Reinforcing Assembly Best Practices

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Learning Objectives

- Explain the fundamental properties of concrete and why reinforcing is necessary.
- Identify different types of reinforcing materials and their ASTM Standards.
- Apply fabrication and placement tolerances to reinforcing assemblies.
- Predict how improper placement of reinforcement impacts the strength of the final product.

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Overview

- Purpose of Reinforcement
- Types and Identification
- Positioning and Spacing
- Cage Fabrication
- Do's and Don'ts
- QC Certification Program Requirements

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Overview

- **Purpose of Reinforcement**
- Types and Identification
- Positioning and Spacing
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- QC Certification Program Requirements

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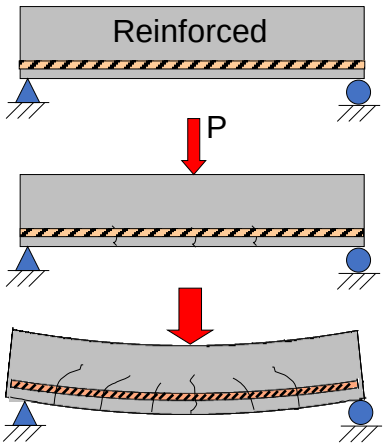
Purpose of Reinforcement



Reinforcement must be added wherever concrete is in **tension**.

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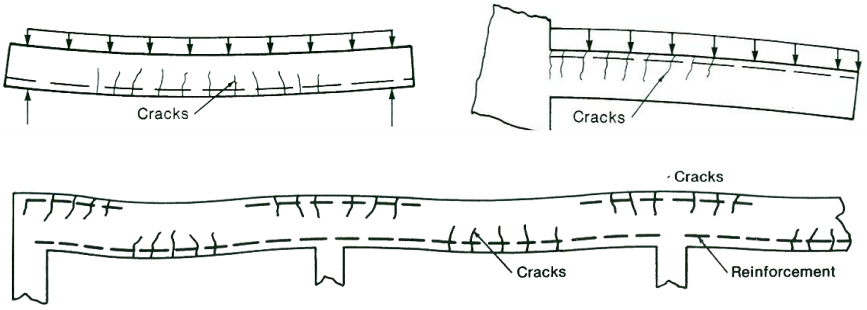
Purpose of Reinforcement

Where to place reinforcement?

Anywhere that concrete might be in tension:

Tensile fibers in flexure

Tension can be at top, bottom, or both



J.G. MacGregor, Reinforced Concrete © 1997, Prentice Hall

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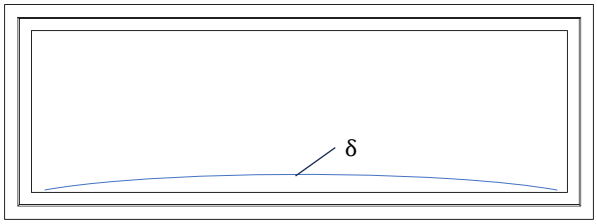
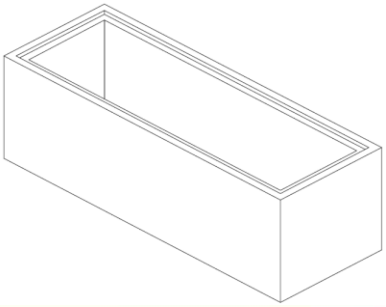
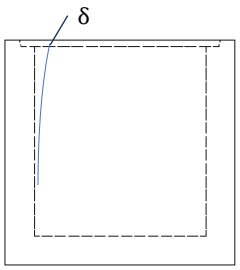
Purpose of Reinforcement





5-Sided Bases:
Slabs and Walls

- Horizontal stress
  vs.
  Vertical stress



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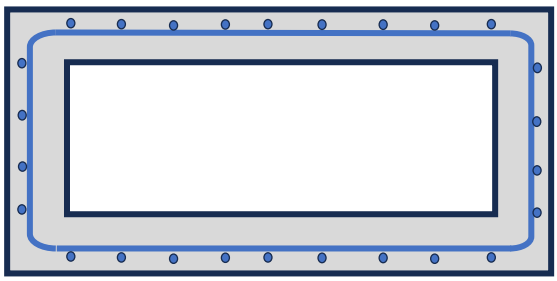
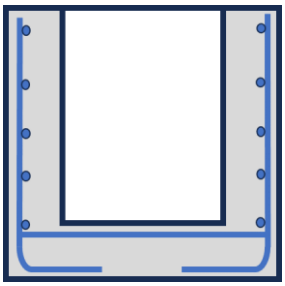
Purpose of Reinforcement

Example of reinforcing placement in 5-sided sections

- Monolithic “clamshell” tops
- Bases



Plan View



Elevation

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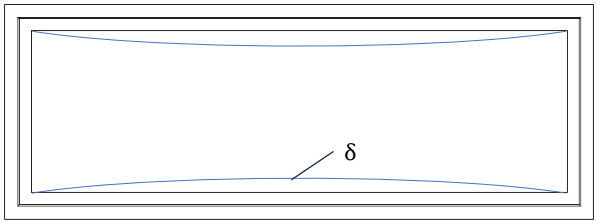
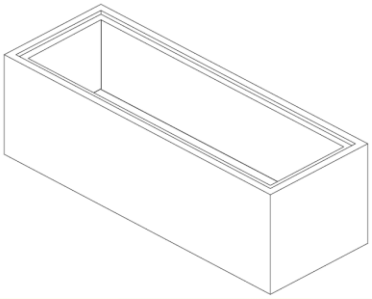
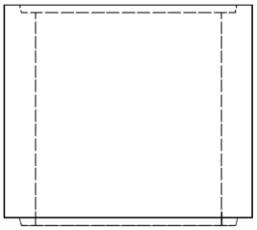
Purpose of Reinforcement



Extensions / Risers

- No integral slabs to control deflections





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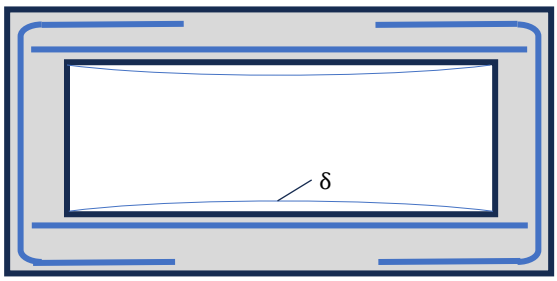
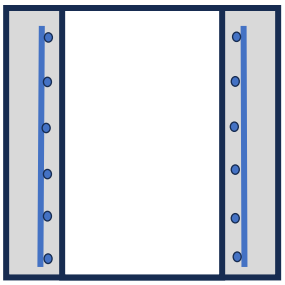
Purpose of Reinforcement

Example of reinforcing placement in 4-sided sections

- Risers / Extensions



Plan View



Elevation

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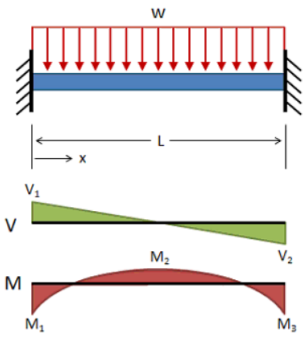
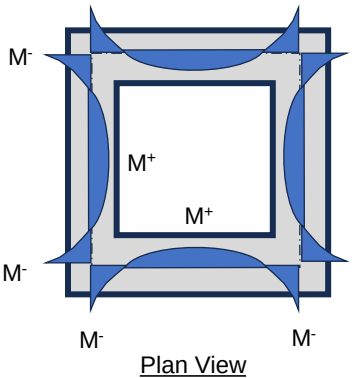
Purpose of Reinforcement

How stresses are manifest in square/rectangular structures

- Moment transfer – square shapes



Uniform Load

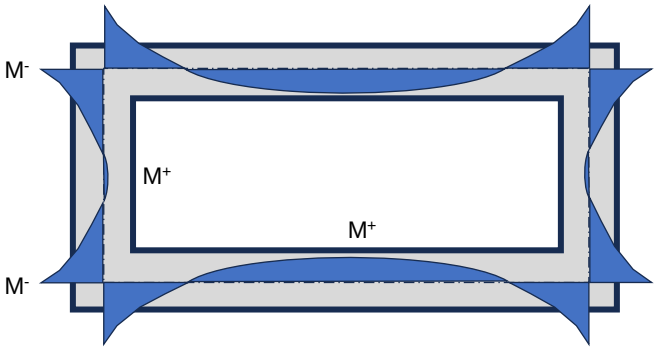


Plan View

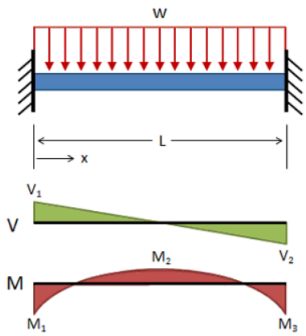
Purpose of Reinforcement

Continuous reinforcing in corners

- Moment transfer – rectangular shapes



Plan View

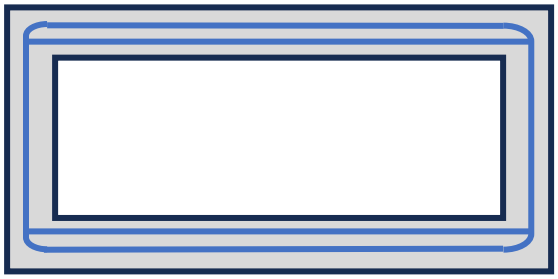


Fixed end support

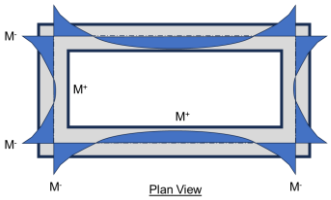
Purpose of Reinforcement

Continuous reinforcing in corners – Moment transfer

- Reinforcing placement example



Plan View



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Purpose of Reinforcement

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Purpose of Reinforcement

- Round manholes
  - Bases
  - Risers

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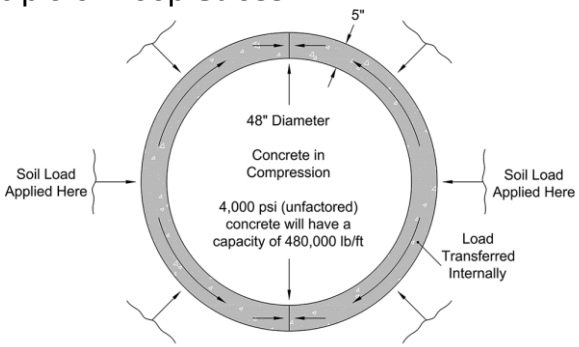
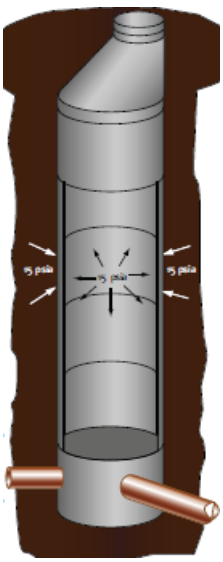
Purpose of Reinforcement

- Round manholes
  - Principle of Hoop Stress





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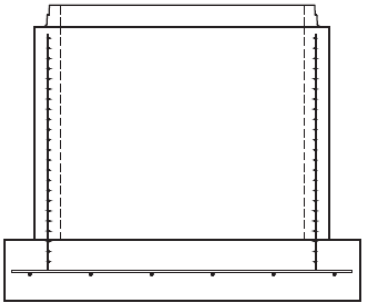
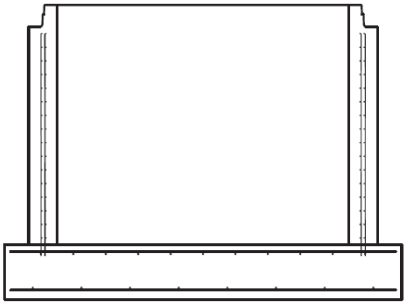
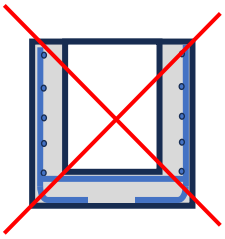
Purpose of Reinforcement

- Round manholes
  - Base slab design







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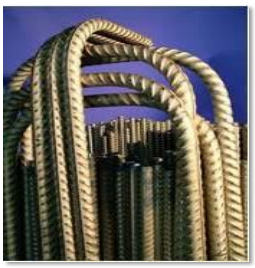
Types and Identification

- Steel Bars
- Steel Wires
- Bar Mats and Welded Wire Reinforcement (WWR)
- Coated Steel Bars
- Other reinforcement (Fiberglass, Basalt, etc.)



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Reinforcing Steel Bars (Rebar)

- Hot rolled carbon-steel bars
- Plain or Deformed (surface lugs)
  - Deformed bars provide better bonding
- Cylindrical (square bars are mostly obsolete)
- Bar number in US units (up to #8):
  - Ex.: #3 means 3/8” diameter bar

surface area = $\left(\frac{\pi}{4}\right)\left(\frac{3}{8}\right)^2 = 0.11$ in^2

- Available in #3 to #11, also #14 and #18

Photo: istockphoto

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ASTM Standards for Steel Bars

- Gradation based on ASTM Standards (controls strength, ductility, and chemical composition of steel bars):
  - ASTM A615: General purpose carbon-steel bars for concrete reinforcement (most common)
  - ASTM A706: Low-alloy steel bars (special chemical composition to allow proper weld-ability and extra ductility)
  - ASTM A775 and A934: Epoxy-coated
  - ASTM A767: Galvanized (no ASTM standard for zinc-plated)
  - ASTM D7957: GFRP Bars (non-metallic glass fiber reinforced polymer)

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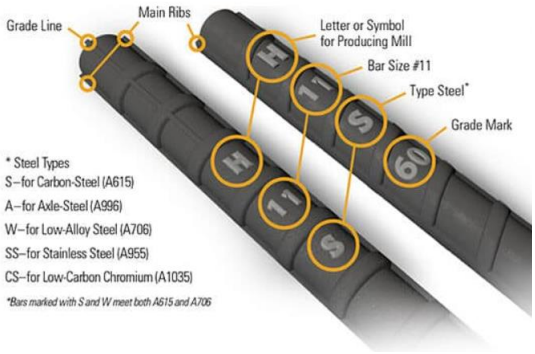
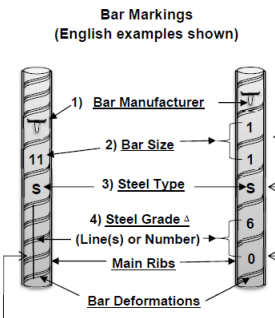
Reinforcing Steel Bars (Rebar)

- Identification marks





Bar Size		
English Bar Size	Metric Equivalent Bar Size	Diameter (in.)
3	10	0.375
4	13	0.500
5	16	0.625
6	19	0.750
7	22	0.875
8	25	1.000
9	29	1.128
10	32	1.270
11	36	1.410
14	43	1.693
18	57	2.257

Steel Type	
S	A 615
W	A 706 (Weldable)
A	A 996, Type A (Axle)
R	A 996, Type R (Rail)

Note: May show "S" and "W" if bar is produced to meet both ASTM A615 & A706.

Steel Grade - Line(s) Δ			
English		Metric Equivalent	
Grade	# of Line(s)	Grade	# of Line(s)
40	(no lines)	280	(no lines)
60	1 line	420	1 line
75	2 lines	520	2 lines
80	3 lines	550	3 lines

Steel Grade - Number Δ			
English		Metric Equivalent	
40	(none req.)	280	(none req.)
60	60	420	4
75	75	520	5
80	80	550	6

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Steel Wires

- Cold drawn cylindrical wires
- Produced according to ASTM A1064
- Usually uncoated but can be galvanized (ASTM A1094)
- Used for fabrication of WWR
- Minimum yield strength: 70 ksi

TABLE 4 Tension Test Requirements (Material for Welded Wire Reinforcement)

	MPa [psi] min
Tensile strength	550 [80 000]
Yield strength	485 [70 000]

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Bar Mats and Welded Wire Reinforcement (WWR)

- Mesh consist of Smooth (W) or Deformed (D) wires
- Welded Wire Reinforcement (WWR) produced according to ASTM A1064 (plain and deformed)
- ASTM A884 for epoxy-coated
- ASTM A184 for bar mats
- Can be purchased in rolls or sheets
- Desirable when regular reinforcement patterns are needed
- Reduces time for building reinforcement mesh

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Welded Wire Reinforcement (WWR)

- Tips for using WWR
  - Larger quantities most cost-effective
  - Combine designs as much as possible
  - Cost killers:
    - Small orders
    - Pre-bent sheets
    - Variabilities in sheets

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GFRP Reinforcing

- ACI Code 440.11-22 – Design
- ACU Spec 440.5 - Construction
- Applications
  - Concrete exposed to deicing chemicals
  - Marine environments
  - Conductive environments
    - High voltage conduits
    - MRI rooms in hospitals
  - Lightweight

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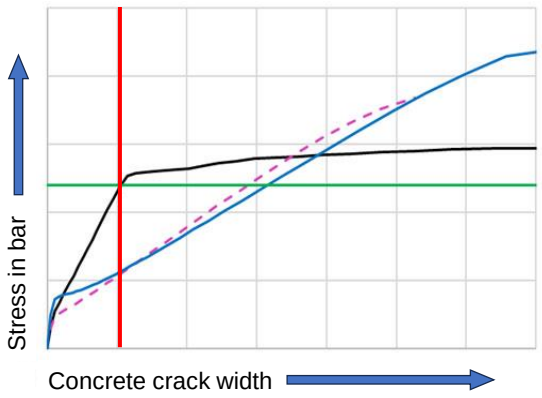
GFRP Reinforcing

- GFRP rebar
  - Although GFRP may have a higher strength than steel, serviceability considerations usually govern the design
  - Can be cut, but not bent
  - Anisotropic behavior (composite strength, depends on axis through which force is applied)



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Fiber Reinforcement

- ASTM A820, C1116
- Most Significant Properties
  - Geometry (anchorage)
  - Aspect ratio
  - Material type
  - Tensile strength
  - Elastic modulus
- Typical uses
  - Crack control
  - Impact resistance
  - Some steel replacement

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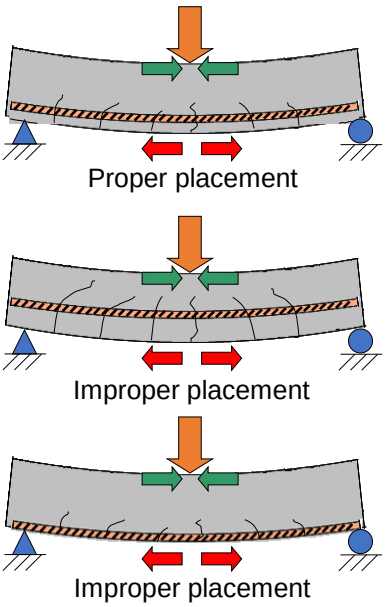
Positioning & Spacing: Concrete Cover

- Reinforcement must be placed close to concrete surface to arrest the cracks and to increase strength of the concrete member
- **However**, a minimum cover is needed to ensure bond between concrete and steel and to protect steel against corrosion



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Positioning and Spacing

Concrete Cover: Why does it vary?

- Exposure to earth, weather, deicing salts and/or effluent (sewage), size of reinforcing bars, design codes, etc.
- ACI 318 Building Code: Depends on exposure and product
- ACI 350 Environmental Structures Code: 1-½” min.
- ASTM: 1” minimum for precast
- AASHTO: Depends on exposure and product

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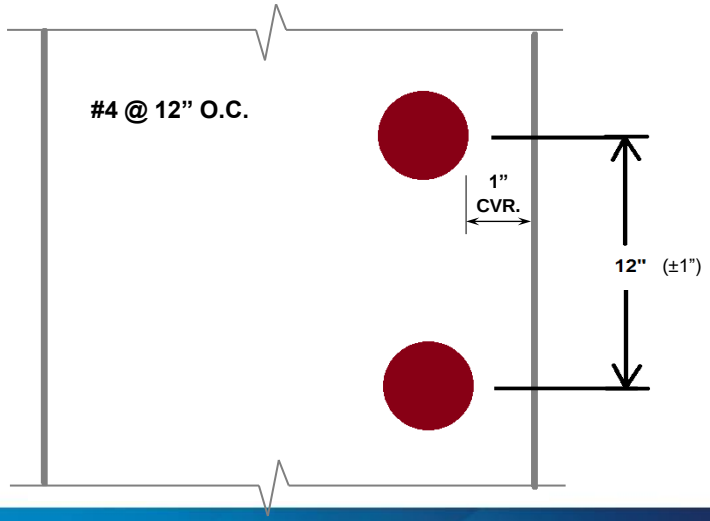
Positioning and Spacing

- Spacing
  - Placement tolerance: ±½” *
  - Spacing tolerance: ±1”
- Clearance
  - ±1/3rd of nominal, ±½” Max. *



* NPCA QC Manual Section 4.3.3

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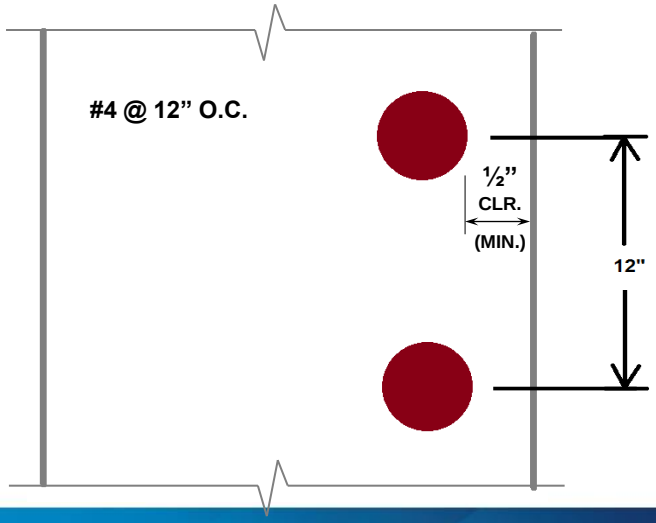
Positioning and Spacing

- Spacing
  - Placement tolerance: ±½" *
  - Spacing tolerance: ±1"
- Clearance
  - ±1/3rd of nominal, ±½" Max. *
  - ½" CLR. (Min.) *



* NPCA QC Manual Section 4.3.3

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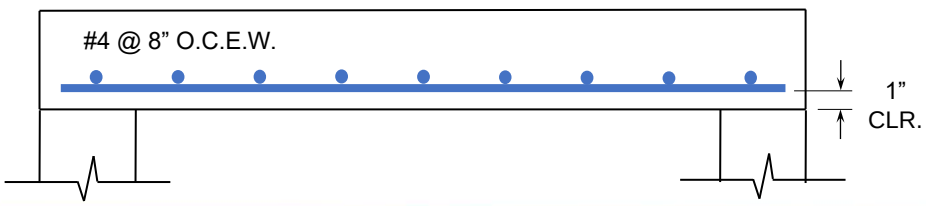
Positioning and Spacing

- Importance of proper reinforcing clearance



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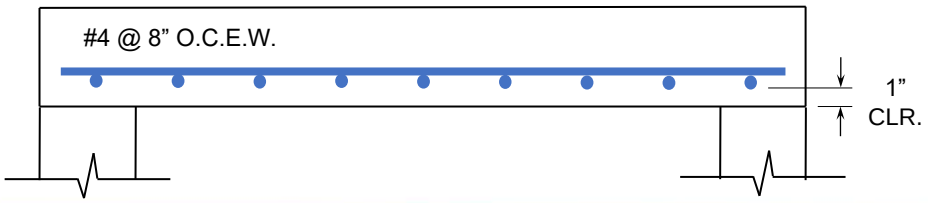
Positioning and Spacing

- Importance of proper reinforcing clearance
  - Transposing the reinforcing layers could result in a 15% to 35% decrease in load capacity



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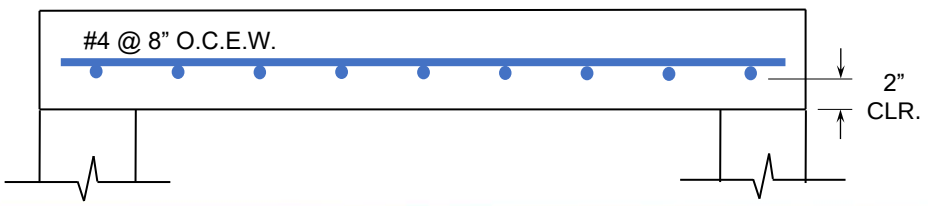
Positioning and Spacing

- Importance of proper reinforcing clearance
  - Transposing the reinforcing layers could result in a 15% to 35% decrease in load capacity
  - An increase in cover of 1" could result in a decrease in capacity of 25% to more than 50%
  - Total reduction in capacity of <u>40% to 70% or more!</u>



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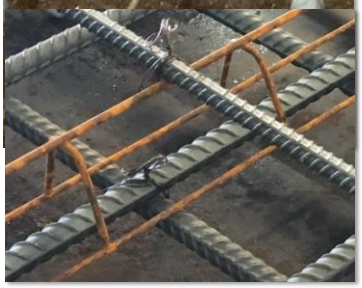
Positioning and Spacing

- Concrete Cover
  - Chairs and stand-offs, sufficiently and properly spaced
    - Bar chairs
    - Support wheels
    - Slab bolsters
  - Max. spacing 48”
    - Maintain consistent cover throughout length of bar
    - Bar should not flex between supports
  - Cage should not move or shift



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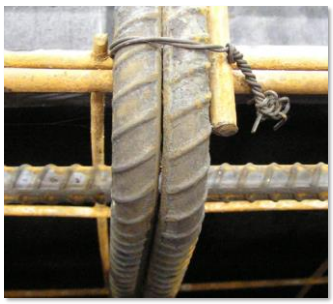
Cage Fabrication

- Spacing
  - Minimum: 0” -or- 1.33 * max. aggregate size
  - Maximum: Per design code; generally 18”
  - Bundling OK but requires addtl. design considerations



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Positioning and Spacing

- Bar Size vs. Steel Area
  - Bar number (#3 thru #8)
    - Diameter in 8ths of an inch
    - Example: #4 rebar = 4/8 inches dia. = ½" dia. (ø0.5")
  - A_s = Area of Steel
    - Cross-sectional area (end area) of bar
  - Area of steel computations are typically specified per lineal foot.

Bar Size	Diameter (in)	A_s (in^2)
3	.375	.11
4	.500	.20
5	.625	.31
6	.750	.44
7	.875	.60
8	1.00	.79
9	1.128	1.00
10	1.270	1.27
11	1.410	1.56

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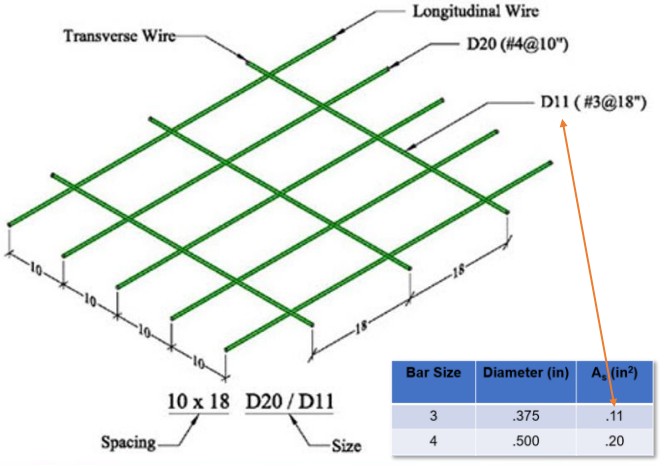
Positioning and Spacing

- WWR (Welded Wire Reinforcement)
  - "D" or "W" numbers vs. diameter and area
  - Longitudinal vs. Transverse size and spacing
  - Clear cover typically referencing the Longitudinal or primary wire
  - In pipe practice:
    - Longitudinal = Circumferential
    - Transverse = Longitudinal



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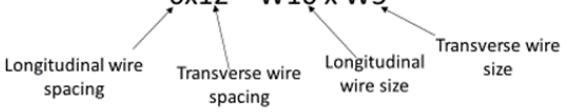
Positioning and Spacing

Method of Welded Wire Reinforcement Style

- Example of Industry Method of Designating Style:

6x12 – W10 x W5



Size of steel = area in square inch x 100

W10 = 0.10 Sq. In. W5 = 0.05 Sq. In.

Sectional Areas of Welded Wire Fabric

Wire Size Number		Diameter,	Weight,	A - Sq. In. Per Lin. Ft.						
Smooth	Deformed	Inches	Lbs./Lin.Ft.	2"	3"	4"	6"	8"	10"	12"
W10	D10	0.357	0.340	0.60	0.40	0.30	0.20	0.15	0.12	0.10
W6.5	D6.5	0.288	0.221	0.39	0.26	0.20	0.13	0.10	0.08	0.07
W5	D5	0.252	0.170	0.30	0.20	0.15	0.10	0.08	0.06	0.05
W3	D3	0.195	0..102	0.18	0.12	0.09	0.06	0.05	0.04	0.03

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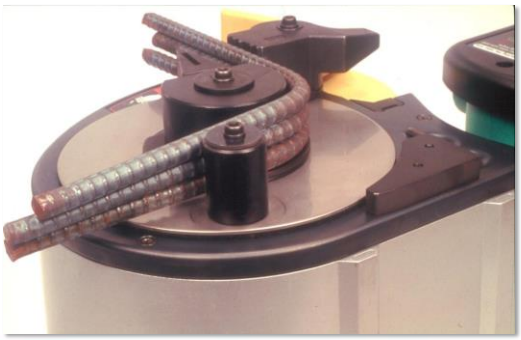
Reinforcement Bends

- Rebar Detailing



Source: Concrete Reinforcing Steel Institute - CRSI

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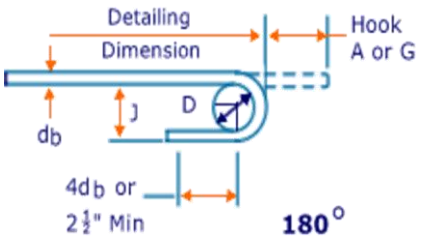
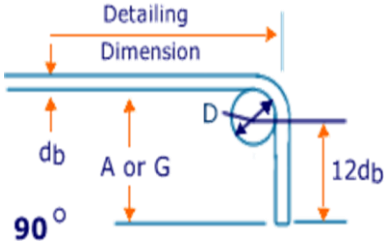
Reinforcement Bends

TABLE 7.2 — MINIMUM DIAMETERS OF BEND

Bar size	Minimum diameter
No. 3 through No. 8	$6d_b$
No. 9, No. 10, and No. 11	$8d_b$
No. 14 and No. 18	$10d_b$





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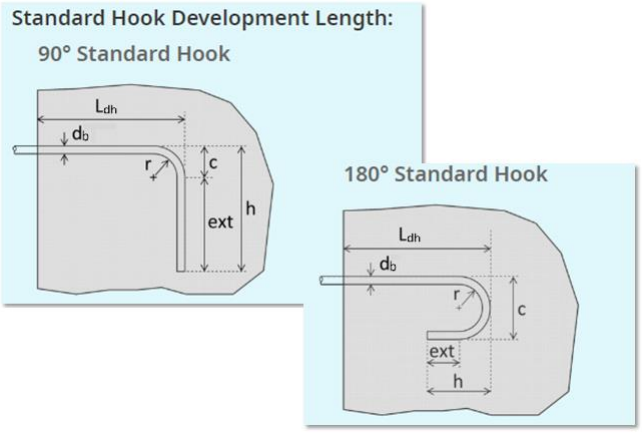
Reinforcement Bends

- Rebar Detailing
  - Cut / bend length
    - Measured to outside of bend, **not** center of bar
  - Bend radius / diameter
    - CRSI Manual of Practice
  - Cut-off length or Extension length



Source: Concrete Reinforcing Steel Institute - CRSI

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Reinforcement Bends

For WWR:

- 4x wire diameter (d_b) for deformed wires larger than D6
- 2x wire diameter (d_b) for all other wires
- Bends with inside diameter less than $8d_b$ must not be less than $4d_b$ from nearest welded intersection

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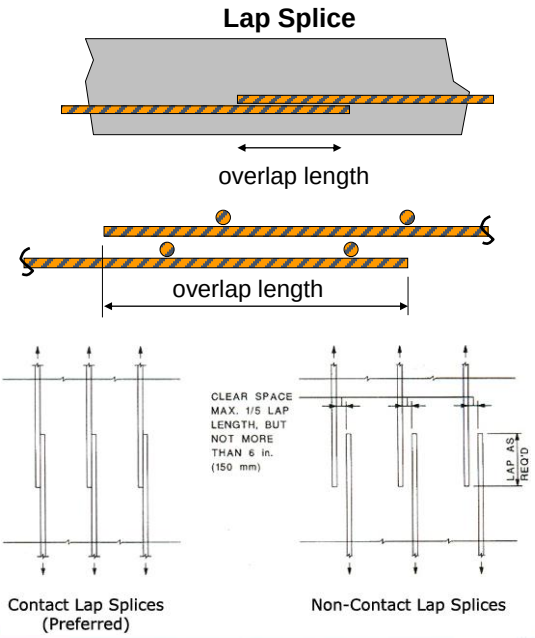
Cage Fabrication

- Splices
  - Length depends on many factors (governing design code, concrete strength, size, grade, spacing, concrete cover)
  - Generally not less than 12” in any case
  - Contact Lap Splice
    vs.
    Non-Contact Lap Splice
    - Bond
    - Double-shear



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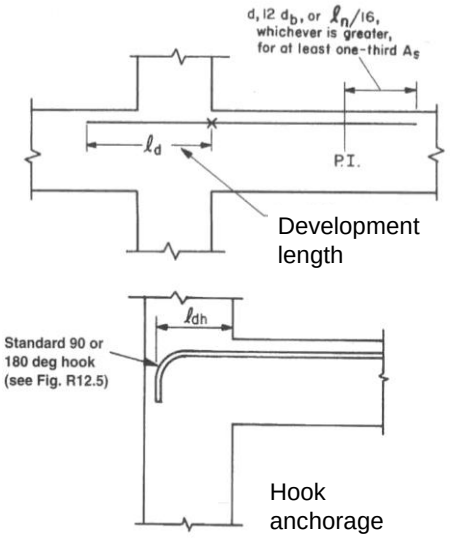
Cage Fabrication

- Development Length
  - To prevent the pull-out of reinforcement (specially for plain bars and wires), anchorage of steel bar may be required
  - This must be determined by engineer who must also design the details of anchorage:
    - Development length
    - Geometry of hooks
    - Mechanical anchorage



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Cage Fabrication

What About Welding?

- NPCA QC Manual, Section 4.2.2: "…*used for structural purposes* may be welded <u>as long as it is accomplished…[per] AWS D1.4</u>…"

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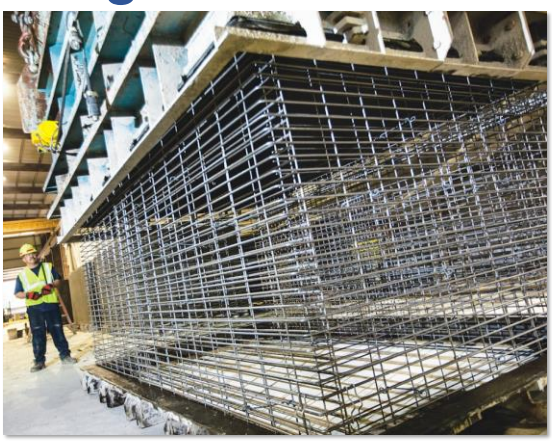
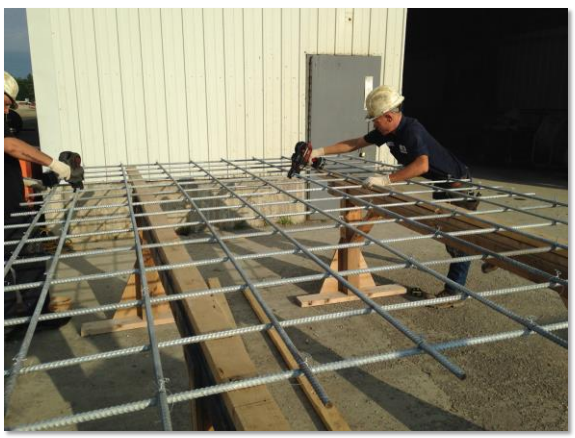
Cage Fabrication



Welded Wire Reinforcement



Tied Reinforcing Steel (rebar)

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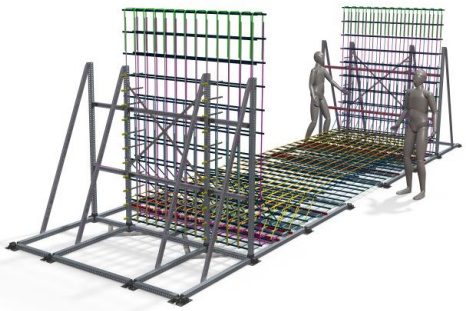
Cage Fabrication

- Set Up – Jigs
  - Ideal for consistency



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Cage Fabrication

- Set Up – Freehand
  - Tried and true
  - More time required
  - Relies *heavily* on skilled labor force
  - Vitally important for ***all*** of the crew to know the “why’s” of proper steel placement

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Cage Fabrication

Things that make your QC Manager like his/her job:

- Secure from movement; excellent use of chairs on bottom and sides
- Lifters, other inserts & embeds securely tied in
- Every other intersection tied
- Minimal oxidation on rebar
- Rebar is dry; no form release
- Could use more attention to placement of the diagonal bars, but otherwise, great job!

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Cage Fabrication

Reinforcement: Precast Learning Lab
https://www.youtube.com/playlist?list=PL2iDpO3EO42p6gs9PJz97kwsT6ZYYLhQ6

- Precast Learning Lab: Form Oil Application
  https://youtu.be/eRU7vdq_hM0?si=ppAMaNEy1RnNgehR
- Precast Learning Lab: Reinforcement Fabrication
  https://youtu.be/yUlPEryelMA?si=bYINL7y9LuCvMqM9
- Precast Learning Lab: Reinforcement Inspection
  https://youtu.be/GNlwUeflfD4?si=WOrqeoNN2XIfgCCj

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Cage Fabrication

Area of Steel

Can you have too little reinforcing?

Yes

Can you have too much reinforcing?

Yes!

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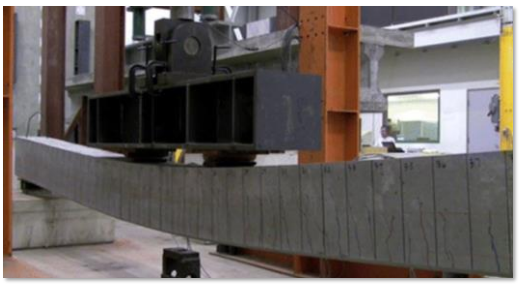
Cage Fabrication

Steel reaches its strength limit before concrete crushes

- Called a tension controlled ("**under reinforced**") section
- Crack widths will be quite large
- Steel reinforcement will yield and not return to original shape
- Failure can be seen as very large crack widths



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Cage Fabrication

Concrete crushes before steel has reached its strength limit

- This is called compression controlled ("**over reinforced**").
- Too much steel and the precast concrete fails in compression
- Crushing – non-ductile
- NO WARNING OF FAILURE

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Overview

- Purpose of Reinforcement
- Types and Identification
- Positioning and Spacing
- Cage Fabrication
- **Do's and Don'ts**
- QC Certification Program Requirements

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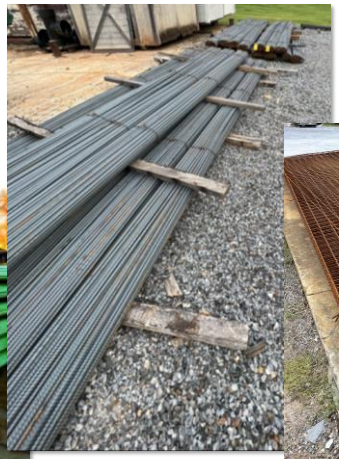
Do's and Don'ts

- Reinforcing storage



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Do's and Don'ts

- Reinforcing storage
  - Please don't!

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Do's and Don'ts

- Reinforcing condition (oxidation, rust)

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Do's and Don'ts

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Do's and Don'ts

- How many problems do you see?

This is a good practice; reinforces the joint as well as provides tie points for straight bars

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Concrete Cover

- No chairs used
- There is no concrete cover to the inside core

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Do's and Don'ts

- Improper use of chairs

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Concrete Cover

Improper use of chairs:

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Do's and Don'ts

- Reinforcing congestion causing concrete blockage during pouring

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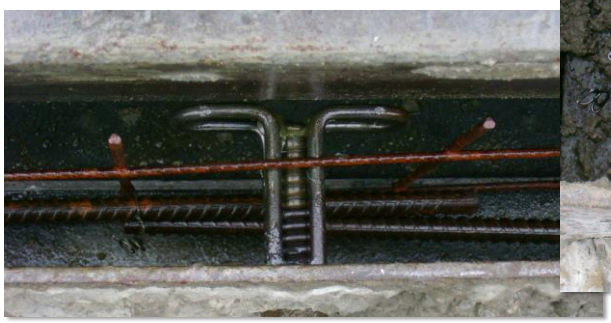
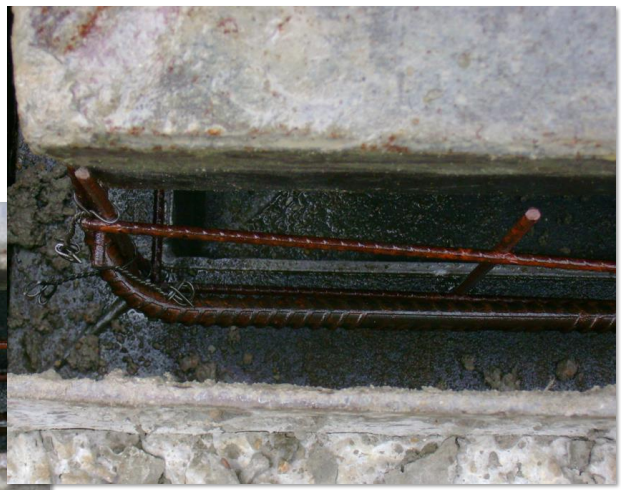
Do's and Don'ts

- Form release on reinforcing





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Do's and Don'ts

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Do's and Don'ts

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Overview

- Purpose of Reinforcement
- Types and Identification
- Positioning and Spacing
- Cage Fabrication
- Do's and Don'ts
- **QC Certification Program Requirements**

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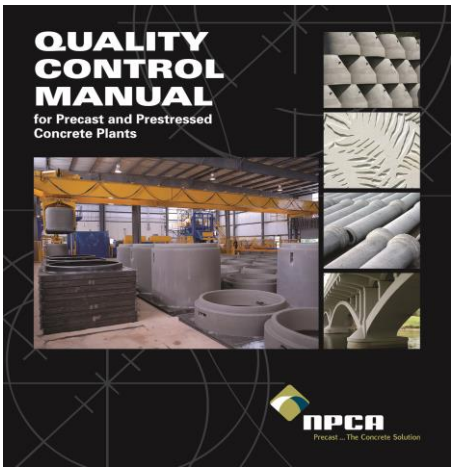
QC Certification Program Requirements

- Fabrication of Reinforcement
- Pre-Pour Operations
- Verification of Reinforcing Steel Conformance with Design



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QC Certification Program Requirements

- 1.1.2 Plant-specific Quality Control Manual
  - 6.) Product pre-pour, casting, post-pour and final inspection procedures
  - 9.) Product repair policy and procedures
- 2.2.5 Reinforcement - Plant Requirements
  - 2.) Cross check heat numbers on tag bundles match documents on-file
- 4.1.7 Production Practices - Plant Requirements
  - 3.) Documented reinforcing checks on one (1) cage or 3% of each production run daily
  - 6.) Maintain records for three (3) years (also referenced in 5.1.1)

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QC Certification Program Requirements

- 4.2.1 Fabrication of Reinforcement (*critical section*)
  - Detailed reinforcing steel plan document
  - Tolerances shown on plans or in plant-specific QC manual
  - Bent per CRSI and RSIC/IAAC standards
  - Rigid by tying or clipping
  - Epoxy coatings repaired
- 4.2.5 Fabrication - Plant requirements
  - Tolerances, welding procedure meeting AWS D1.4/D1.4M

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QC Certification Program Requirements

- 4.3.3 Positioning of Reinforcement (*critical section*)
  - Min. ½" concrete cover
  - Reinforcing does not move
  - Documented reinforcing checks on one (1) cage or 3% of each production run daily
  - Bar/WWR size and spacing
  - Location
  - Concrete cover
  - Cage dimensions
  - Lap splice lengths
  - Steel condition
  - Proper hooks/bends

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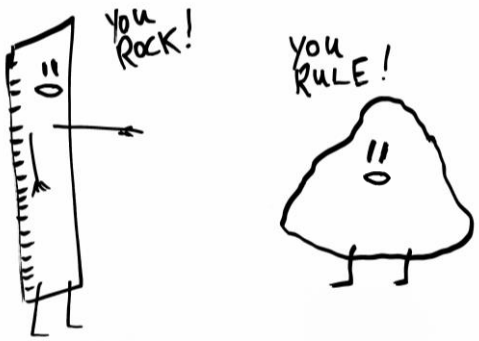
Questions?



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Reinforcing Assembly Best Practices

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