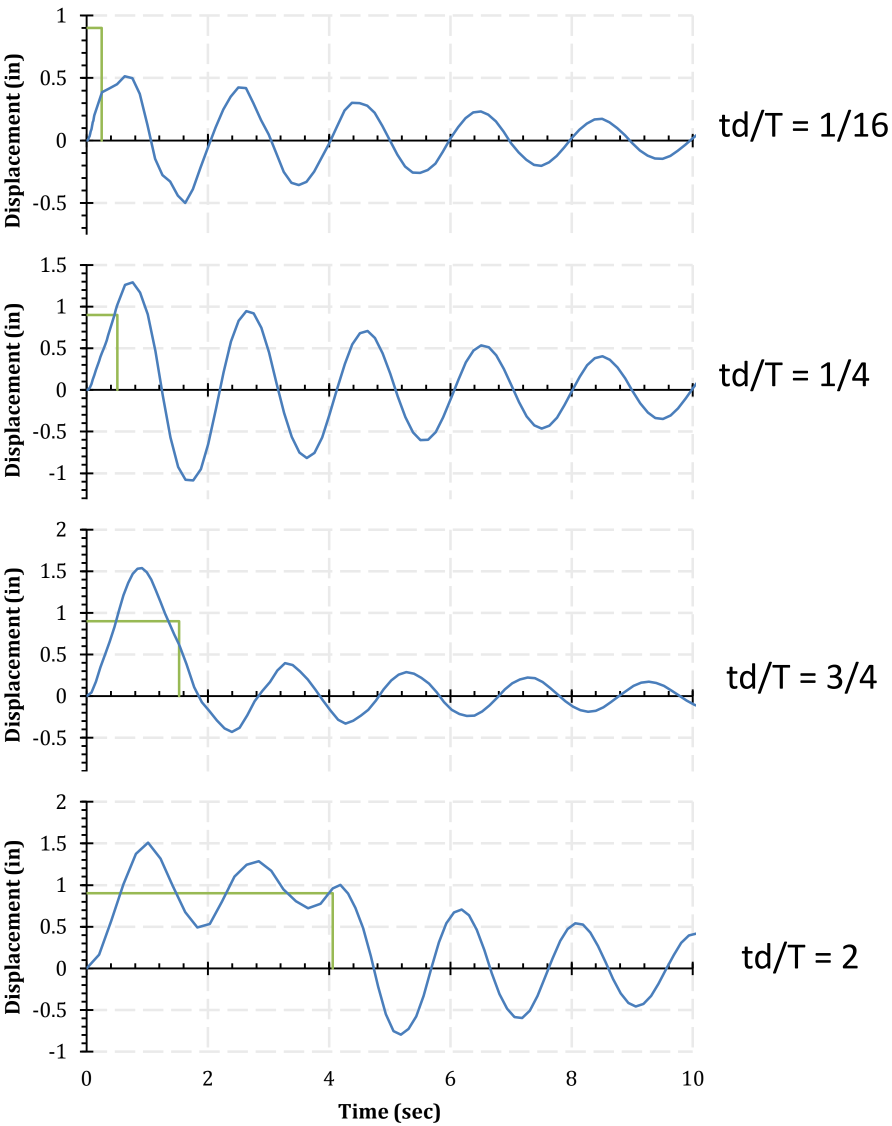


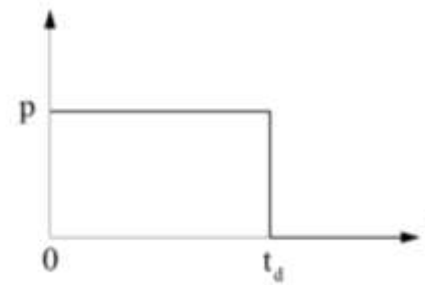
T2 = 1.90 sec

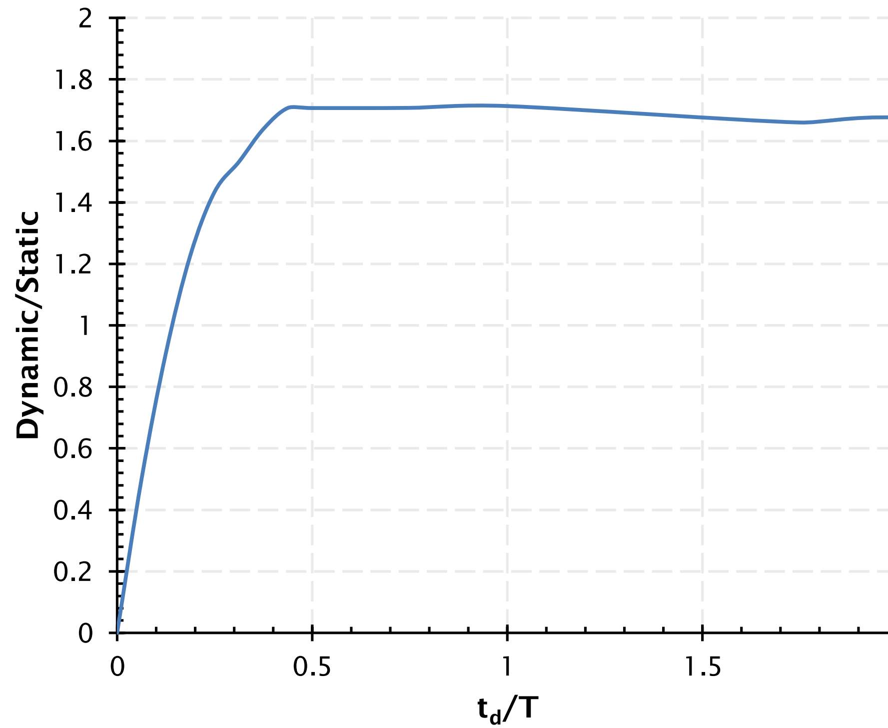


T3 = 1.33 sec

Dynamic Response under Accidental Loading







Common Practice in Rebar Cage Assembly

- Bar Placement
  - Spacing of template hoops
  - Number and Location of pick-up bars
  - Number of connections in field zones
- Tie Wire Connections
  - Types and Locations
- Braces
  - Box braces (#8 and #11)
  - Spacing
  - Connections to pick-up bars
- CRSI “Placing Reinforcing Bars” and State DOT Standard Specs

CT Standard Specs 52-1.03D-2010

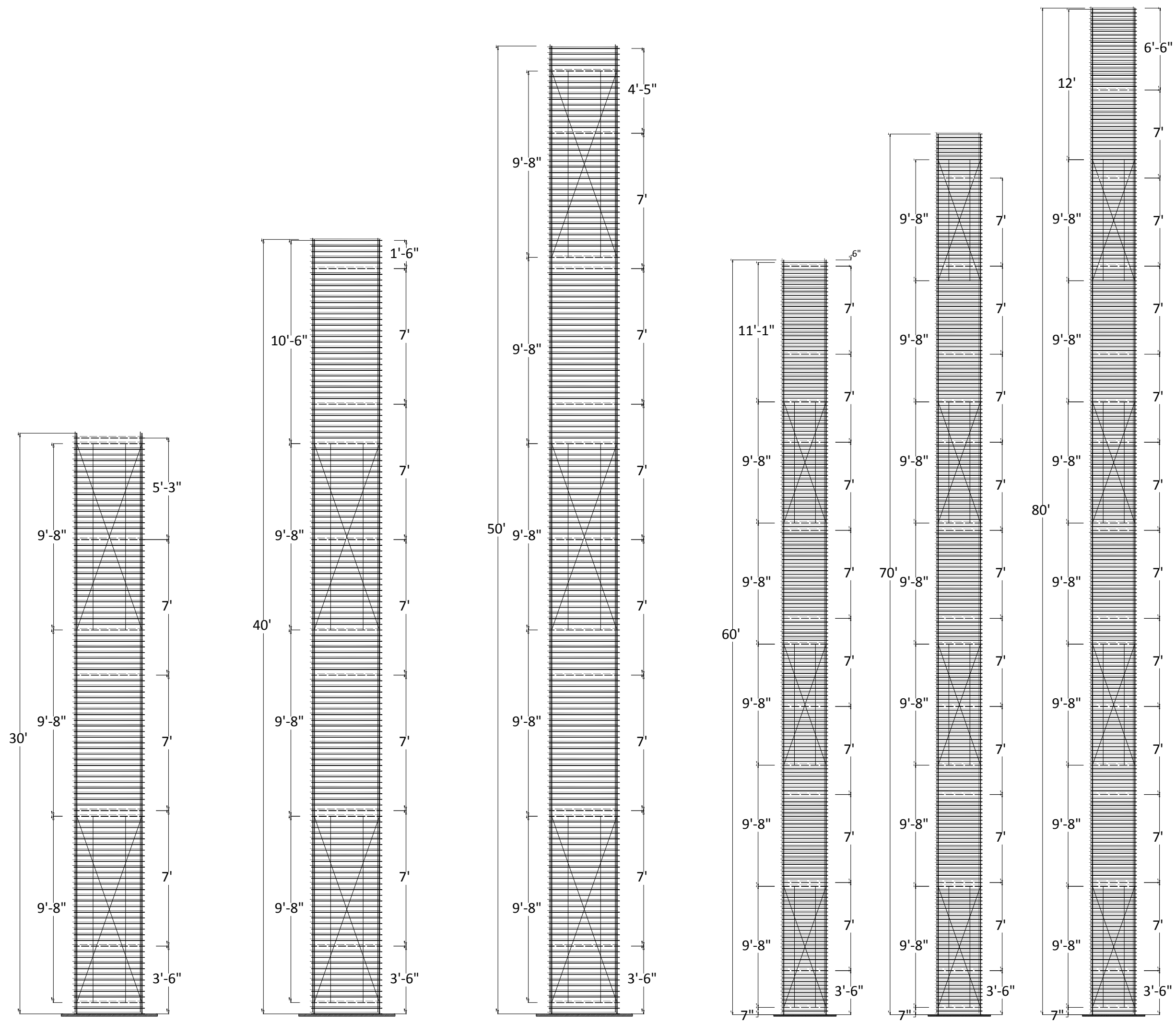
For column and pile bar reinforcing cages measuring 4 feet in diameter and larger:

1. Tie all reinforcement intersections with double wire ties on at least 4 vertical bars of each cage equally spaced around the circumference.
2. Tie at least 25 percent of remaining reinforcement intersections in each cage with single wire ties. Stagger tied intersections from adjacent ties.
3. Provide bracing to avoid collapse of the cage during assembly, transportation, and installation.

Rebar Cage Stiffness

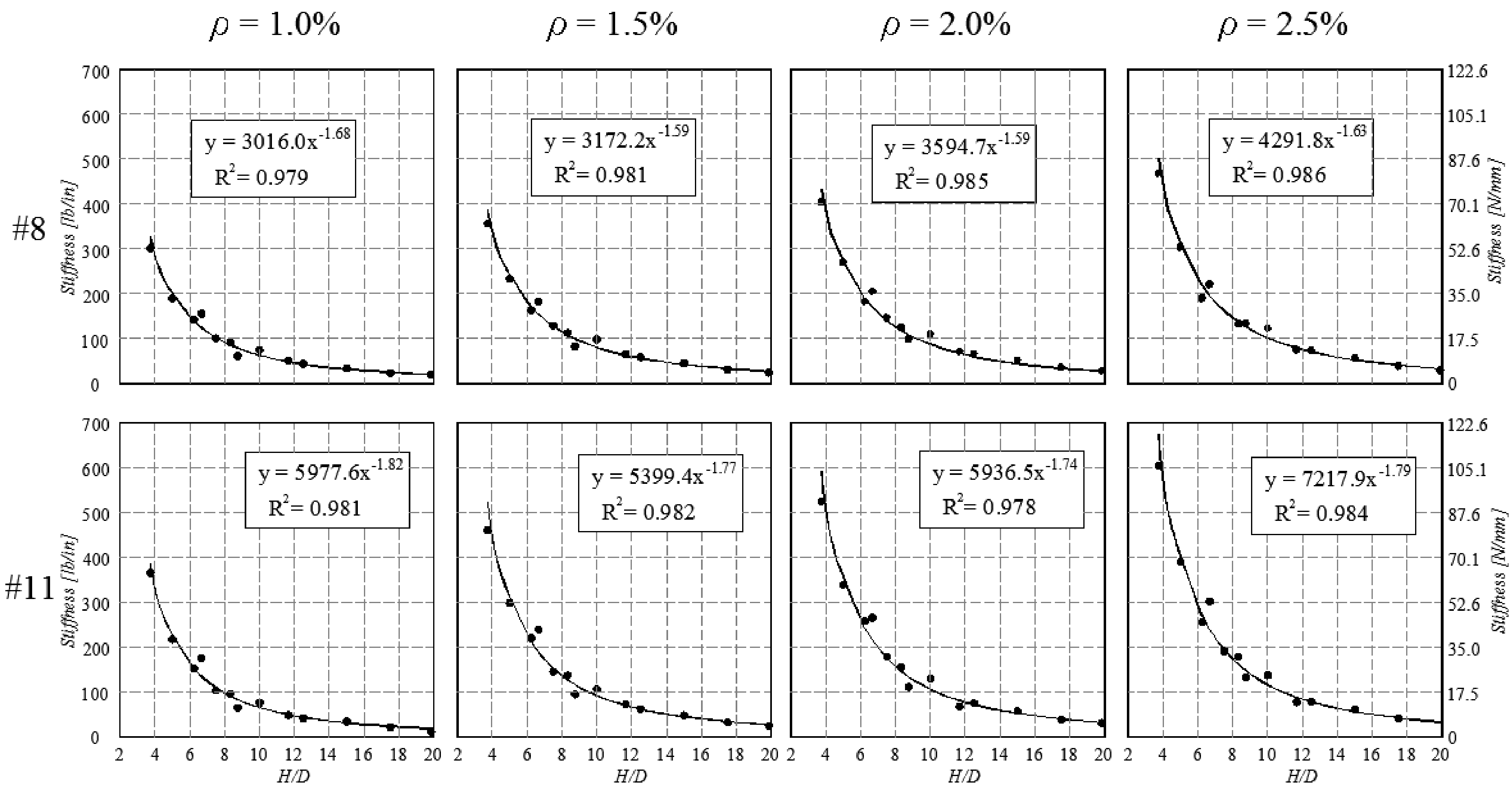
- Common Bridge Rebar Cages
  - 4, 6, and 8 ft diameter
  - ρ=1, 1.5, 2.0, 2.5% Reinforcement
  - H=30, 40, 50, 60, 70, 80 ft
- Template Hoops @7'-0"
- Bracings
  - Box #8 bars
  - Box #11 bars
- Tying
  - #15 Gauge, Wrap-and-saddle
  - Template Hoops and Pick-up Bars only

Parametric Analysis



H= 30 ft H= 40 ft H= 50 ft H= 60 ft H= 70 ft H= 80 ft

Results of Parametric Analysis

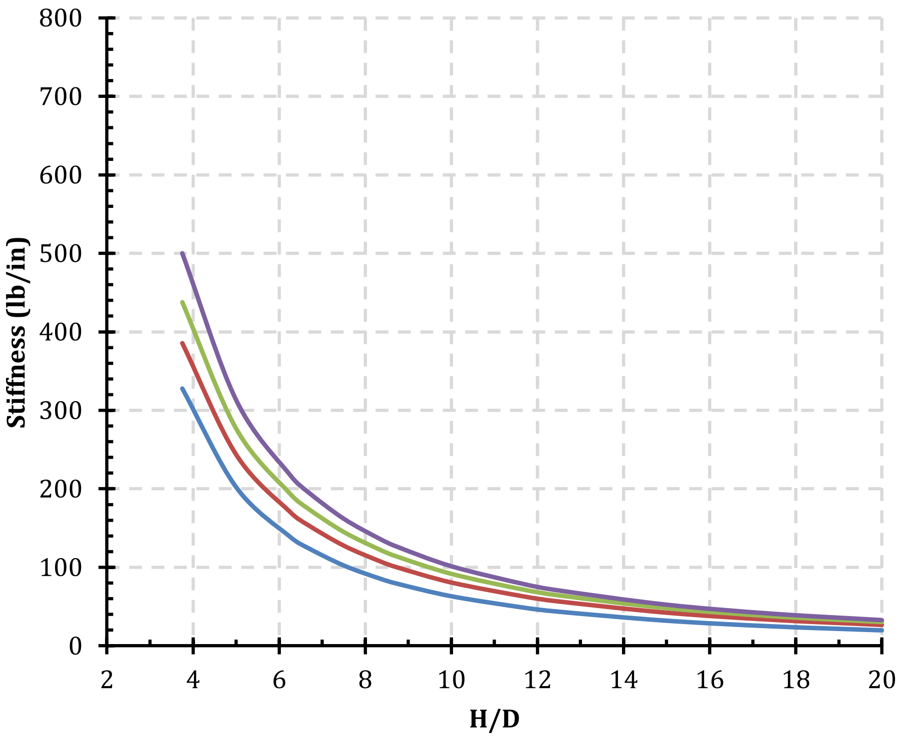


#8 brace bar Average Limit Drift =3%

#11 brace bar Average Limit Drift =4%

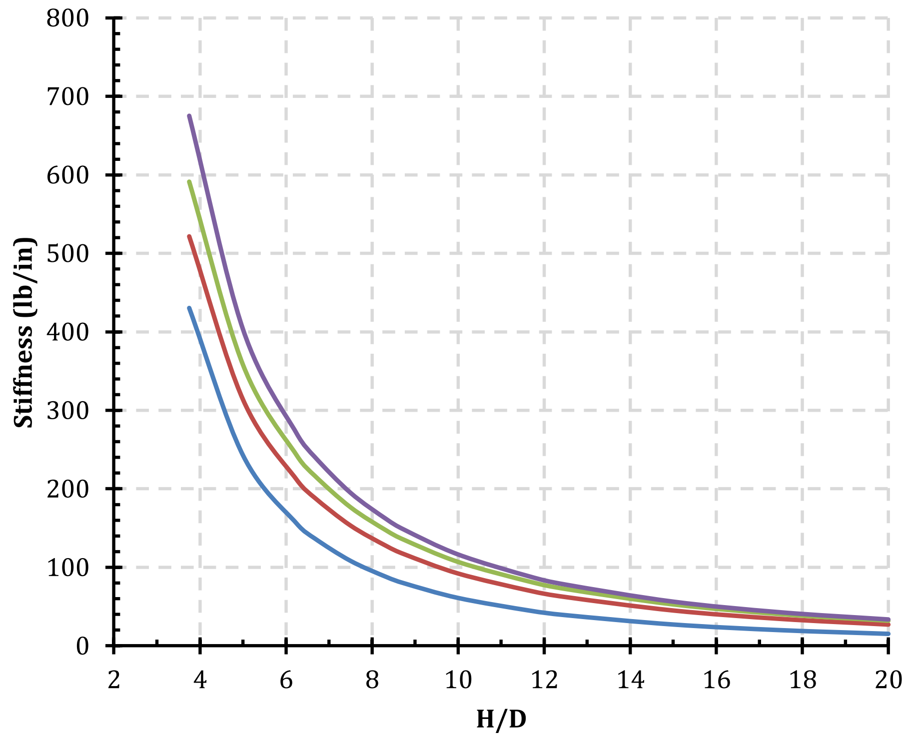
Proposed Elastic Stiffness Equations

Internal Braces using #8 rebar



ρ: 1.0% 1.5% 2.0% 2.5%

Internal Braces using #11 rebar



ρ: 1.0% 1.5% 2.0% 2.5%

$$K_{\#8\text{-brace}} = \frac{85000\rho + 2031}{\left(\frac{H}{D}\right)^{1.62}}$$

$$K_{\#11\text{-brace}} = \frac{188113\rho + 2412}{\left(\frac{H}{D}\right)^{1.78}}$$

Example Rebar Cage Stiffness

- H=34 ft, p=2%, D=4 ft, Box Braces #8

$$K_{\#8\text{-brace}} = \frac{85000\rho + 2031}{\left(\frac{H}{D}\right)^{1.62}}$$

- Elastic Stiffness K=120 lb/in

Guyed Temporary Structure

- A Guy is defined in Dictionary.com as: “*Rope or cable used to steady an object.*”
- Current Practice
  - Wire ropes are attached to cage and to anchor weights
  - Analyzed and designed to resist wind load only.

Standards and Guidelines for Temporary Structure Design and Analysis

- Lack of standards and guidelines!
- CT Guidelines for Only wind analysis and design of guy wires, attachments, and anchor weights


REVIEWING
GUY WIRE PLANS

March 2003

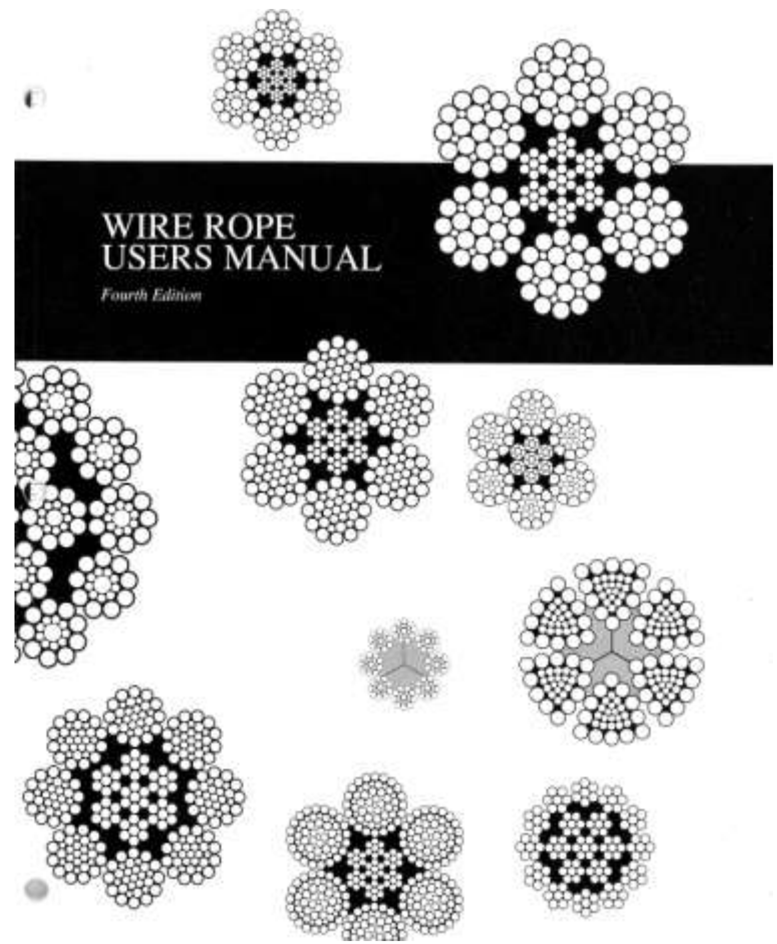
Caltrans

By:
Dan Dait, P.E.
CT Senior Bridge Specialist

Reviewed By:
Robert Crain, P.E.
CT Senior Bridge Engineer

Guy Wires

- EIPS IWRC 6x19 Guy Wire



Guy Wires in Rebar Cages

- Tensile strength 245 to 340 ksi
- Size dia. 3/8", 7/16", 1/2" , 5/8"
- Area= .11, .15, .196, .307
- E=Young's Modulus and Wire Rope Manual
  – Nominal Value and Reduced Value
  – 11,000 to 14,500 ksi
  – Nominal value used for loads greater than 20% of breaking strength

Stretch in Wire Ropes

- Constructional Stretch and Elastic Stretch: different values of E at various stages of loading.
  - Constructional stretch occurs when a cable is loaded for the first time. Depends on wire number of strands, number of wire in each strand and the type of core
  - Elastic Stretch result of inherent elasticity or recoverable deformation of the metal itsef

Pre-tensioned Guy Wires

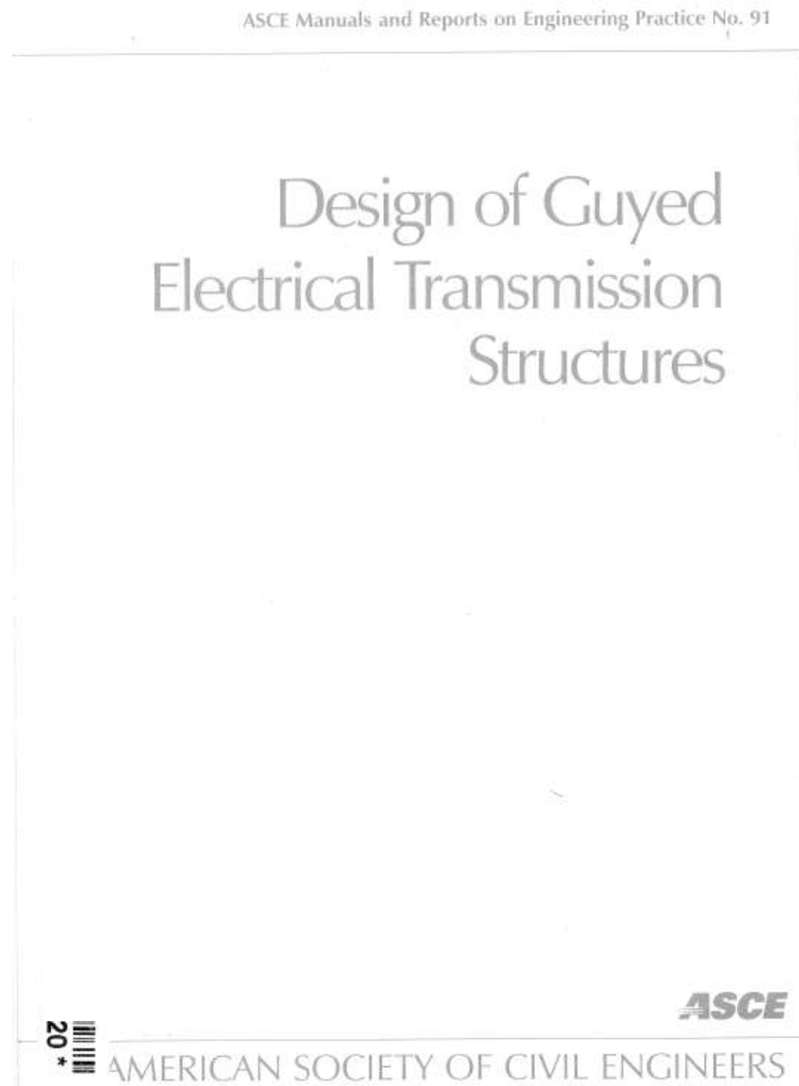
- Caltrans Falsework Manual
- Preloading is necessary to ensure that cable units will act elastically when load are applied.
- Remove any slack wire!
- Come-along, Jaw Turnbuckle

Why Pre-tension Guy Wires?

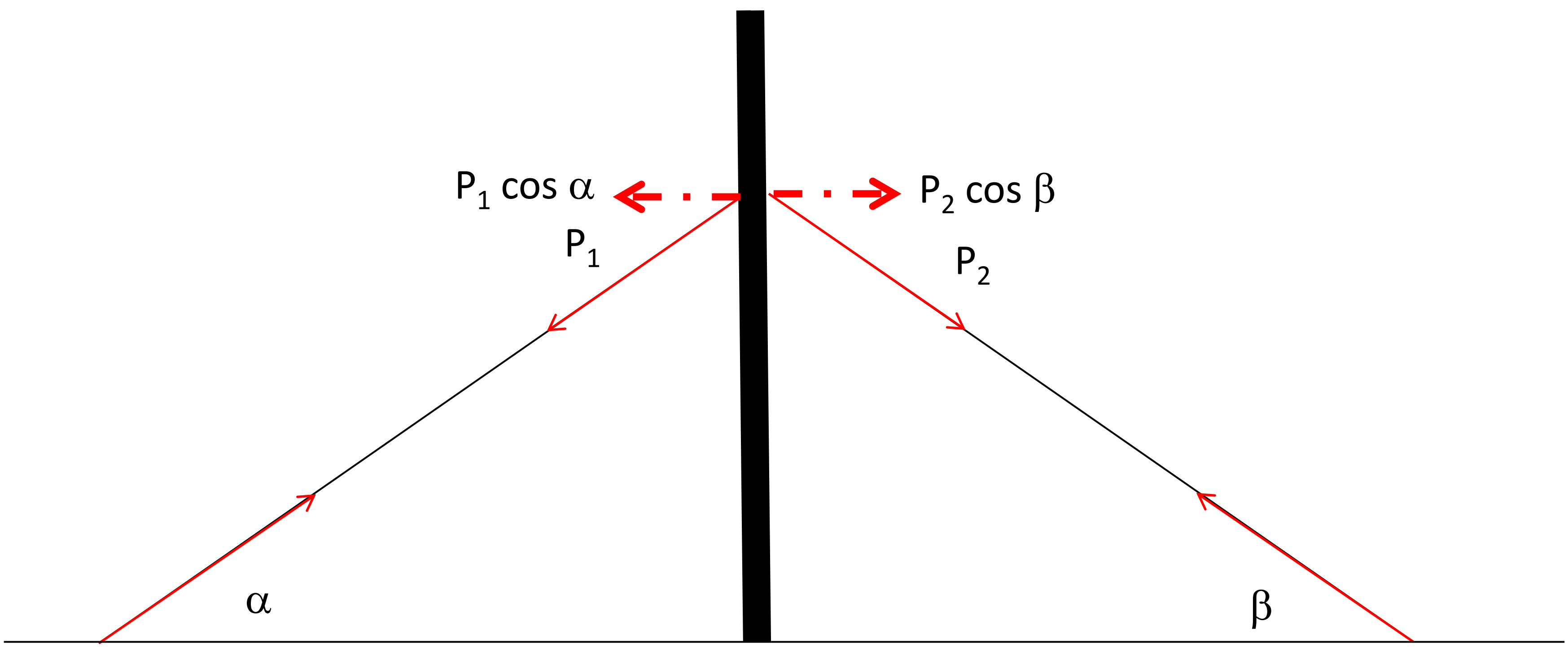
- Guyed Electrical Transmission Structures
- Pretensioned Wires
  - Wind Galloping Effect-Tension too low
  - Wind Aeolian Effect-Tension is too high

$$f = \frac{1}{2L}\sqrt{\frac{P}{m}}$$

  - Normally tensioned 10% of break strength
  - Example 3/8”-dia wire rop: P/T=1,500 lb



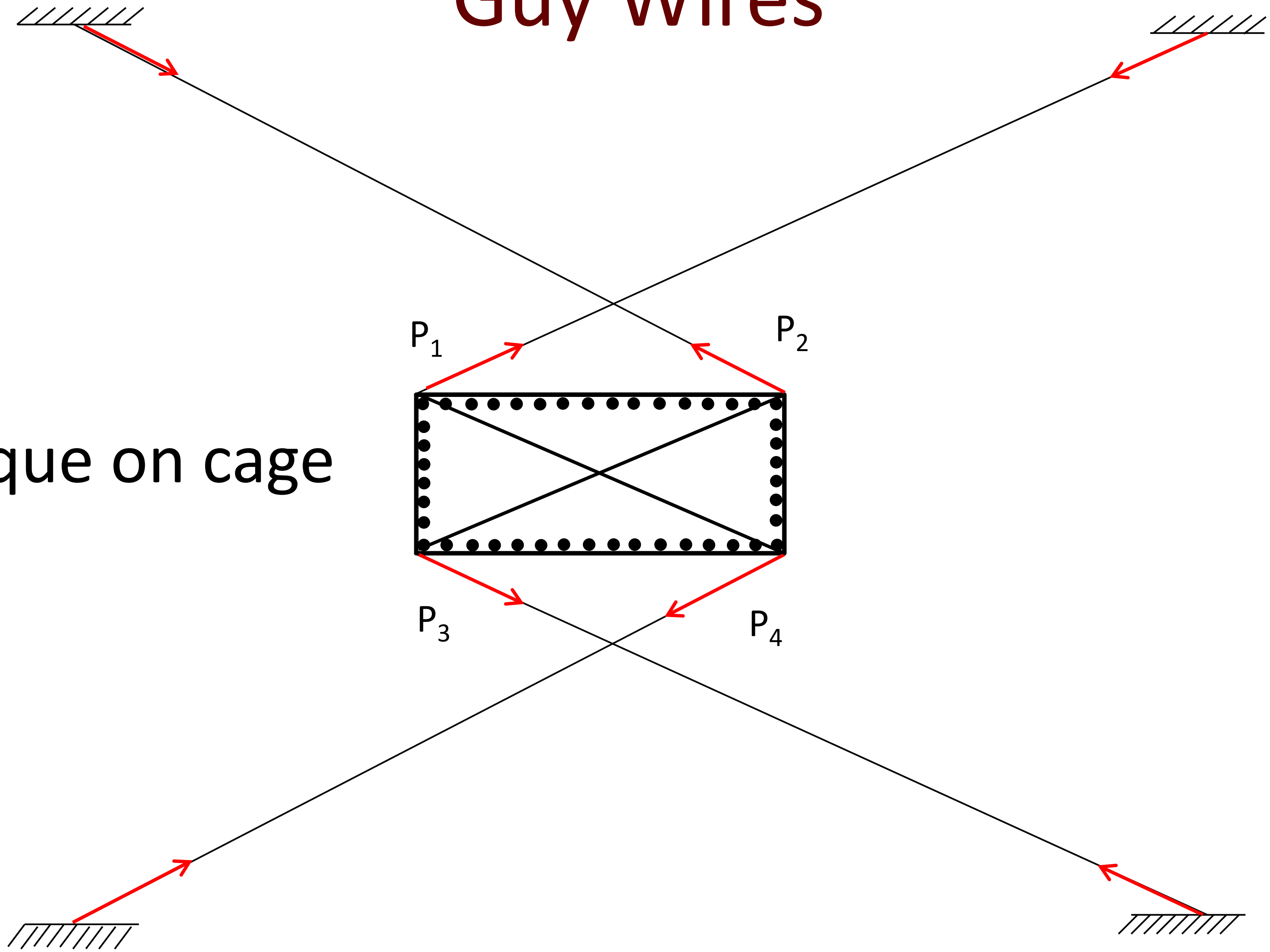
Unsymmetrical Guy Wire Pretensioned Forces



Lateral Load on Rebar Cage

Plan View of Cage and Different P/T of Guy Wires

Torque on cage



Needs for Guy Wire Plans

- Need to specify P/T force in the field.
- Need make sure that P/T forces are balanced.
- Net lateral force should be very small!
- Wire Tension Meter up to 10,000 lb

Common Practice in Analysis of Guyed Temporary Structures

- No National Standards
- California Bridge Contractors
  - Tributary area and statics to determine guy wire force for wind loads
  - CT min Wind Pressure from 20 psf up to 35 psf
- No Checks on other Loads!
- No checks on rebar cages!

CT Static Analysis for Guy Wire Design

$$\sum M_x = 0$$

$$F_{cx}(A_Z) - W(H/2) = 0$$

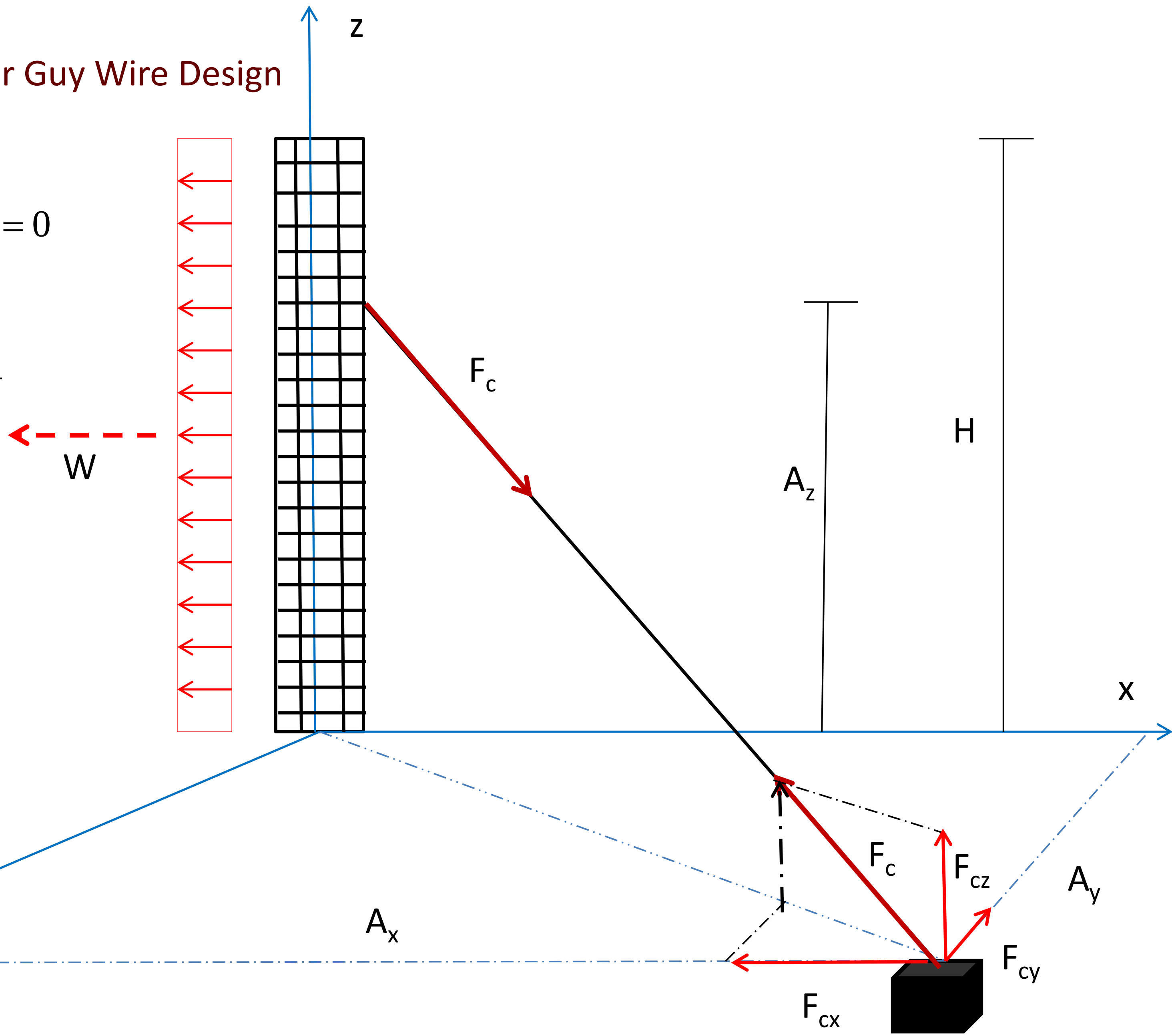
$$F_{cx} = \frac{WH}{2A_z}$$

$$A = \sqrt{A_x^2 + A_y^2 + A_z^2}$$

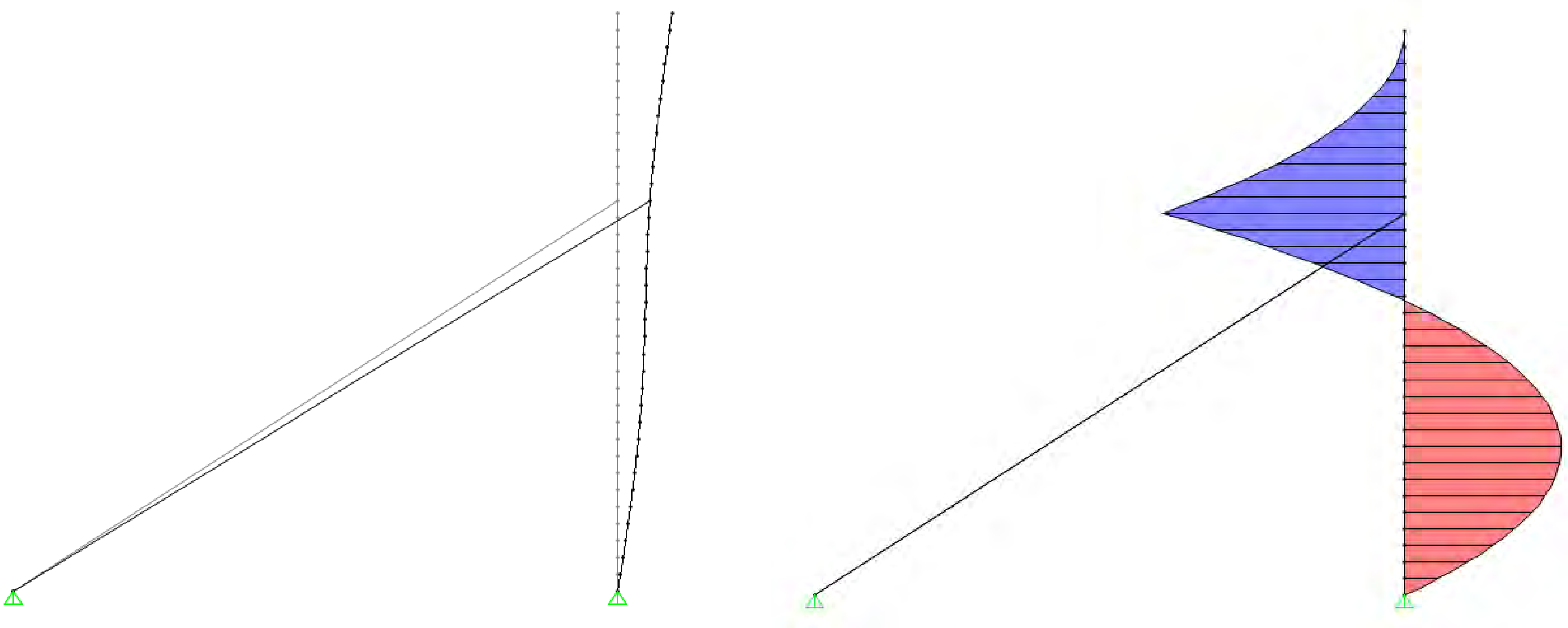
$$F_c = F_{cx}\frac{A}{A_x}$$

$$F_{cy} = F_c\frac{A_y}{A}$$

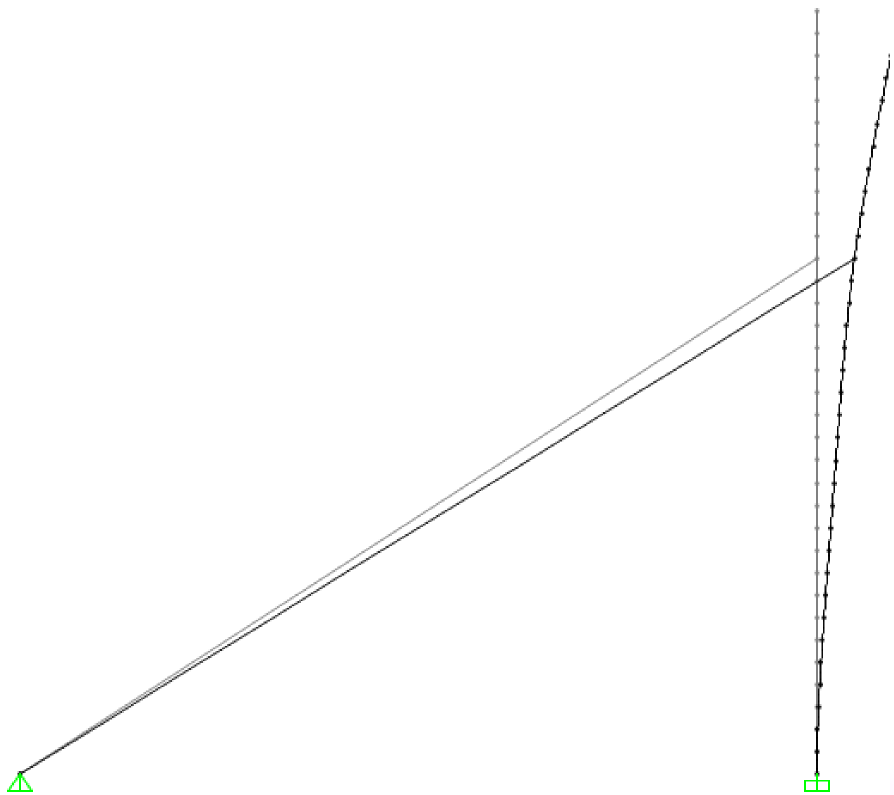
$$F_{cz} = F_c\frac{A_z}{A}$$

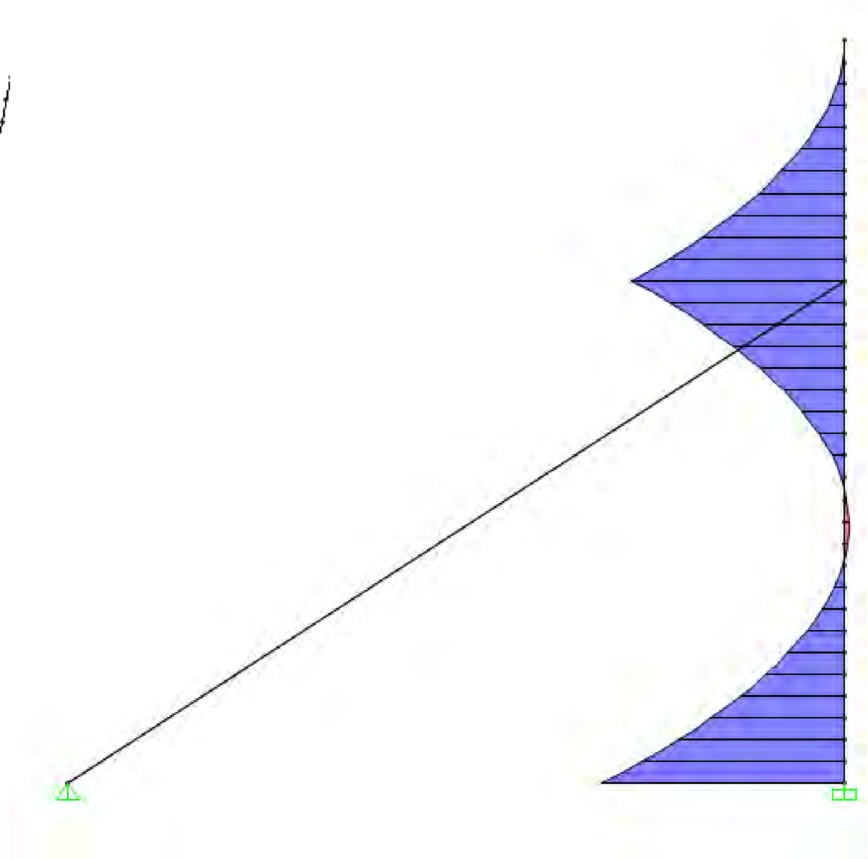


Analysis with Pin Base, Effect of Wire Flexibility and Cage Stiffness



Analysis with Fix Base, Effect of Wire Flexibility and Cage Stiffness



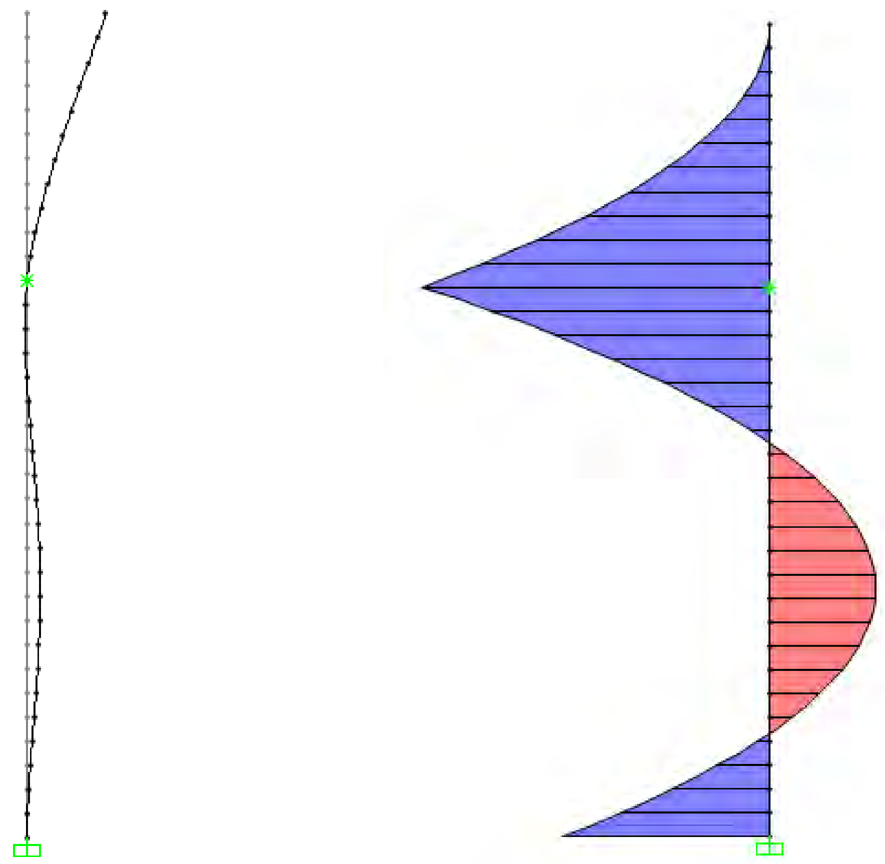


Other Bridge Contractors

- Use structural analysis with fixed base and rigid roller support at the guy wire location!

- ASCE 7 Wind Loading!

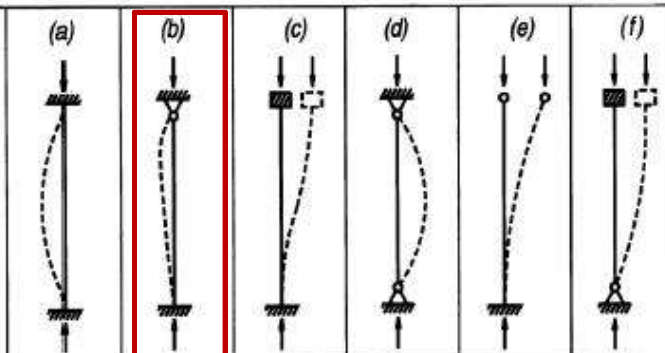
Analysis with Fixed Base and Rigid Roller Support



Effect of Guy Wires on Cage Stability

- Can guy wire enhance the stability of rebar cage by reducing the K?

Approximate Values of Effective Length Factor, K



Buckled shape of column is shown by dashed line.	(a)	(b)	(c)	(d)	(e)	(f)
Theoretical K value	0.5	0.7	1.0	1.0	2.0	2.0
Recommended design value when ideal conditions are approximated	0.65	0.80	1.2	1.0	2.10	2.0
End condition code	Rotation fixed and translation fixed Rotation free and translation fixed Rotation fixed and translation free Rotation free and translation free					

Stiffness Needed in Guy Wires
AISC Appendix 6

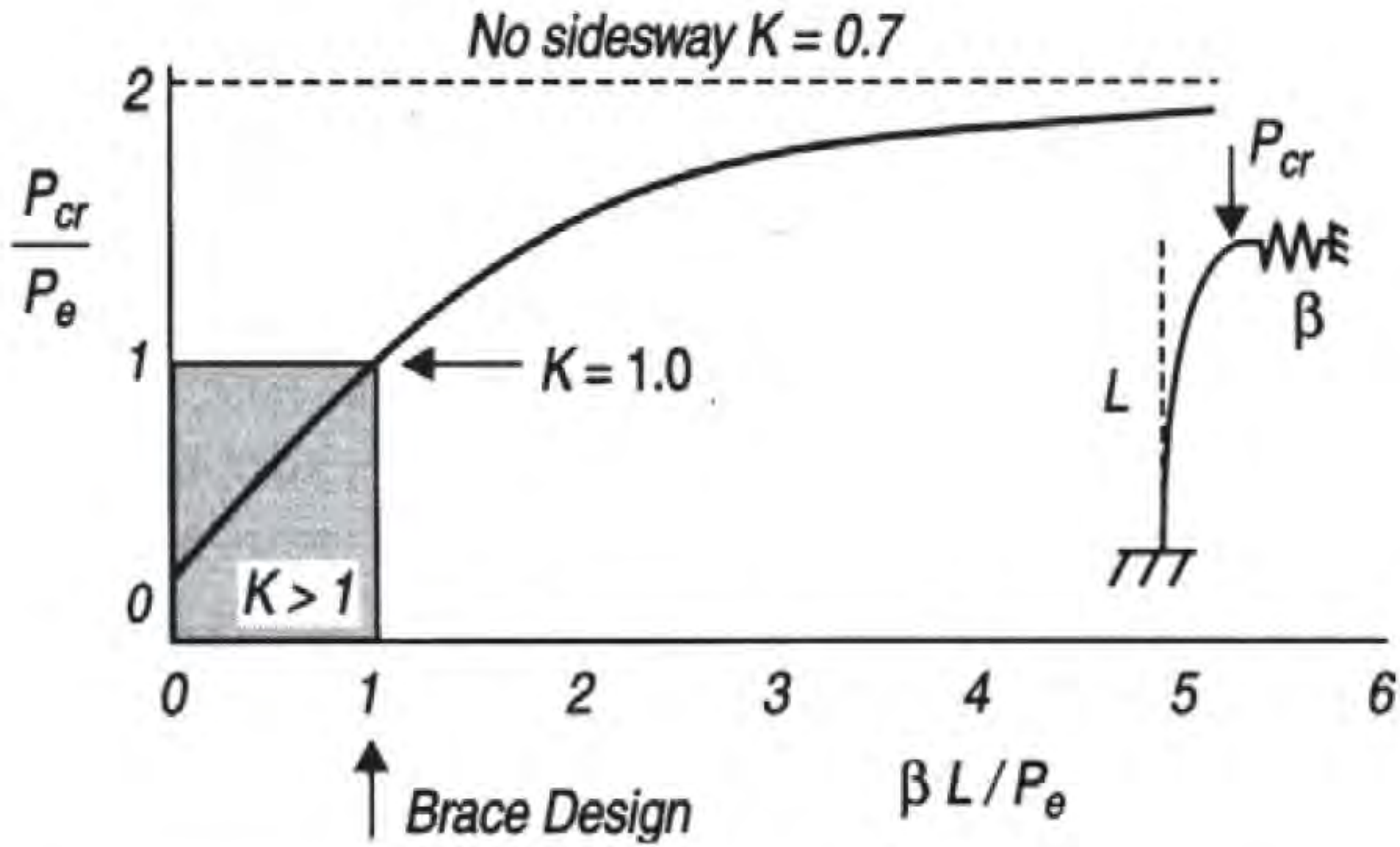


Fig. C-A-6.2. Cantilevered column with brace at top.

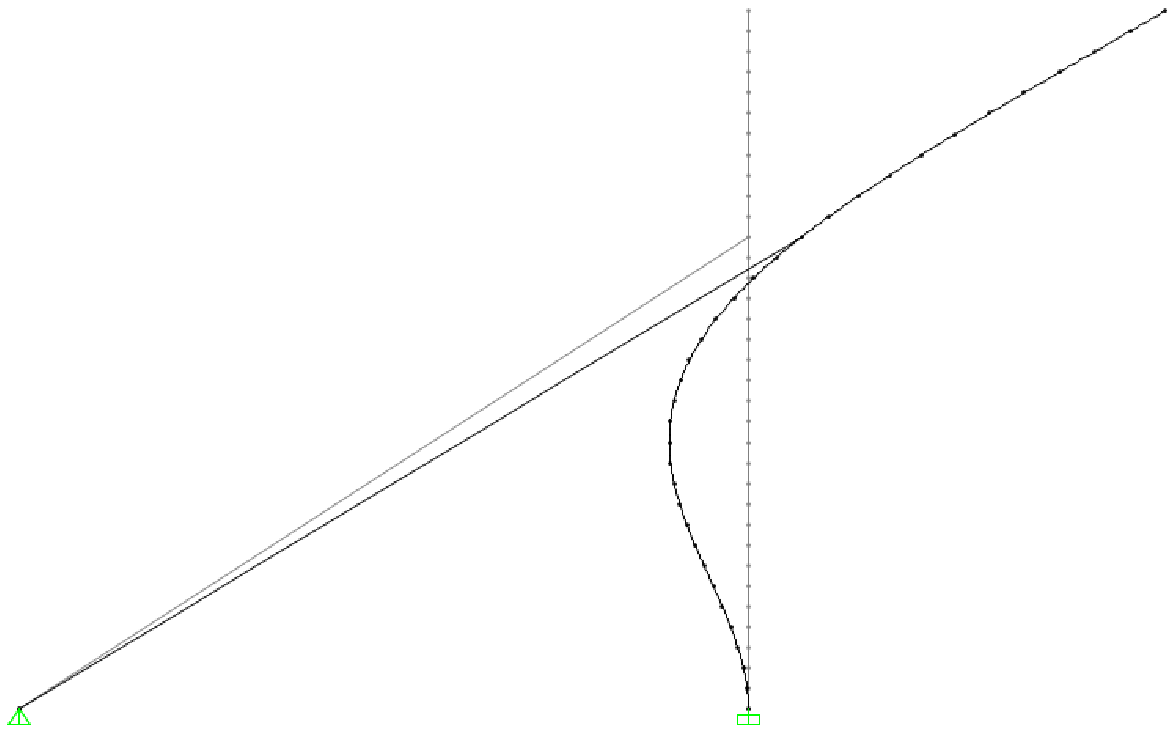
Required Stiffness in Guy Wires

- Required stiffness for guy wire at height h, and cage height L

$$K_s = 2P_{cr}\left(\frac{L}{h}\right)^3\left(\frac{1}{3L-2h}\right)$$

- Required lateral stiffness $K_s=(EA/L)\cos^2\alpha$ to be effective in cage stability

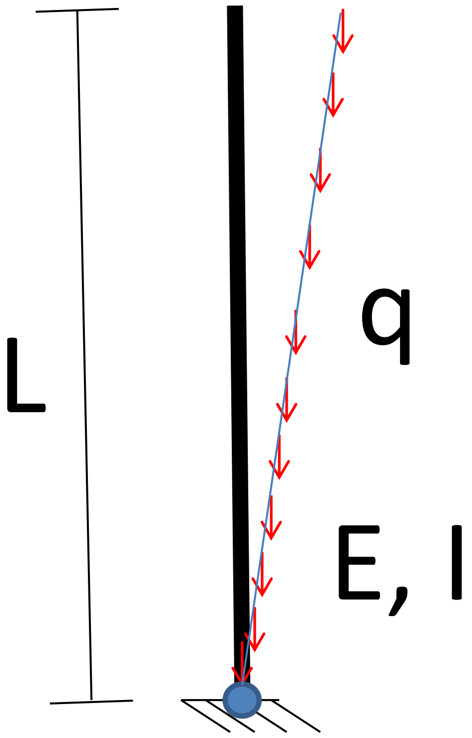
Buckled Mode Shape with Effective Guy Wire Stiffness



$$(qL)_{cr} = \frac{\pi^2 EI}{(1.0L)^2}$$

What about Pin Base or Lap Splice?

Buckling Load on Pin Base Column



$$(qL)_{cr} = \frac{\pi^2 EI}{(KL)^2}$$

K=?

Stability in Pined Base Rebar Cage with Effective Guy Wire Stiffness

- **VERY CRITICAL** and Potential of <u>**Collapse is HIGH**</u>
- Stability depends on:
  - Presence of internal braces
  - Guy wire stiffness
  - Strength of guy wire connections
- High uncertainties, use TWO CRANES operation
- Cage should be held at all times till it is secured inside column forms

Effect of Lap Splice in Rebar Cage

- For fixed column base with lap splice (dowels), still used in many parts of the US.
- Strength of the splice is the strength of the tie wire connections (number, type, workmanship)
- Splice will slip under construction load
- Treat rebar cage as PINNED Base!

Observations and Conclusions

- Rebar cages with no internal braces have low stiffness.
- Guy wires needed to be checked for stiffness in addition to strength
- Need to perform dead load and stability analysis in addition to wind analysis.
- Cage height and base boundary condition play a critical role in stability.

Rebar Cage Assembly

- Rebar Cage should have internal braces (X or square #8 or #11 bars)
- ‘Template Hoops’ and Pick-up bars tying is critical.
- Internal braces should be connected to ‘Pick-Up’ bars.
- Number of tying in field zone does <u>NOT</u> have significant effect on lateral stiffness and strength.

Proposed Specifications

- Tie wire connections shall use No. 15 gage, soft annealed black steel with min F_u=40 ksi.

- At least four vertical bars that form a square shall be tied at every intersection with at least double tie wire connections. The strength of these connections shall be adequate for cage pick-up.

- At a maximum of eight feet increments, template hoops shall be tied at every intersection with wrap-and-saddle tie wire connection.
- At least 25% of the remaining reinforcement intersection shall be tied with single tie wire connections. Ties shall be staggered from adjacent ties.
- At a maximum of alternating ten feet increments, internal braces with square configurations, min #8 bars, with interlocking hoops at the ends shall be provided and connected to the pick-up bars. These bracing shall be adequate for cage lift and transportation.

Needs to Mitigate Rebar Cage Failure

1. Develop guidelines and examples
   - Analysis and Design of rebar cages for gravity and lateral loading
   - One and multi-level guying

2. Understand the behavior of rebar cages during transporting and erecting.
   - Develop best practices

Transporting Rebar Cages

- Horizontal Pick
  - Location of Pick-up Points
  - Cage Bending
    - Type and number of internal braces
- Cage Tilt
  - Distribution of Pick Forces
  - Effect of Ground Contact
- Vertical Pick
  - Location of Pick Points
  - Distribution of Forces along Pick-up Bars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Concluding Remarks

- Structural failures are not just accidents.... They are the results of human error originating from lack of knowledge, no specifications and standards or oversight.

- Adequate analysis, design and construction will save larger costs in repair, schedule delays and litigation!

Project Team

Caltrans

- S. El-Azazy
- J. Drury
- A. Sehgal

University of Nevada, Reno

- A. Itani (PI)
- J. C. Builes

PCS PACIFIC COAST STEEL
In partnership with GERDAU AMERISTEEL

- H. Bennion
- M. Briggs
- K. Byrnes

SC Solutions

- H. Sedarat
- A. Krimotat

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- Steel Rebar Fabricators
  - Pacific Coast Steel (H. Bennion, M. Briggs and K. Byrnes)
  - Harris Rebar (L. Sieg)
- Contractors
  - CC Myers donated crane use for two days!
- CRSI
  - B. Hennings

Safety in Construction Temporary Reinforcing Structures

Vancouver March 27, 2012
Calgary March 28, 2012
Edmonton March 29, 2012

Lyle Sieg, P. Eng. Executive V.P. Safety, Harris Rebar

Dr. Ahmad Itani, Ph. D., SE, F. ASCE, Professor – University of Nevada

Location:

Iron Workers Union Training Center

3150 Bayshore Road

Benica, CA

94510

List of Speakers

Dr. Ahmad M. Itani, Ph.D. P.E.,S.E., F.ASCE
Michael J. Casey, Ph.D, P.E., George Mason University, ASCE's Construction Institute
Lyle Sieg, P. Eng, Executive Vice President of Safety, Harris Rebar
Robert D. Peterson, ESQ
Steve Rank, Director Western Region, Ironworkers IMPACT Group
Len Welsh, Chief Cal/OSHA

Invites Sent to:

AGC Members
CRSI Members
Reinforcing Subcontractors
Iron Worker Local
Engineering Students
Structural Engineers Association
Cal/OSHA Representatives
Insurance Companies

For Registration, visit www.crsi.org. Select **Robert Ceja Safety Training Seminar** under **Upcoming Events**.

If you have any questions regarding this program, contact Lyle Sieg, Harris Rebar at lsieg@harrisrebar.com or (925) 525-3621.

ASCE AMERICAN SOCIETY OF CIVIL ENGINEERS

CRSI

June 14th, 2011

Robert Ceja Memorial Reinforcing Seminar

Underwritten and Sponsored by:

HARRIS SALINAS REBAR, INC.

Safety in Construction:
Temporary Reinforcing Structure

Free Safety Seminar and Round Table Discussions*

Robert Ceja, a valued member of the Harris Salinas Rebar employee family, was fatally injured when a reinforced steel column, on which he was working, collapsed. Determined to help enhance safety and health awareness associated with construction of steel columns, we dedicate this safety seminar to Robert Ceja and his family.

In cooperation with the American Society of Civil Engineers, Harris Salinas Rebar, Inc. is sponsoring a panel of construction industry leaders, regulators, and academic experts to discuss the need ***for simple and practical*** guidelines on ***methods of analysis*** for erecting and placing reinforcement cages on construction sites. An ASCE Committee Report compiling best practices for consideration by the industry will be offered.

Please join Harris Salinas Rebar, the ASCE-CI, Concrete Reinforcing Steel Institute, Iron Workers IMPACT, Cal/OSHA and various company stakeholders to study, discuss and assist with the development for simple and practical guidelines on the methods to design, build and erect temporary reinforcing structures for all construction sites.

THIS SEMINAR IS OPEN AND FREE TO ATTENDEES

Agenda

8:00am-1:30pm

(Continental Breakfast Included)

Introduction

- Industry Concern (30 mins): Review of various reinforcing accidents in California involving failure of reinforcing structures (Presentation lead by Lyle Sieg, Harris Salinas Rebar with Steve Rank, Iron Worker IMPACT)
- Stability of Rebar cages during construction (45 mins) - Dr. Ahmad M. Itani

Session 2

- Cal/OSHA (30 mins) - Len Welsh
- Legal Responsibilities (30 mins) - Robert Peterson
- Break

Session 3

- Research in Safety Best Practices from designer to builder (30 mins) - Dr. Michael Casey
- Panel Discussion (60 mins) - What steps do we collectively take to ensure safety when working with these structures? Question Period
- Lunch

Robert Ceja

Hazards are out there!

CRSI

Robert Ceja – 2007 Fatality

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THIS IS WHY YOU DON'T TAKE DOWN THE GUY LINES!!!!!!

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What do we do from here as Industry Members?

- Continue this type of education
- Applying this knowledge to all aspects of cage construction
- Clearly establish who has custody of care
- Proper planning of procedures and putting them in writing to ensure good communication through out the process
- Support further research and forums to share lessons learned

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Labor & Management Responsibilities

- Shared responsibility for zero fatalities and injuries
- Ensure contract language addresses the best practices and steps required for safe erection
- Get engaged with IMPACT and CRSI Safety Committee work
- Get your local stakeholders together to talk about these issues
- Support the current Reinforcing OSHA Subpart negotiations and rulemaking or public comment

Industry Coalition of Stakeholders

- Iron Workers International
- Department of Reinforcing Ironworkers Advisory Committee
- IMPACT
- Concrete Reinforcing Steel Institute
- Post Tensioning Institute
- National Association of Reinforcing Steel Contractors
- The Center for Construction Research and Training
- Western Steel Council

Specific Requirements for Vertical & Horizontal Column Stability

1926.700??

1. All vertical and horizontal columns shall be guyed, shored, or supported to prevent collapse.
2. The installation and removal of guying, bracing, and shoring shall be under the supervision of a competent and qualified person.

Specific Requirements to Prevent Column Collapse

Requirements to Prevent Collapse of Horizontal Columns

CRSI

Why we work safely!