



# QUALITY SCHOOL



# REINFORCEMENT



# QUALITY SCHOOL



“....water and concrete are the two materials most used by mankind: water in the first place and concrete in the second.”

ACI Honorary Member Adam Neville – December, 2000 issue of Concrete International



# QUALITY SCHOOL



The bitterness of poor quality  
remains long after the  
sweetness of low price is gone

(Unknown)



# QUALITY SCHOOL



## Purpose of Reinforcement

- Concrete properties
  - Strong in compression
  - Weak in tension
- Reinforcement supplies strength to withstand tensile and shear forces experienced by concrete



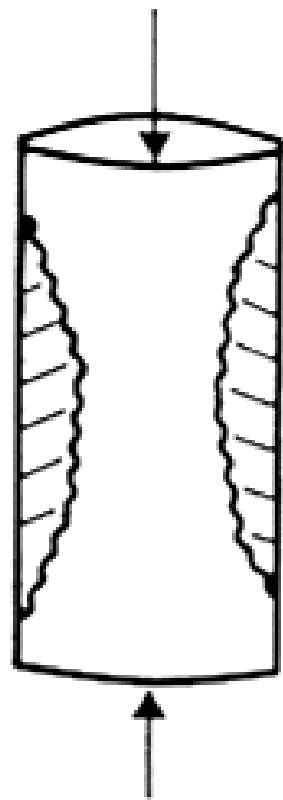


# QUALITY SCHOOL



## Compressive Forces on Concrete

COMPRESSIVE



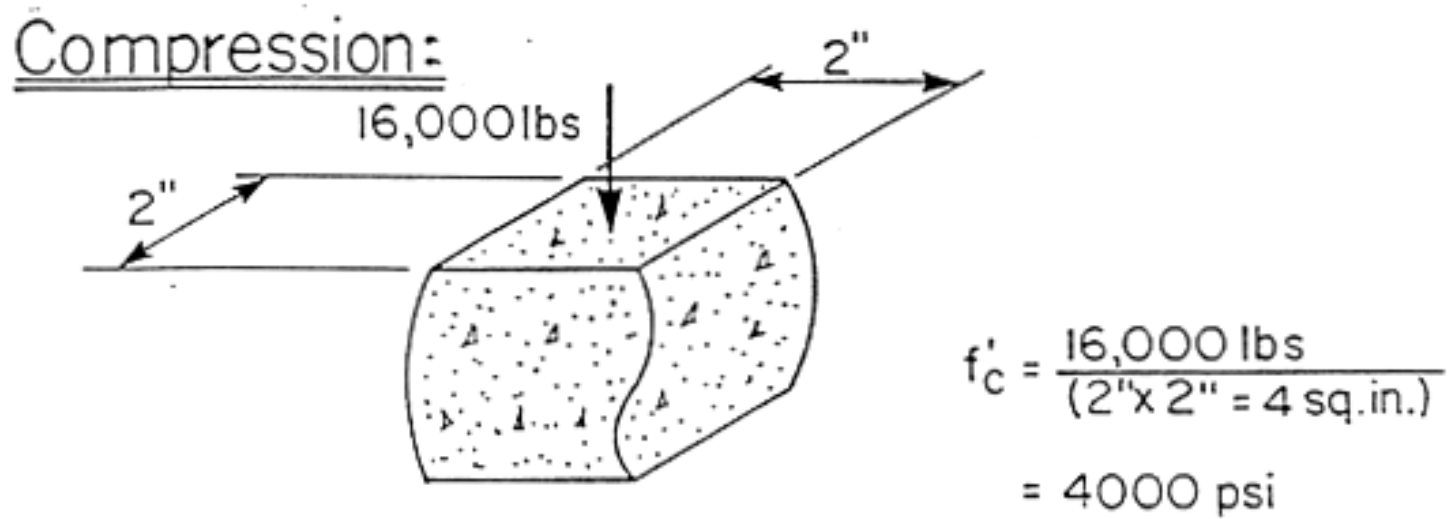
Concrete can withstand compression



# QUALITY SCHOOL



## Concrete Under Compression



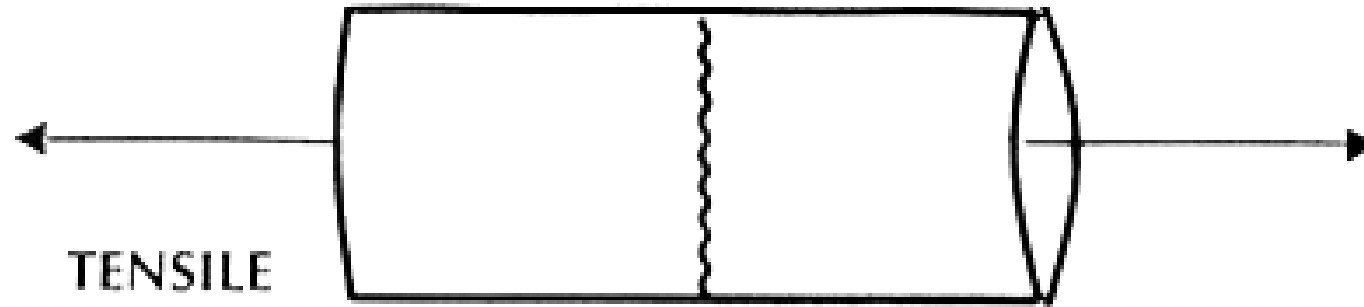
This 2" X 2" cube of concrete withstands a 4000 psi compressive force



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## Tensile Forces on Concrete



Without reinforcement, concrete will fail in tension

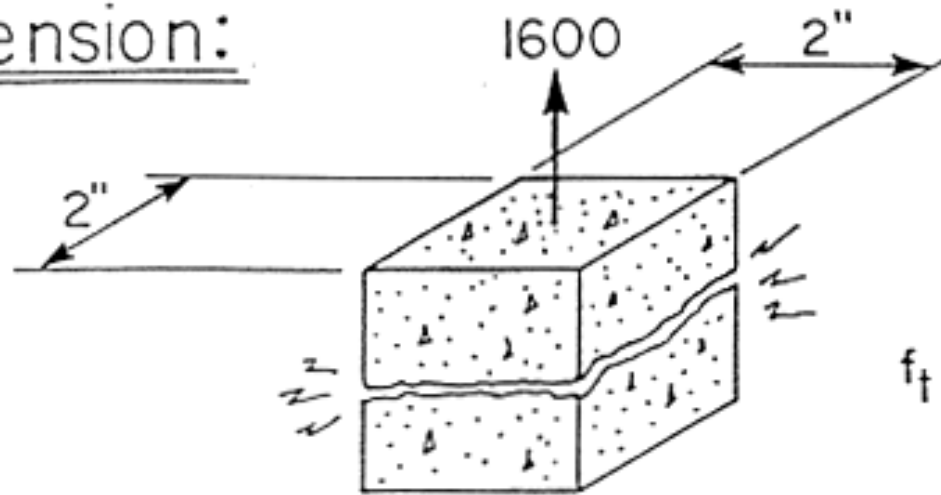


# QUALITY SCHOOL



## Concrete Under Tension

Tension:



$$f_t = \frac{1600}{(2'' \times 2'' = 4 \text{ sq. in.})} = 400 \text{ psi}$$

$$f_t = \frac{1}{10} f'_c$$

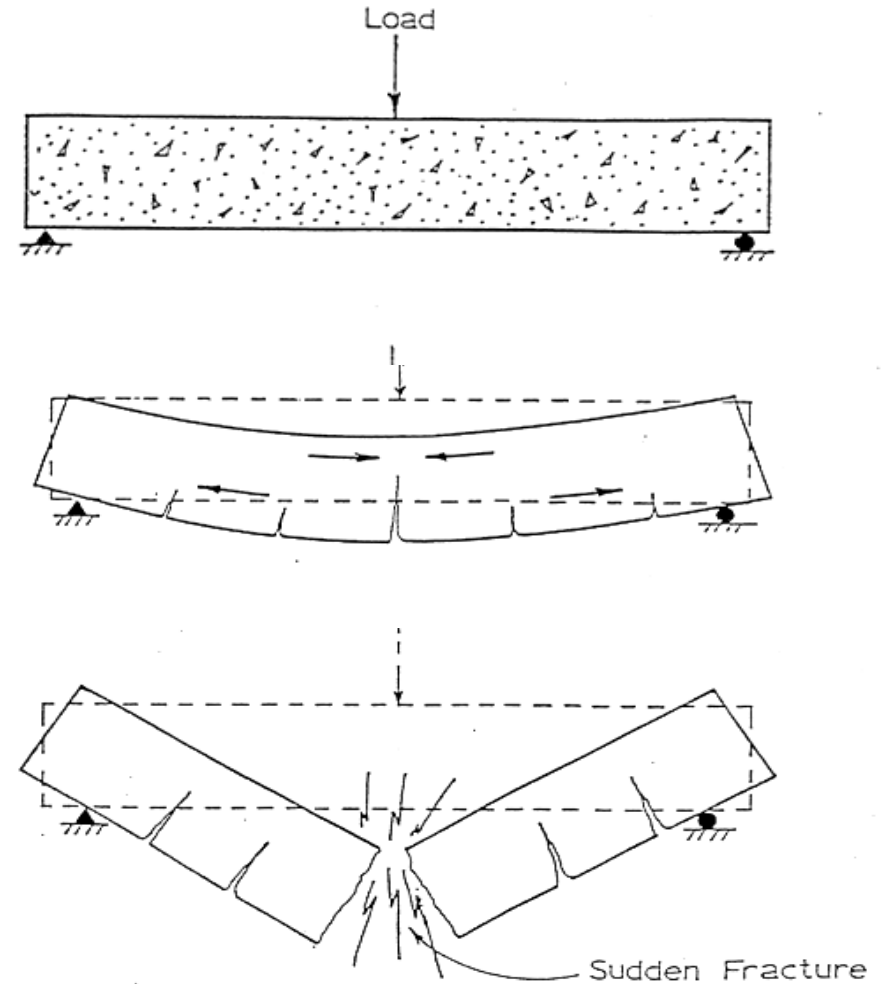
The same 2" X 2" cube of concrete fails under a 400 psi *tensile* force



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## Non-reinforced Concrete Behavior

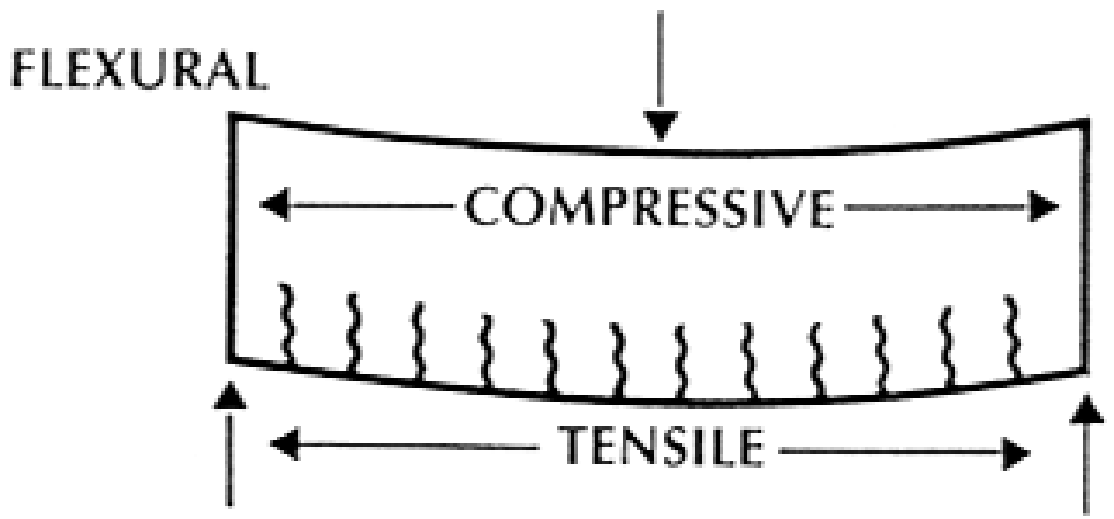




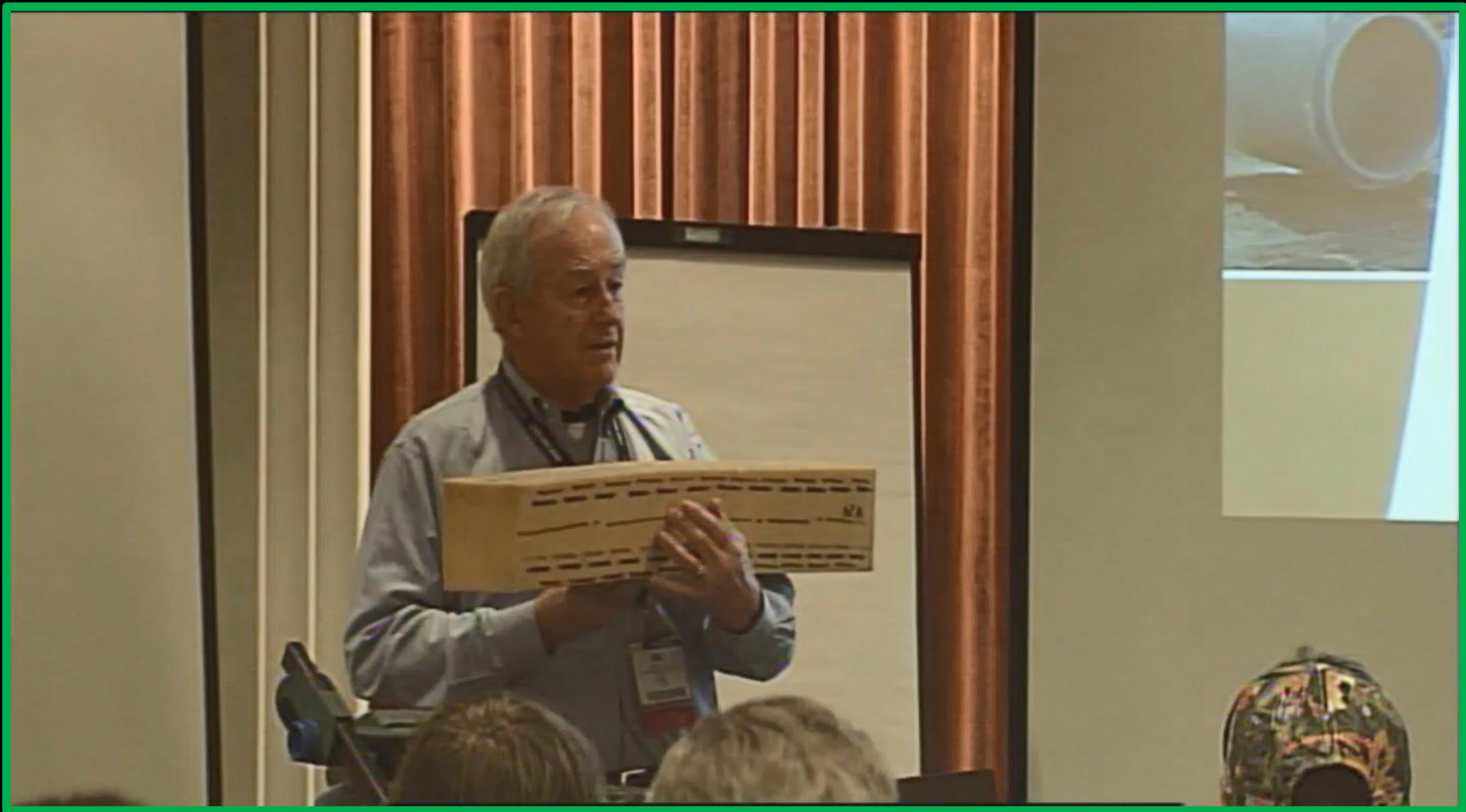
# QUALITY SCHOOL



## Flexural Forces on Concrete



Without reinforcement, the bottom side will fail in tension

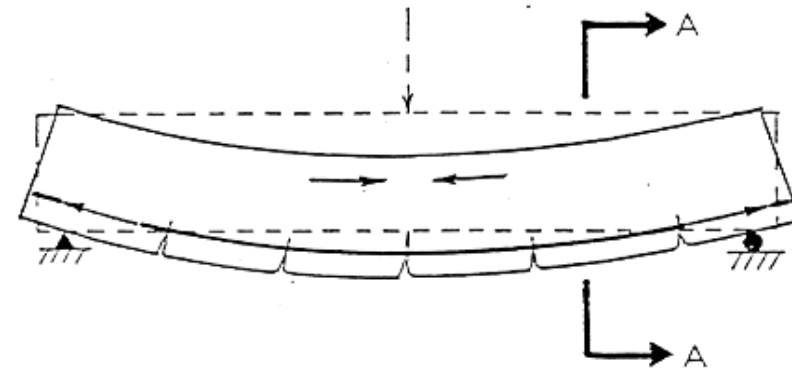
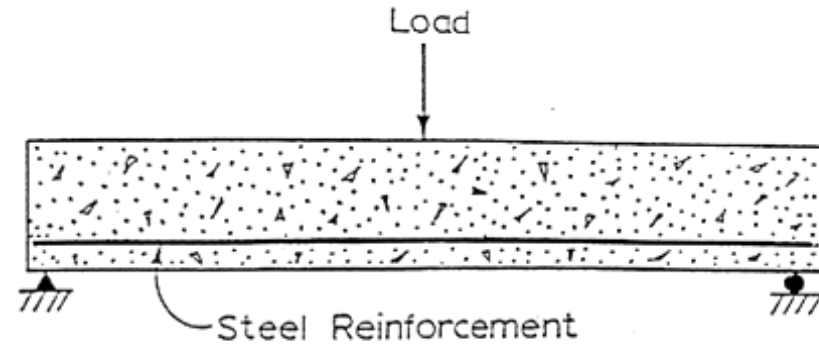




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## Reinforced Concrete Behavior





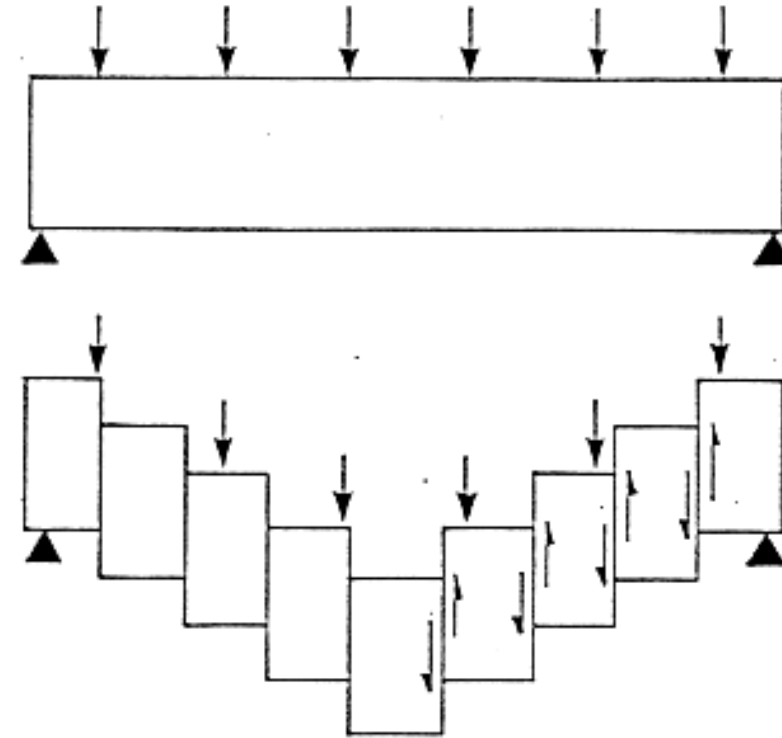


# QUALITY SCHOOL



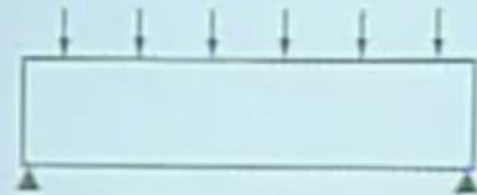
## Concrete Behavior Under Shear

Vertical Shear



## Concrete Behavior Under Shear

- Non-reinforced Concrete



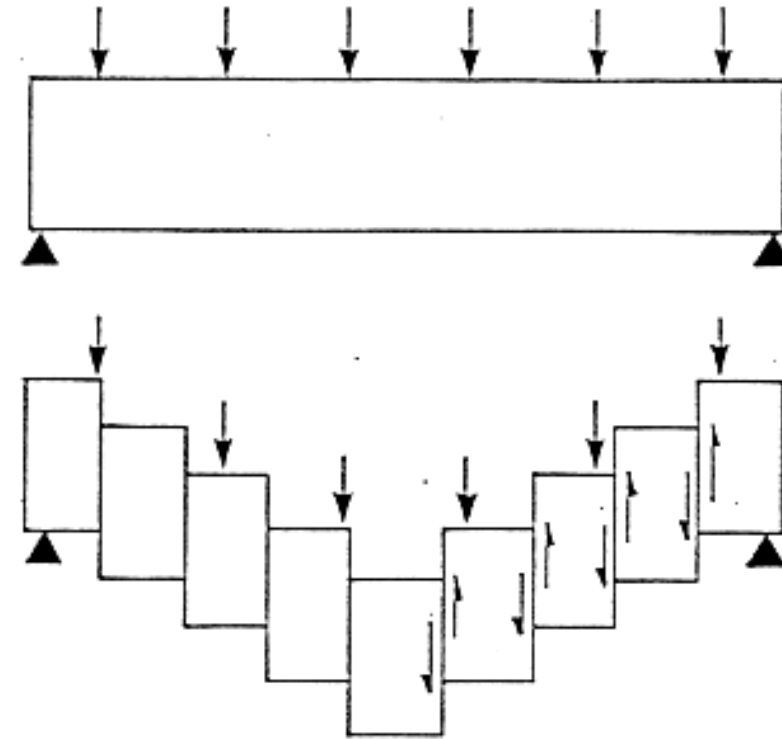


# QUALITY SCHOOL



## Concrete Behavior Under Shear

Vertical Shear







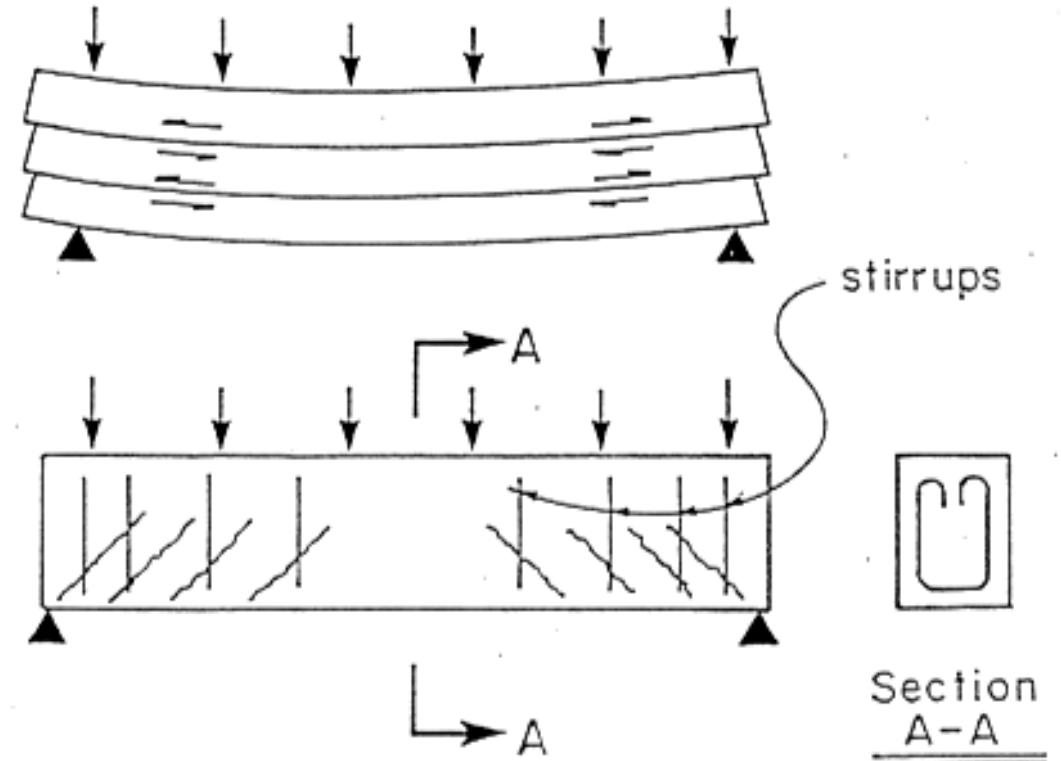
# QUALITY SCHOOL



## Concrete Behavior Under Shear

Horizontal shear

shear reinforcement

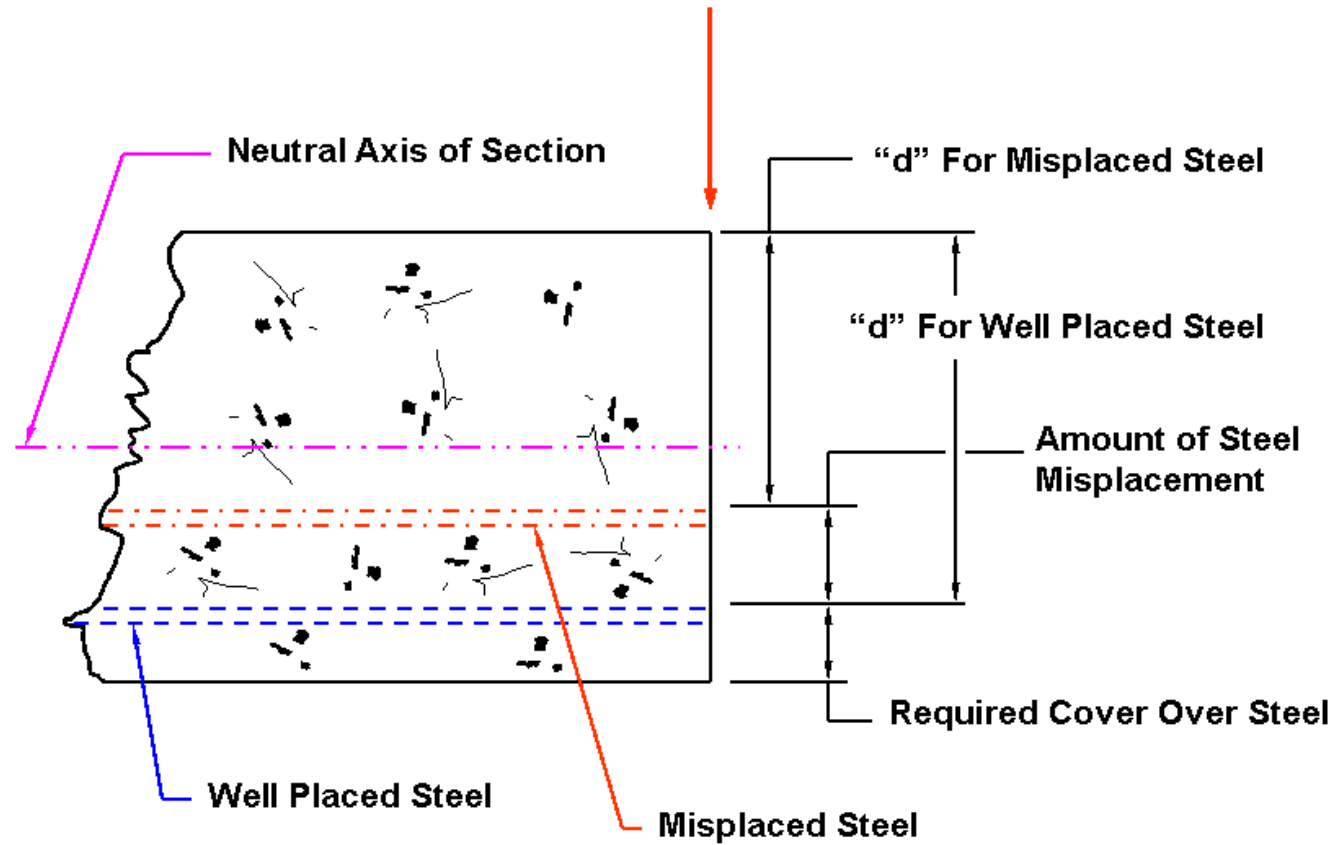


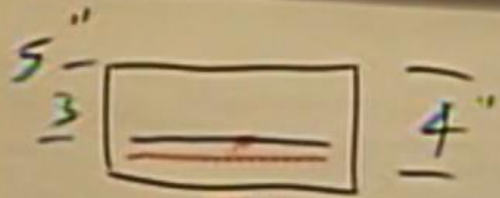


# QUALITY SCHOOL



## Effectiveness of Placement





$$M = Fd$$

$$= 60,000 \times 4$$

$$= 240,000$$

$$= 60,000 \times 3$$

$$= 180,000$$

$$= 20,000 \times 3$$

$$= 60,000$$

$$= 240,000$$

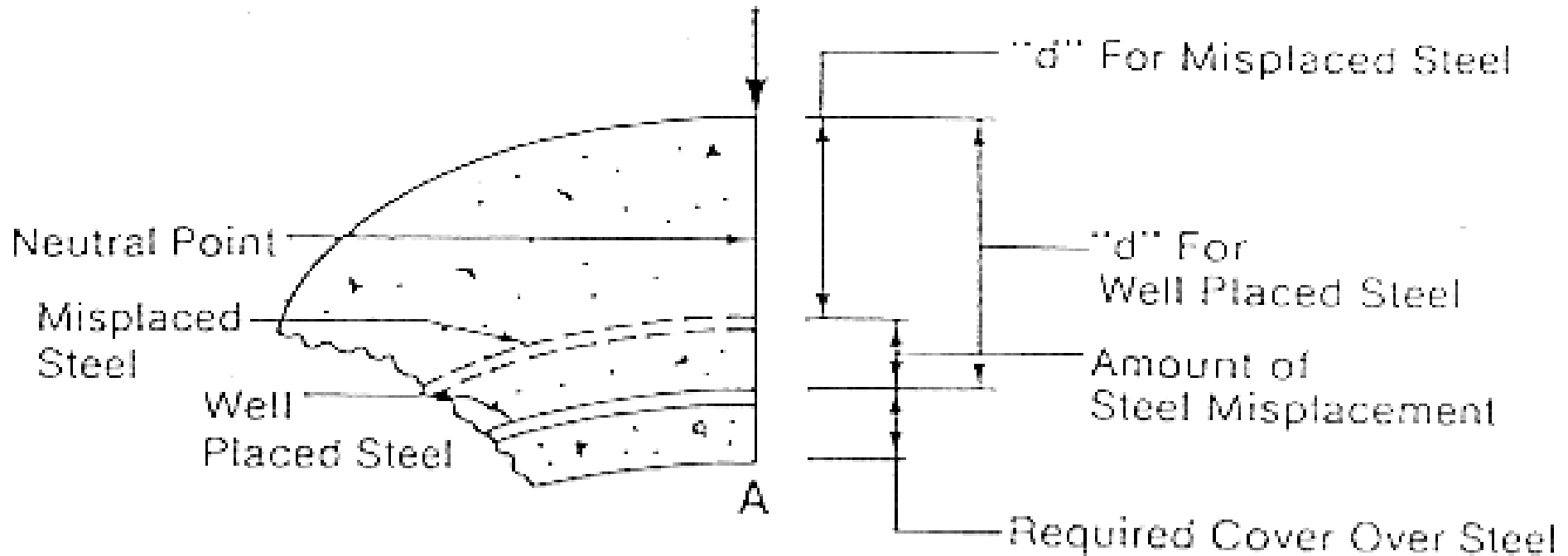




# QUALITY SCHOOL



## Effectiveness of Placement

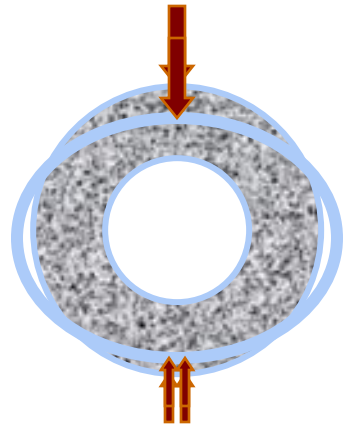




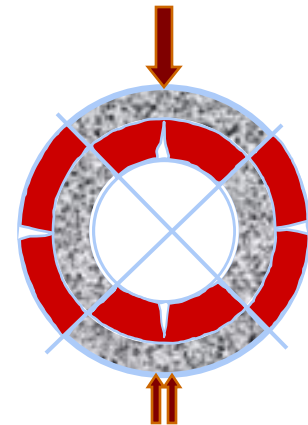
# QUALITY SCHOOL



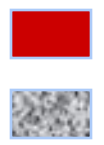
## 0.01" Crack in Pipe



DEFLECTION UNDER TEST CONDITION



STRESS ZONES UNDER TEST CONDITION

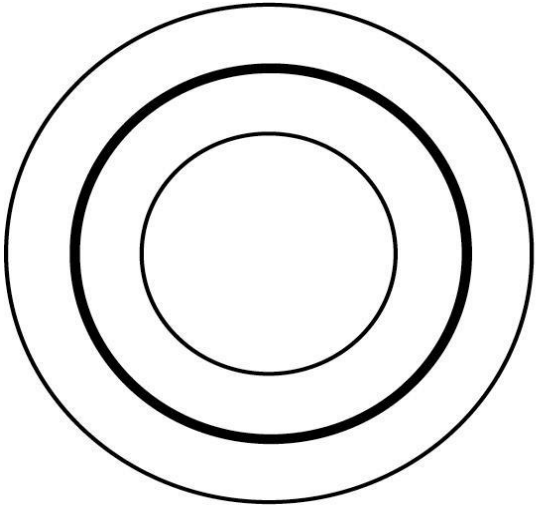


TENSION

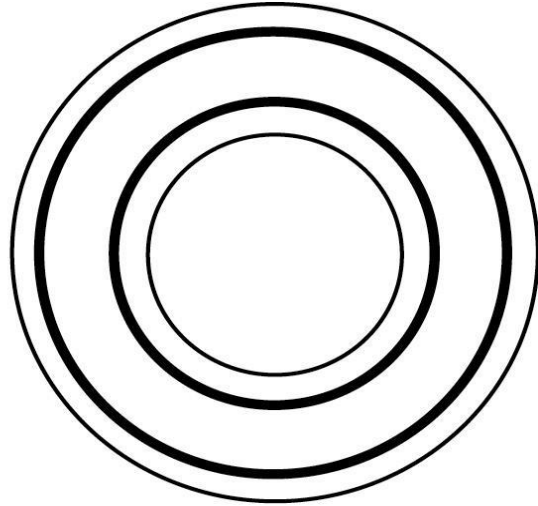
COMPRESSION



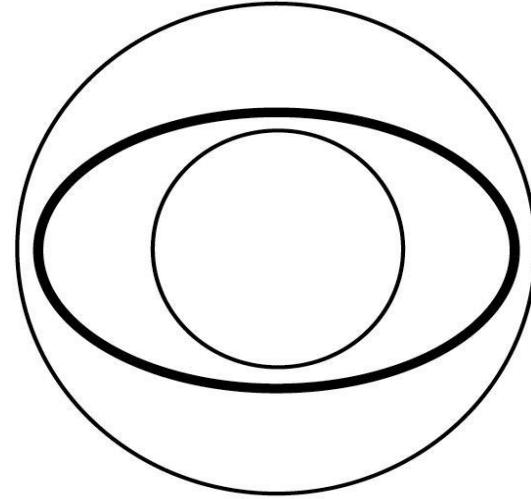
# QUALITY SCHOOL



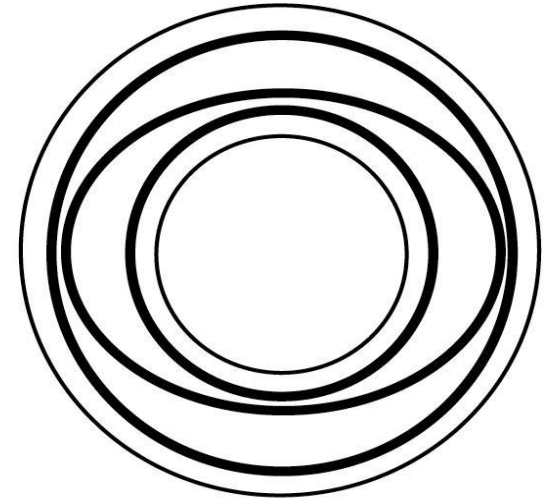
Single Circular Cage



Double Circular Cages



Single Elliptical  
Cage



Combination Elliptical and  
Circular Cages

**Figure 2.1.** Four Cage Configurations Commonly Employed in the Manufacture of Reinforced Concrete Pipe.



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# Box Culvert

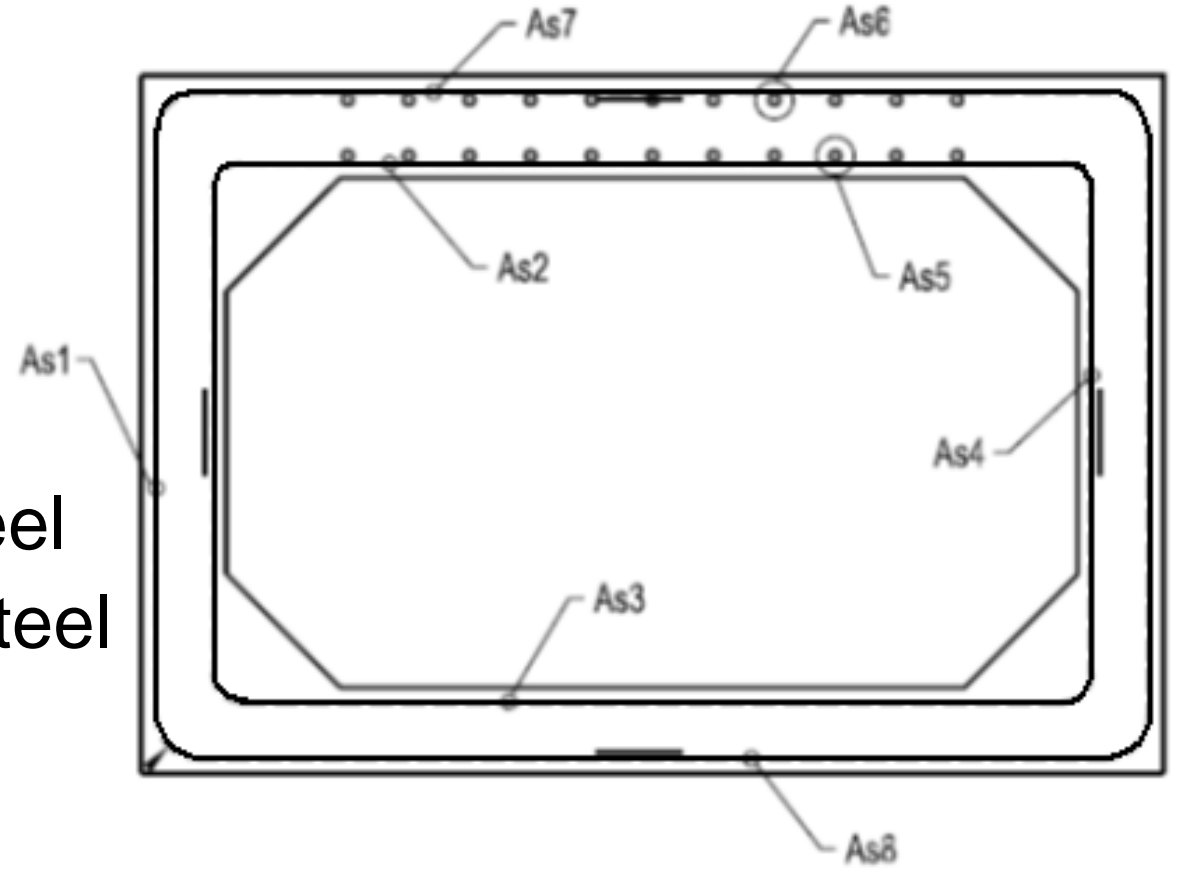


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## Steel Nomenclature

- As<sub>1</sub> = Sidewall outside face
- As<sub>2</sub> = Top slab inside face
- As<sub>3</sub> = Bottom slab inside face
- As<sub>4</sub> = Sidewall inside face
- As<sub>5</sub> = Top slab inside distribution steel
- As<sub>6</sub> = Top slab outside distribution steel
- As<sub>7</sub> = Top slab outside face
- As<sub>8</sub> = Bottom slab outside face

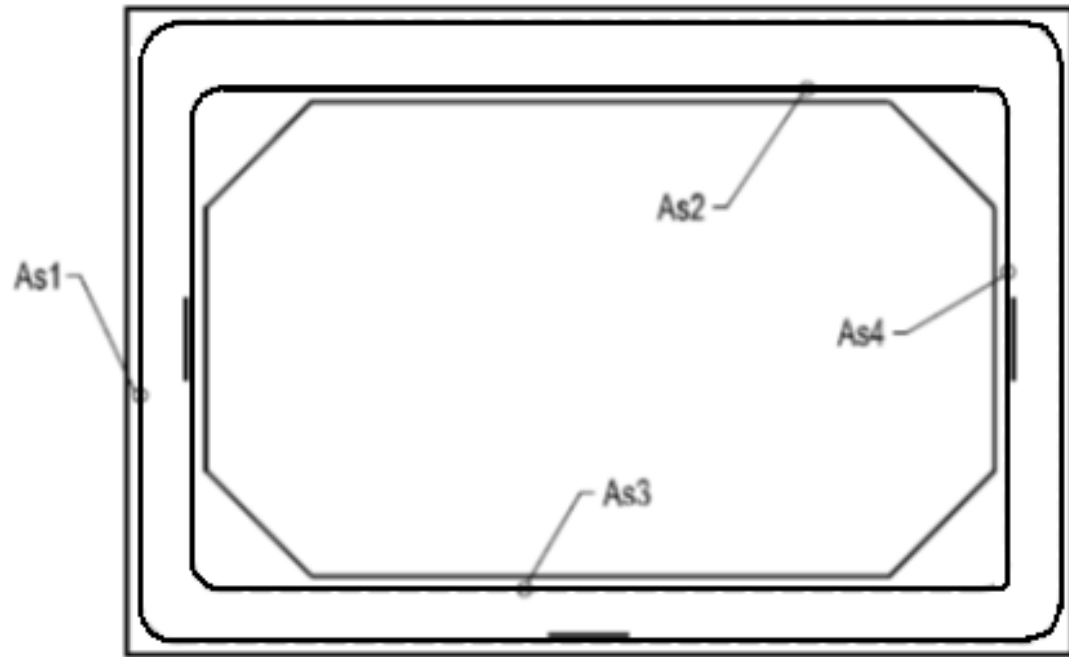




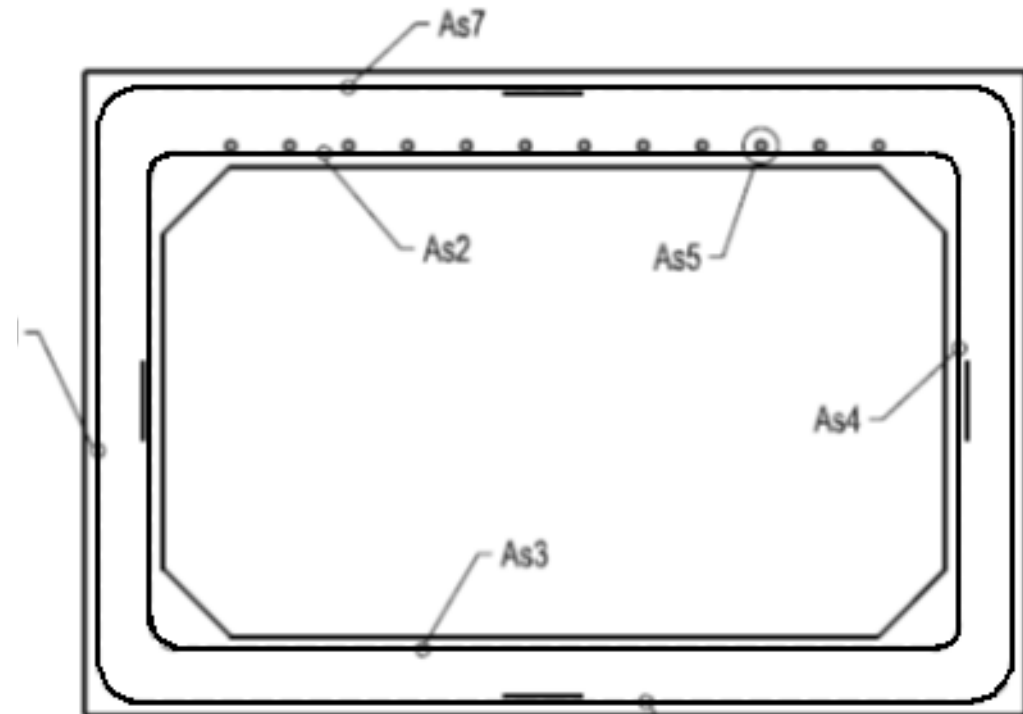
# QUALITY SCHOOL



## ASTM C1433



2" COVER AND GREATER



LESS THAN 2" COVER

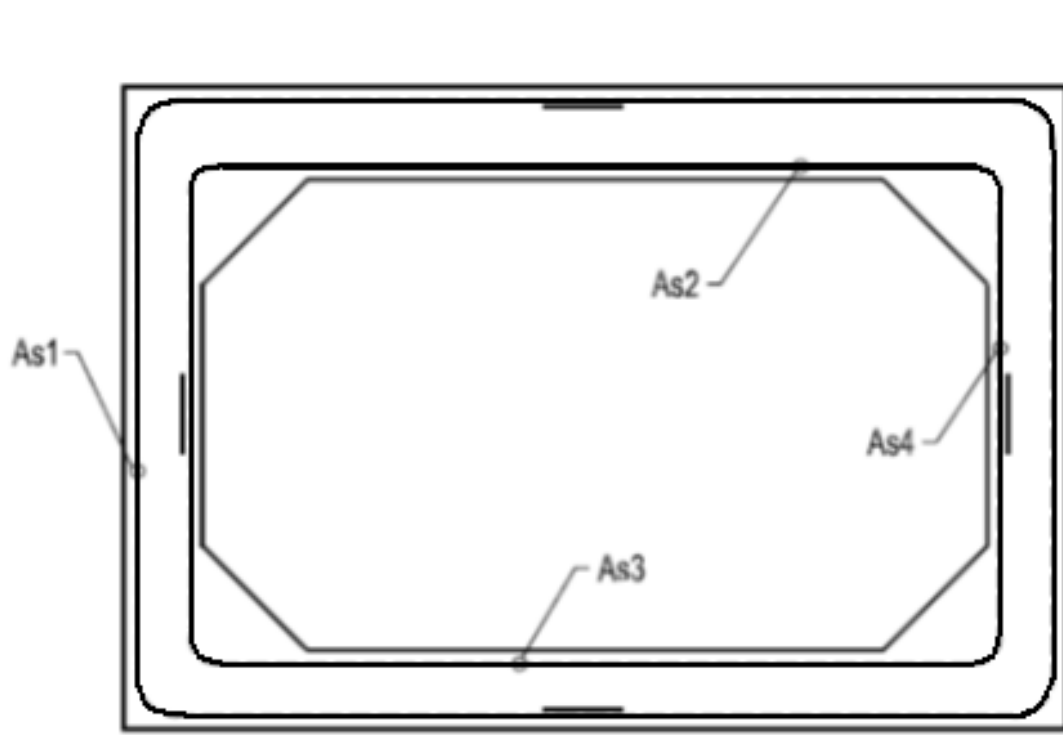




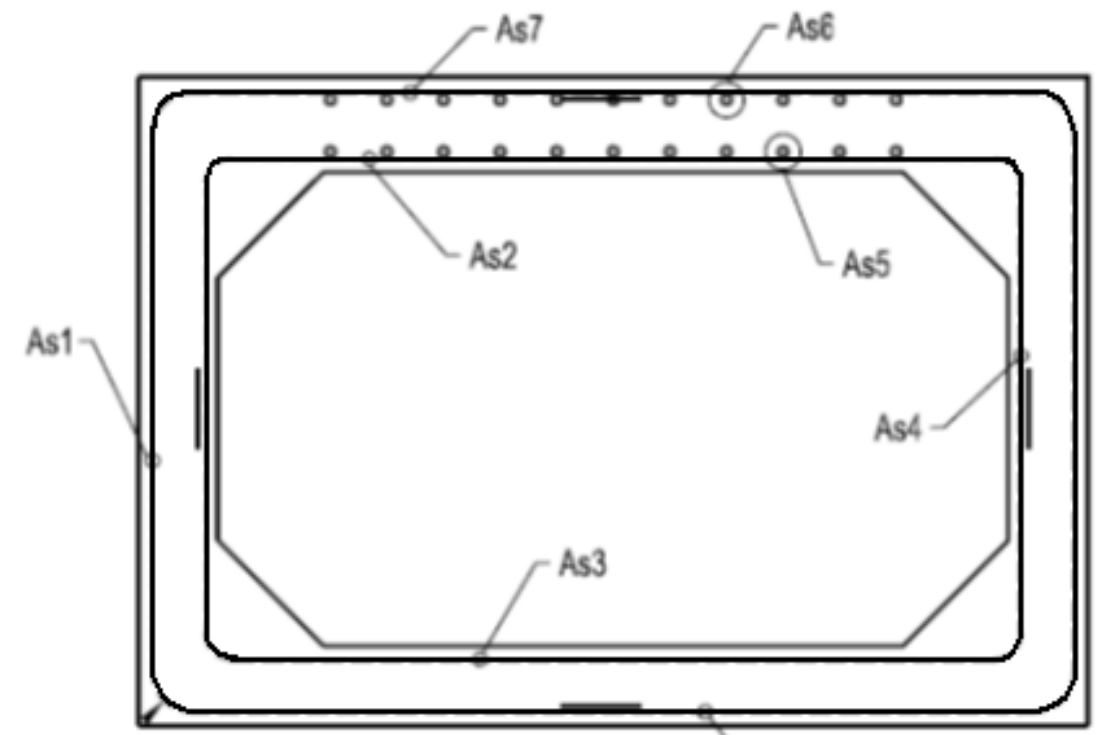
# QUALITY SCHOOL



## ASTM C1577



2" COVER AND GREATER



LESS THAN 2" COVER



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## As6 Steel Area

- No longer required in latest version of C1577
- C1433 – As6 taken out in 2008
- Still required in C1433-07a version and earlier
- Still required in C789 & C850
- Still required in AASHTO M273 & M259





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## Reinforcing Steel Tables

### C1433

- Table 1 HS20 Highway Loading
- Table 2 Interstate Highway Loading

### C1577

- Table 1 HL-93 Highway Loading





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## C1433/C1577 Steel Areas

- 0 to 2 feet of cover has less steel overall (C1577)
  - Fatigue does not govern with C1577
- 3 to 5 feet of cover has more steel overall (C1577)
  - 1.15 live load distribution versus 1.75 live load distribution in C1433, and higher impact factors results in higher live load pressures
- At deeper fills C1577 has less steel overall
  - Crack control in C1577 is more liberal



# 0 – 2' of Cover

# QUALITY SCHOOL



10'x10'	Depth	As1	As2	As3	As4	As5	As6	As7	As8
C1577									
	0<2	0.24	0.44	0.44	0.24	0.24	0	0.24	0.24
	2<3	0.25	0.52	0.48	0.24	0.24	0	0.24	0.24
	3-5	0.24	0.42	0.43	0.24	0.24	0	0.24	0.24
C1433									
	0<2	0.24	0.60	0.36	0.24	0.24	0	0.24	0.24
	2<3	0.24	0.51	0.39	0.24	0.24	0	0.24	0.24
	3-5	0.24	0.35	0.39	0.24	0.24	0	0.24	0.24



# QUALITY SCHOOL



10'x10'	Depth	As1	As2	As3	As4
C1577					
	0<2	0.24	0.44	0.44	0.24
	2<3	0.25	0.52	0.48	0.24
	3-5	0.24	0.42	0.43	0.24
C1433					
	0<2	0.24	0.60	0.36	0.24
	2<3	0.24	0.51	0.39	0.24
	3-5	0.24	0.35	0.39	0.24

# Greater Than 5' of Cover

## QUALITY SCHOOL



10'x10'	Depth	As1	As2	As3	As4
C1577					
	10	0.24	0.44	0.48	0.24
	15	0.30	0.57	0.61	0.24
	20	0.38	0.73	0.77	0.24
C1433					
	10	0.25	0.49	0.54	0.24
	15	0.34	0.67	0.72	0.24
	20	0.42	0.85	0.90	0.24





# QUALITY SCHOOL



## Skewed Box Alignment

- C1433 & C1577 both assume box is laid perpendicular to the road way
- C1433 no limit on amount of skew allowed on the box alignment
- C1577 only allows  $15^{\circ}$  skew before separate analysis is required

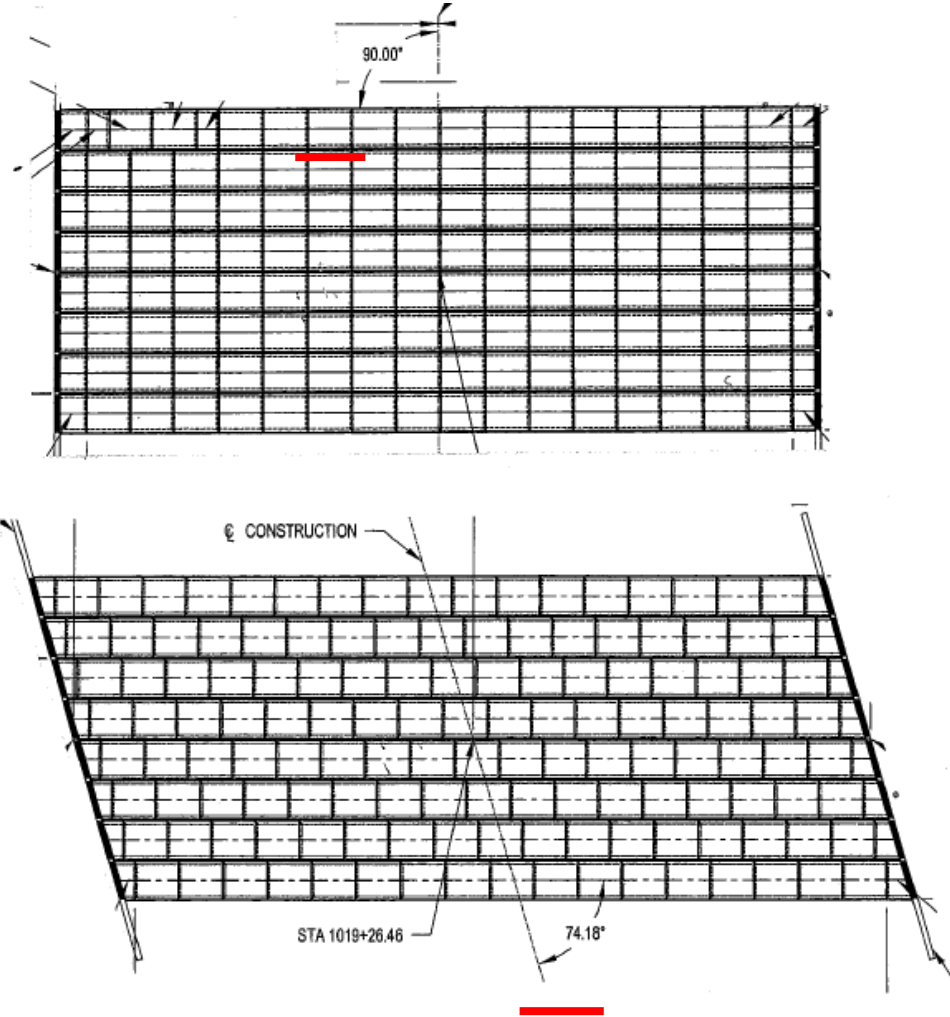




# QUALITY SCHOOL



## Skewed Box Alignment





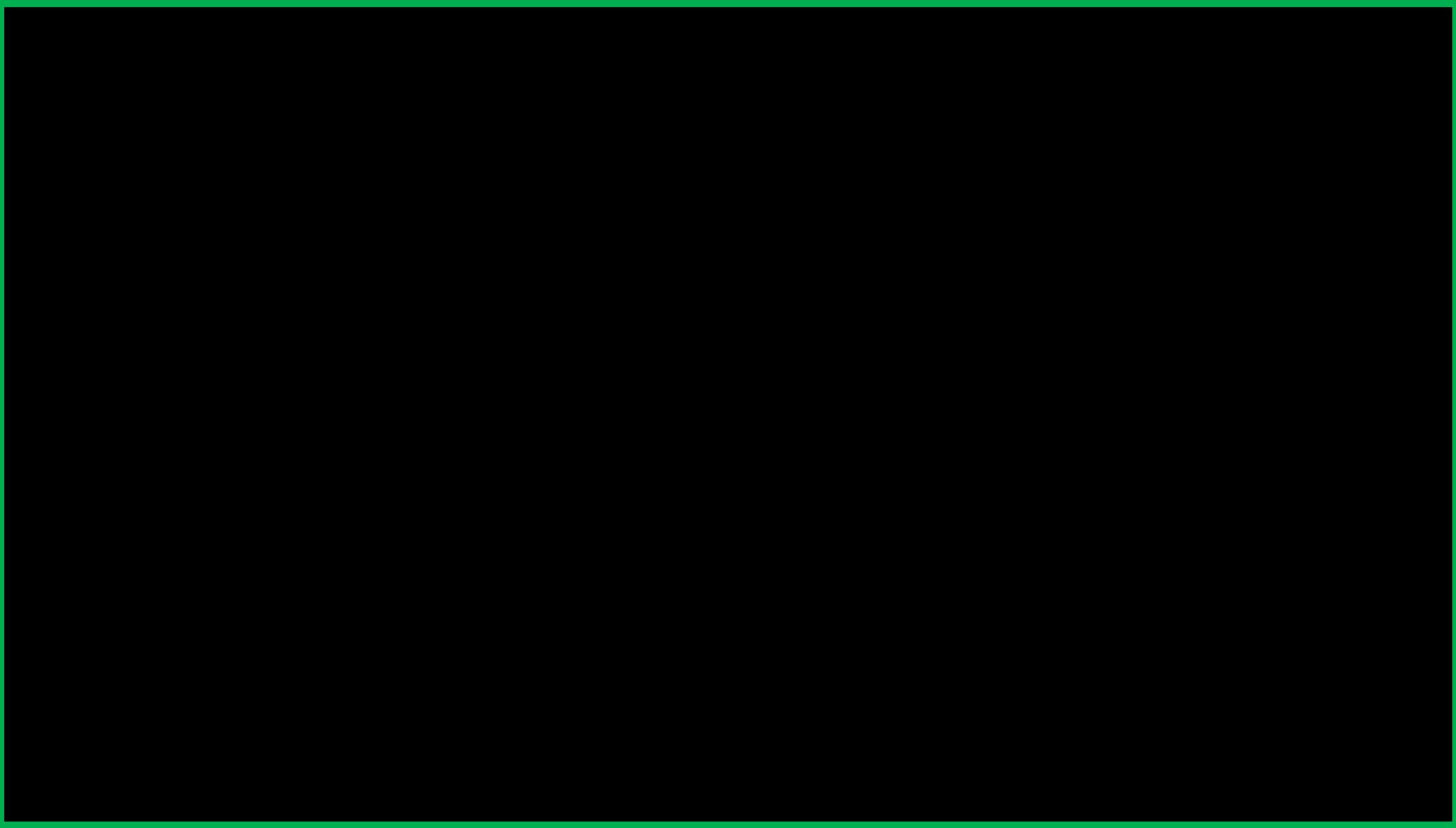
# Effectiveness of Placement

# QUALITY SCHOOL



1" cover vs. 1-1/4" cover for various fill heights

PRECAST BOX CULVERT DESIGNS																											
Spec.	Box Size S x R	Fill Ht.	Live Load	Slab / Wall Thickness				Bx Wt. (lb/ft)	Circumf. Reinf. Areas, in. <sup>2</sup> / ft.								Long.		M	Clear Concrete Cover, in.						f' <sub>c</sub> ksi	f <sub>y</sub> ksi
				Tt	Tb	Ts	H		A <sub>s1</sub>	A <sub>s2</sub>	A <sub>s3</sub>	A <sub>s4</sub>	A <sub>s7</sub>	A <sub>s8</sub>	A <sub>s5</sub>	A <sub>s6</sub>	C <sub>1</sub>	C <sub>2</sub>		C <sub>3</sub>	C <sub>4</sub>	C <sub>7</sub>	C <sub>8</sub>				
C1577	8' x 6'	5'	HL93	8"	8"	8"	8"	3,200	0.19	0.27	0.29	0.19	-	-	-	-	45"	1.00	1.00	1.00	1.00	-	-	5.0	65		
C1577	8' x 6'	5'	HL93	8"	8"	8"	8"	3,200	0.19	0.28	0.30	0.19	-	-	-	-	45"	1.25	1.25	1.25	1.25	-	-	5.0	65		
									0%	4%	3%																
C1577	8' x 6'	10'	HL93	8"	8"	8"	8"	3,200	0.22	0.33	0.35	0.19	-	-	-	-	42"	1.00	1.00	1.00	1.00	-	-	5.0	65		
C1577	8' x 6'	10'	HL93	8"	8"	8"	8"	3,200	0.23	0.35	0.37	0.19	-	-	-	-	42"	1.25	1.25	1.25	1.25	-	-	5.0	65		
									5%	6%	6%																
C1577	8' x 6'	15'	HL93	8"	8"	8"	8"	3,200	0.30	0.45	0.47	0.19	-	-	-	-	42"	1.00	1.00	1.00	1.00	-	-	5.0	65		
C1577	8' x 6'	15'	HL93	8"	8"	8"	8"	3,200	0.31	0.47	0.49	0.19	-	-	-	-	42"	1.25	1.25	1.25	1.25	-	-	5.0	65		
									3%	4%	4%																
C1577	8' x 6'	20'	HL93	8"	8"	8"	8"	3,200	0.38	0.58	0.60	0.19	-	-	-	-	42"	1.00	1.00	1.00	1.00	-	-	5.0	65		
C1577	8' x 6'	20'	HL93	8"	8"	8"	8"	3,200	0.39	0.61	0.63	0.19	-	-	-	-	42"	1.25	1.25	1.25	1.25	-	-	5.0	65		
									3%	5%	5%																
C1577	8' x 6'	25'	HL93	8"	8"	8"	8"	3,200	0.46	0.72	0.74	0.19	-	-	-	-	42"	1.00	1.00	1.00	1.00	-	-	5.0	65		
C1577	8' x 6'	25'	HL93	8"	8"	8"	8"	3,200	0.49	0.75	0.77	0.19	-	-	-	-	42"	1.25	1.25	1.25	1.25	-	-	5.0	65		
									7%	4%	4%																





# QUALITY SCHOOL



## Effectiveness of Placement

- It is critical to have correct steel placement for both pipe and box culverts



# QUALITY SCHOOL



## Concrete Pipe Design



# QUALITY SCHOOL



## Structural Design

- Indirect (D-Load) – (ACPA DD-9)  
Designed for concentrated load (3-Edge Bearing Test) that will produce the same bending moments as in the field
- Direct Design  
Designed for the anticipated soil pressures using typical ultimate strength design methodology





# QUALITY SCHOOL



## Concrete Pipe Strength (ASTM C76/AASHTO M170)

### D-Load

Supporting strength of a pipe loaded under three-edge-bearing test conditions

Expressed in pounds per linear foot per foot of inside diameter or horizontal span

### ASTM C 76 Class IV

$$D_{0.01} = 2,000$$

$$D_{ULT} = 3,000$$



# QUALITY SCHOOL



## ASTM C76

## D-Load

	<u>0.01”D</u>	<u>Ult. D</u>
Class I	800	1200
Class II	1000	1500
Class III	1350	2000
Class IV	2000	3000
Class V	3000	3750





# QUALITY SCHOOL



## D-Load Strength Determination

### 48" Profile Class IV 8'

$$D_{0.01} = 2000$$

$$D_{ULT} = 3000$$

Total Load Required:

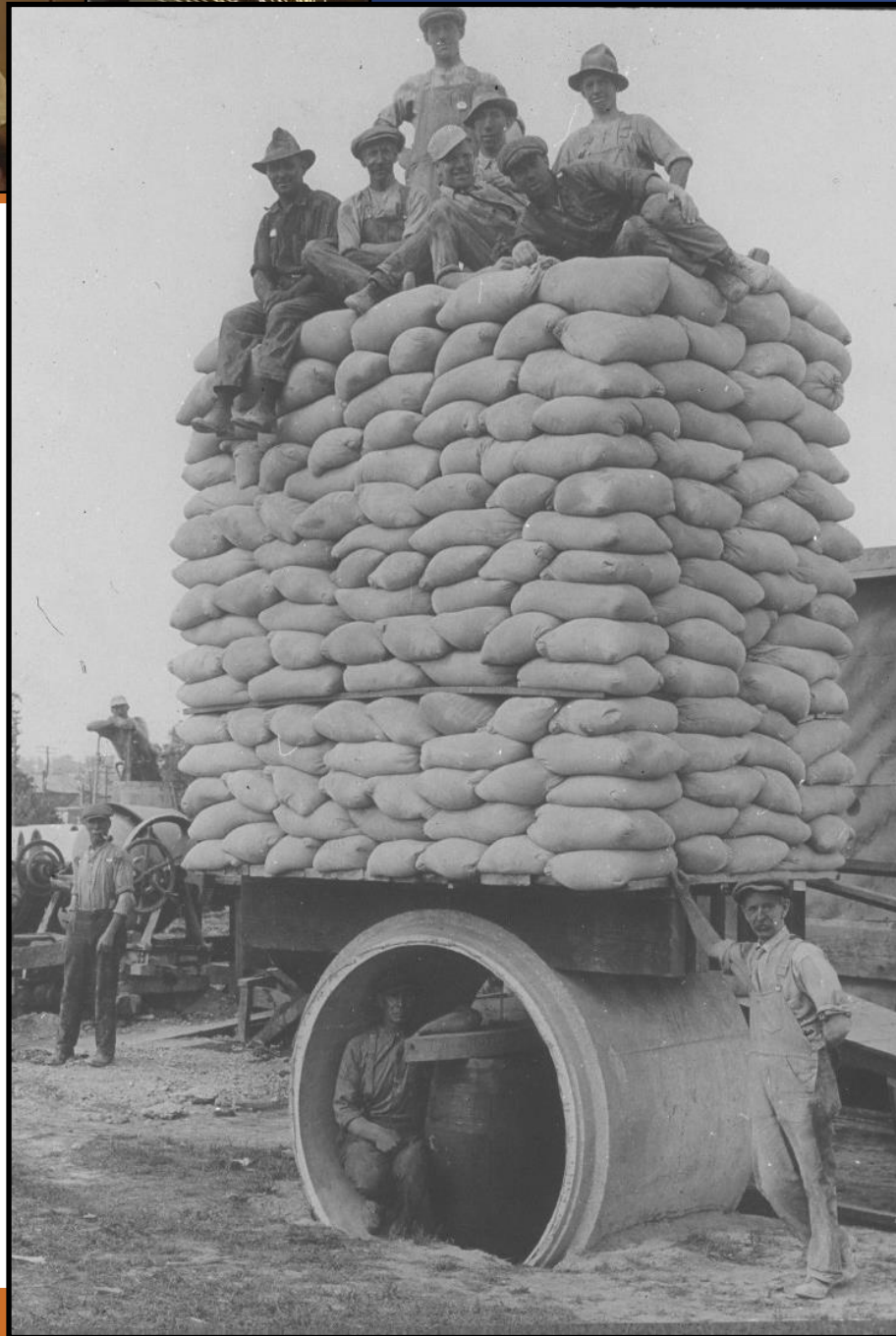
$$D_{0.01} = (48/12)(8)(2000) = 64,000 \text{ lbs}$$

$$D_{ULT} = (48/12)(8)(3000) = 96,000 \text{ lbs}$$





# SCHOOL



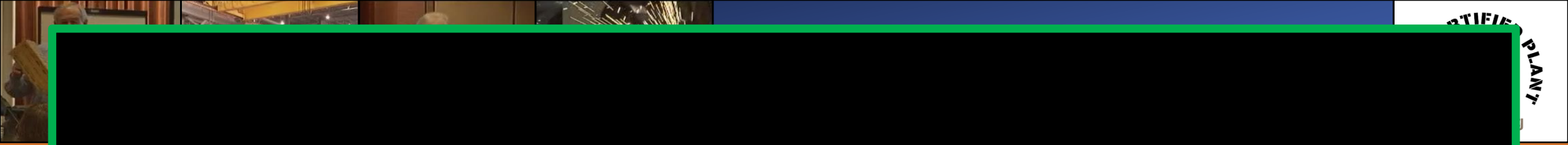






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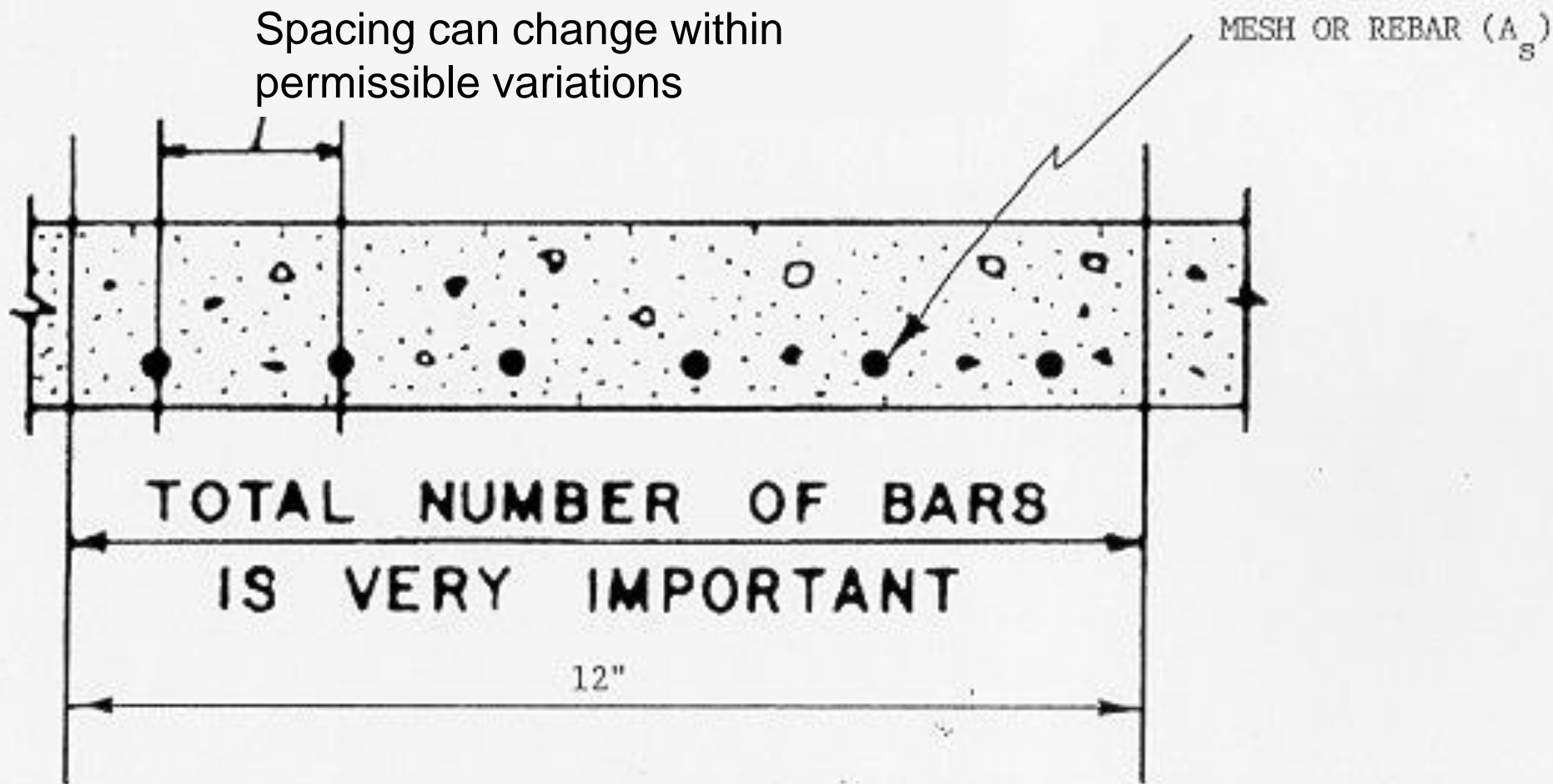




# QUALITY SCHOOL



Spacing can change within permissible variations





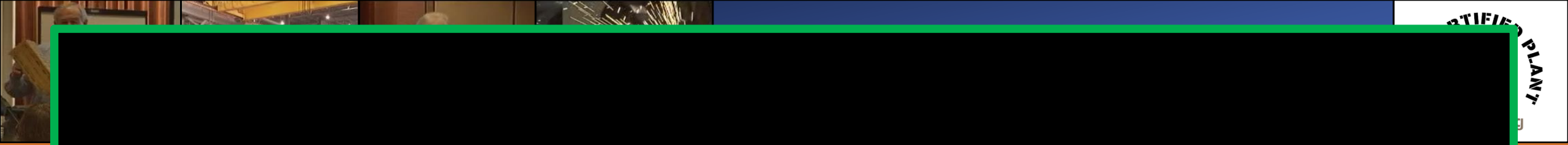
# QUALITY SCHOOL



## Steel Area Using Different Combinations of Bar Sizes and Spacing

		#4	#5	#6	#7	#8	#9	#10	#11
	<u>Spacing</u>								
	2 in.	1.20	1.86	2.64					
	3 in.	0.80	1.24	1.76	2.40	3.16	4.00		
→	4 in.	0.60	0.93	1.32	1.80	2.37	3.00	3.81	4.68
→	5 in.	0.48	0.74	1.06	1.44	1.90	2.40	3.05	3.74
	6 in.	0.40	0.62	0.88	1.20	1.58	2.00	2.54	3.12
	7 in.	0.34	0.53	0.75	1.03	1.35	1.71	2.18	2.67
	8 in.	0.30	0.47	0.66	0.90	1.19	1.50	1.91	2.34
	9 in.	0.27	0.41	0.59	0.80	1.05	1.33	1.69	2.08
	10 in.	0.24	0.37	0.53	0.72	0.95	1.20	1.52	1.87
	11 in.	0.22	0.34	0.48	0.65	0.86	1.09	1.39	1.70
→	12 in.	0.20	0.31	0.44	0.60	0.79	1.00	1.27	1.56
	13 in.	0.18	0.29	0.41	0.55	0.73	0.92	1.17	1.44
	14 in.	0.17	0.27	0.38	0.51	0.68	0.86	1.09	1.34
	15 in.	0.16	0.25	0.35	0.48	0.63	0.80	1.02	1.25
	16 in.	0.15	0.23	0.33	0.45	0.59	0.75	0.95	1.17
	17 in.	0.14	0.22	0.31	0.42	0.56	0.71	0.90	1.10
	18 in.	0.13	0.21	0.29	0.40	0.53	0.67	0.85	1.04

Area of one bar →





# QUALITY SCHOOL



## Reinforcement Type and Identification



# QUALITY SCHOOL



## Reinforcement Types

- Reinforcing bars
- Reinforcing wire
- Bar mats and welded wire fabric
- Zinc or epoxy coated reinforcement
- Prestressing and post tensioning
- ❖ All types must meet “Buy America” Requirements for federally funded projects



# QUALITY SCHOOL



## Reinforcing Bars

- Conform to specifications
  - ASTM A615 (New Billet)
  - ASTM A616 (Rail)
  - ASTM A617 (Axle)
  - ASTM A706 (Weldable)
- Other bars may be used if permitted by design
- Mill certificates required for each shipment

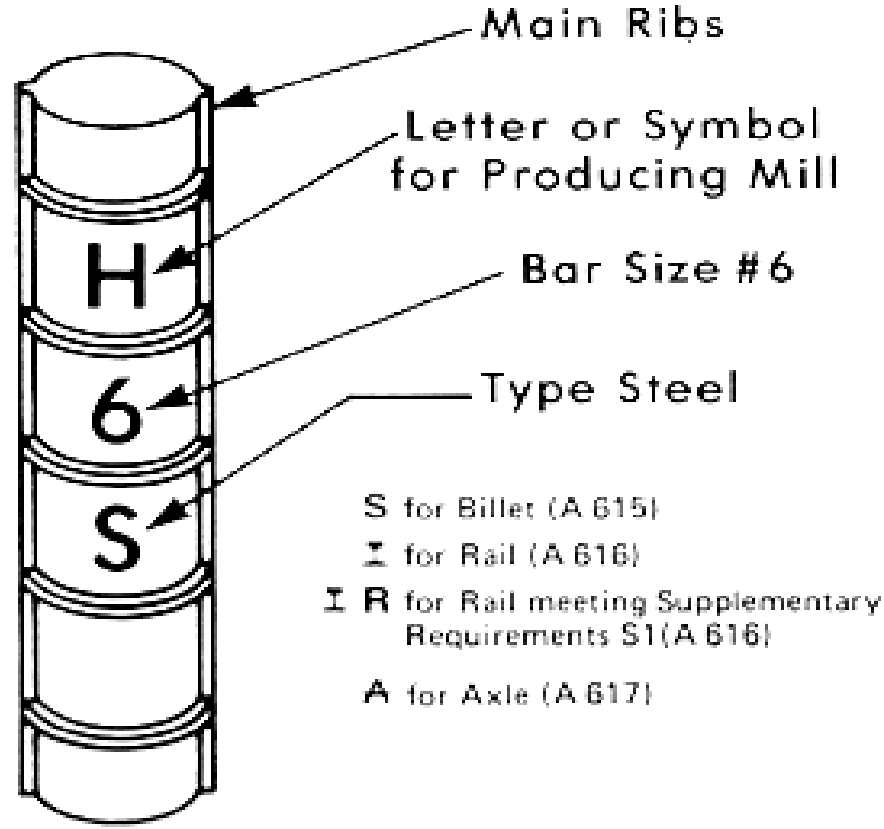




# QUALITY SCHOOL



## Grade 40 & 50 Rebar

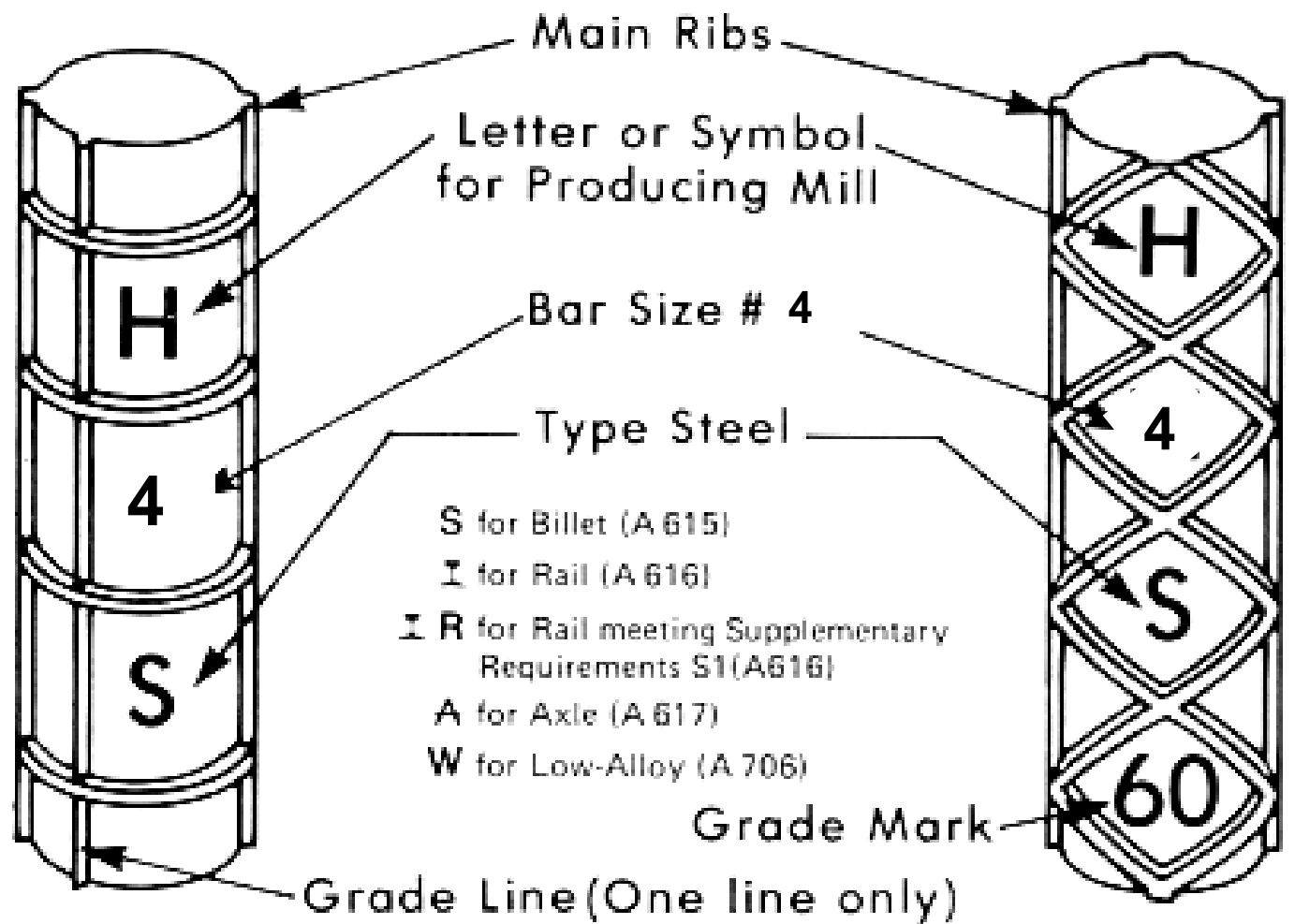




# QUALITY SCHOOL



## Grade 60 & A706 Rebar





# QUALITY SCHOOL



## Reinforcing Wire

- Conform to (except prestressing wire)
  - ASTM A82 (**now A1064**)
  - ASTM A496 (**now A1064**)
- Other wire may be used if permitted by design
- Mill certificates for each shipment





# QUALITY SCHOOL



## Bar Mats and Welded Wire Fabric

- Conform to
  - ASTM A184
  - ASTM A185 (**now A1064**)
  - ASTM A497 (**now A1064**)
- Mill certificates for each shipment
- Applications of rolled vs. straight





# QUALITY SCHOOL



## Plain Welded Wire Fabric

- Must conform to
  - ASTM A 1064 “Standard Specification for Carbon–Steel Wire and Welded Wire Reinforcement, Plain and Deformed, for Concrete”
- Welded intersections must be spaced not more than 12 in





# QUALITY SCHOOL

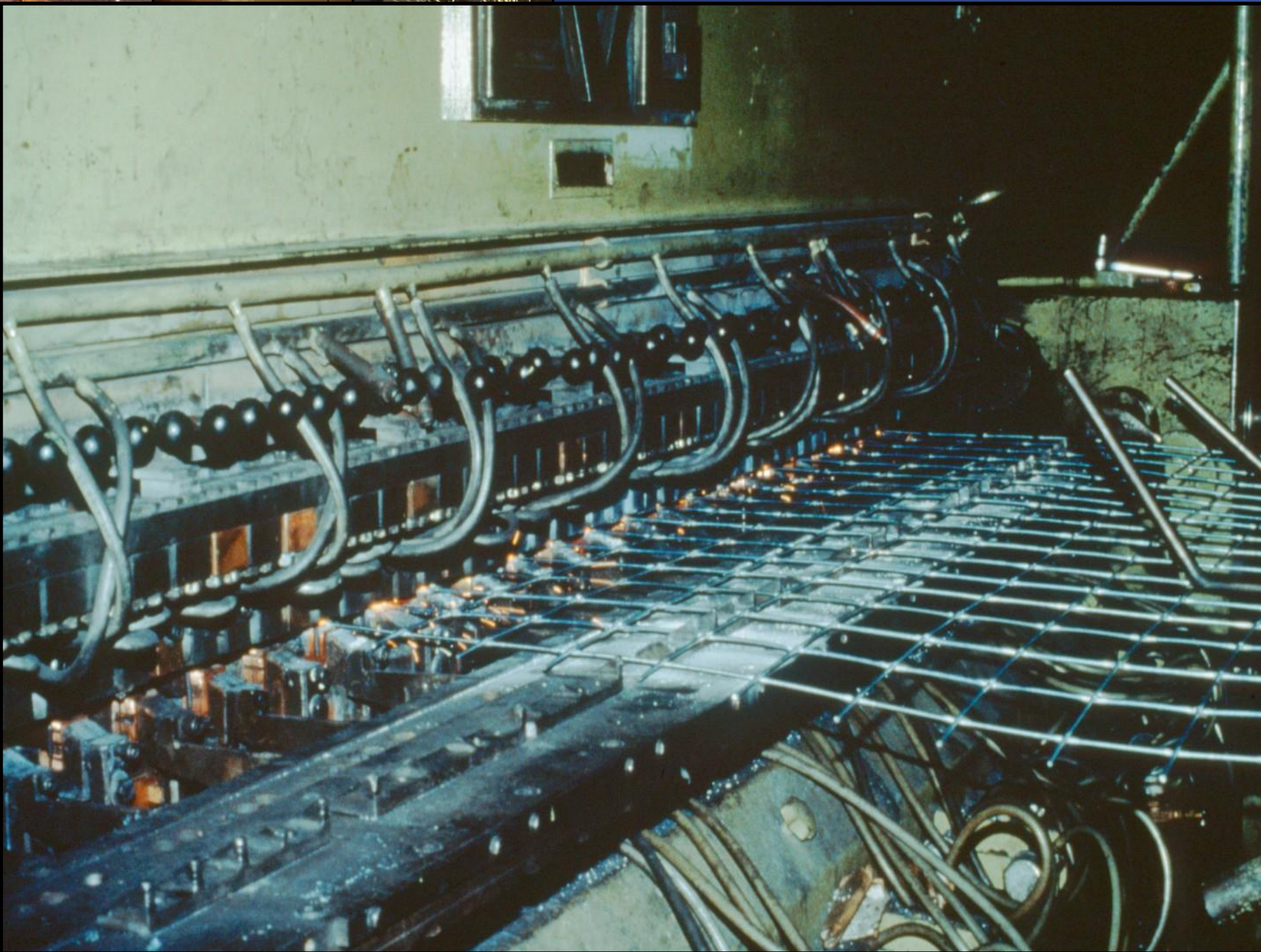


## Deformed Welded Wire Fabric

- Must conform to
  - ASTM A 497 “Specification for Steel Welded Wire Fabric, Deformed, for Concrete Reinforcement” (**now A1064**)
- Welded intersections must be spaced not more than 16 in.





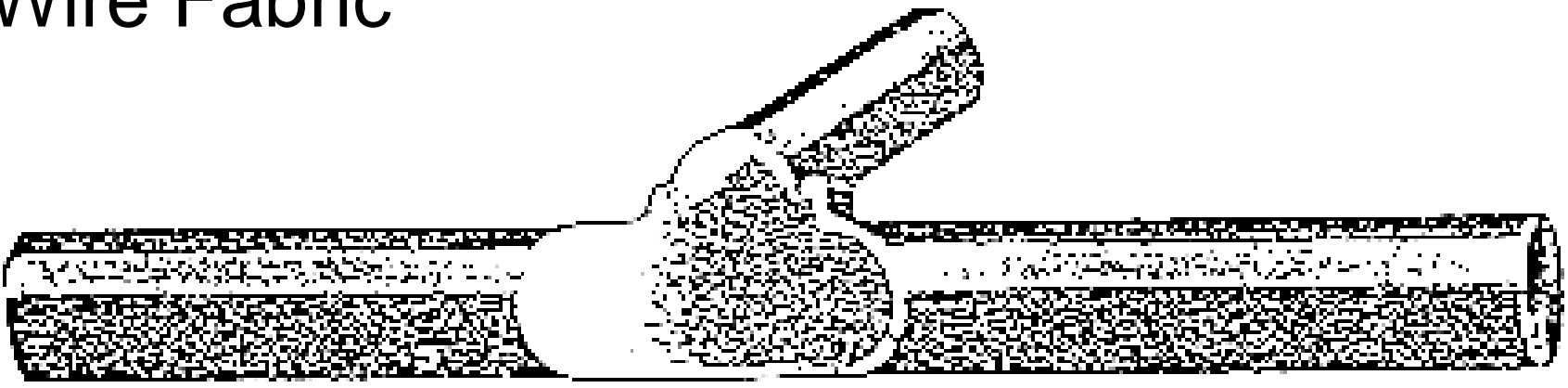




# QUALITY SCHOOL



## Welded Wire Fabric



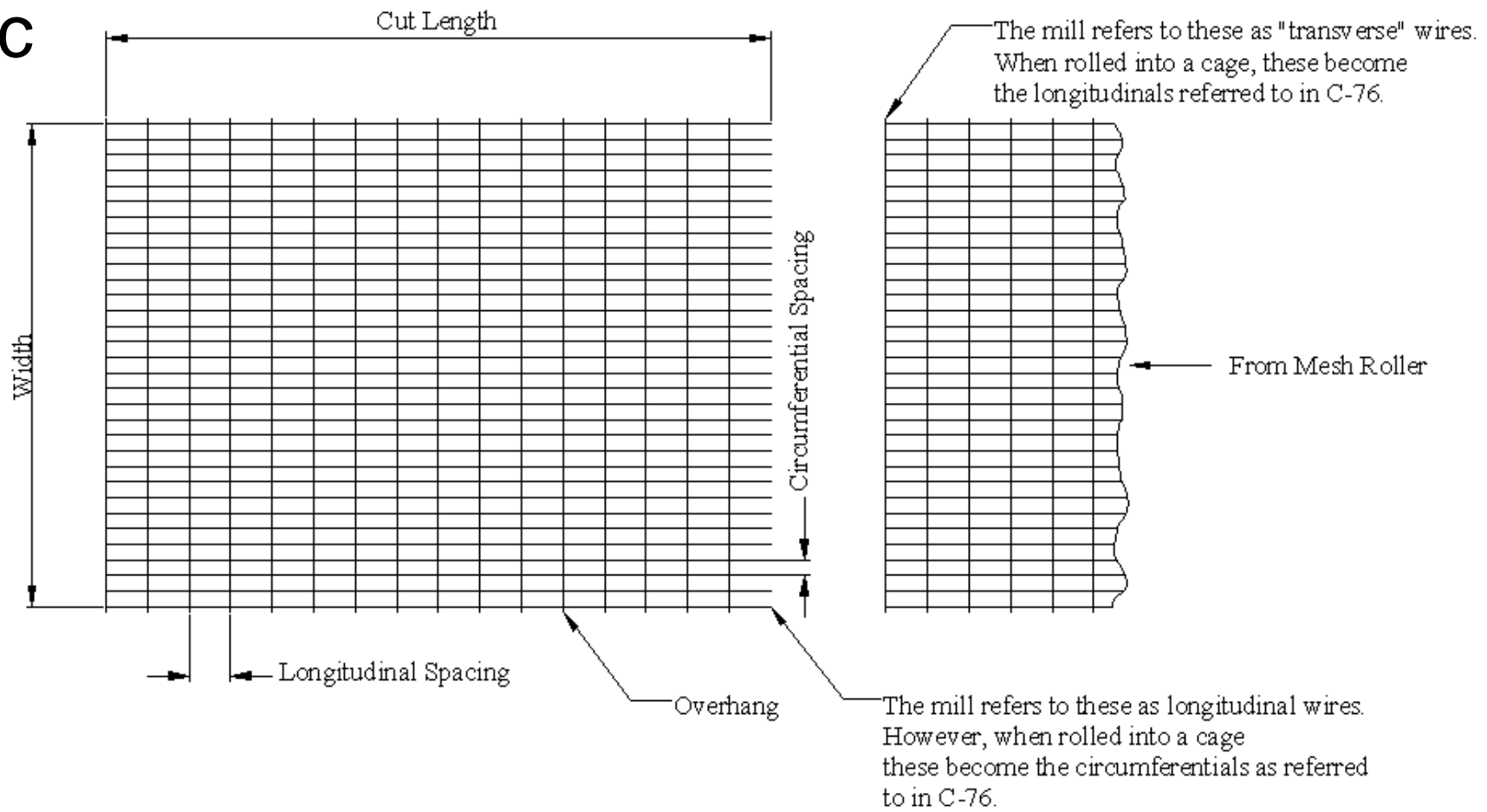
*Section at typical weld showing complete fusion of intersecting wires.*



# QUALITY SCHOOL



## Welded Wire Fabric

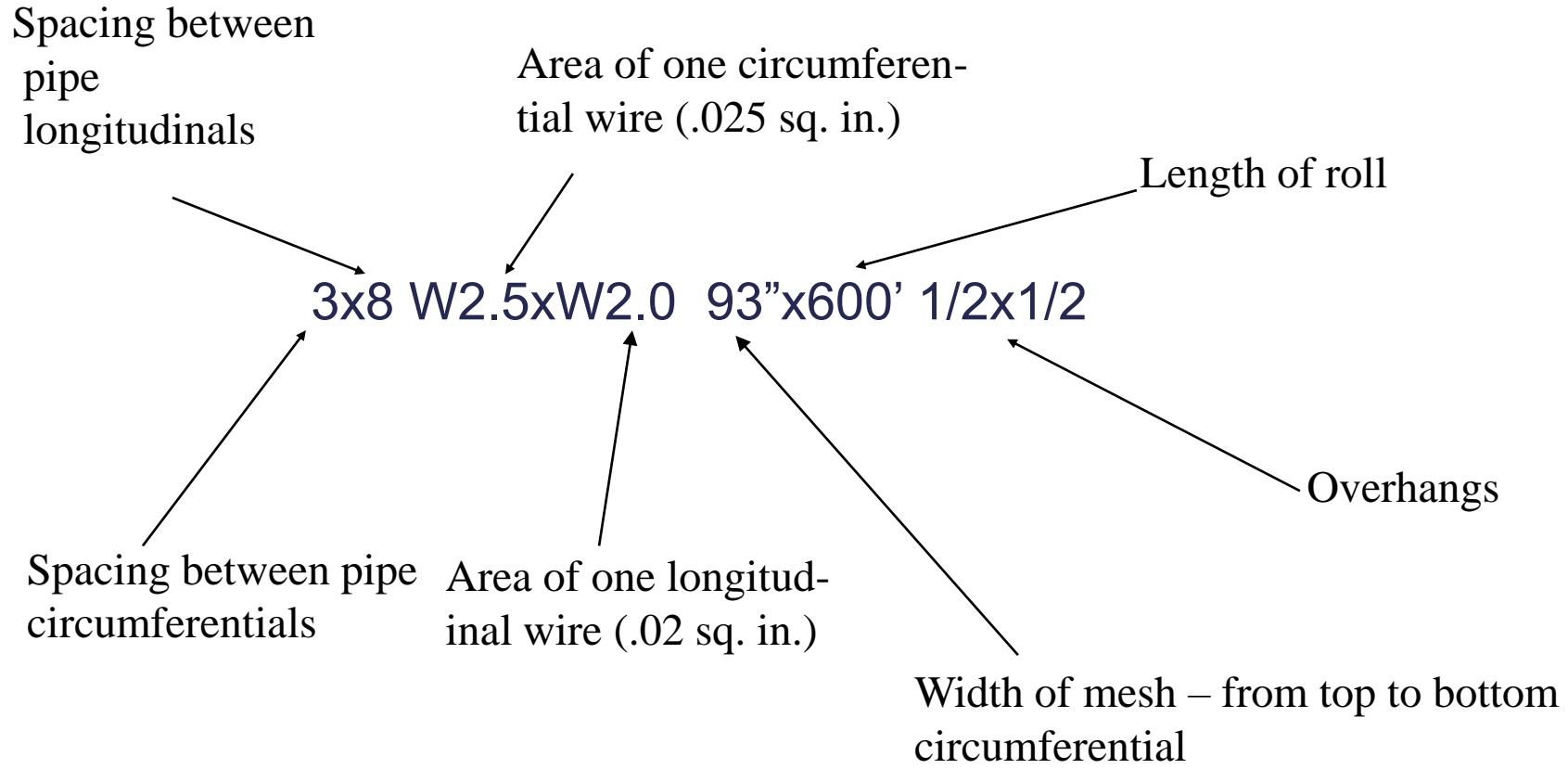




# QUALITY SCHOOL



## Cage Basics



W = Plain/Smooth, D = Deformed



# QUALITY SCHOOL



## Wire Size and Designation

- No. = Cross sectional Area in Hundredths of Sq. In.
- Thus
  - W5 = 0.05 Sq. In.
  - W5.5 = 0.055 Sq. In.
  - D10 = 0.10 Sq. In.





# QUALITY SCHOOL



## Cage Basics

- Given 3x8 W2.5xW2.0
- **What is the steel area per foot of pipe?**

$$A = 0.025 \times \frac{12}{3} = 0.10 \text{ in}^2/\text{ft}$$





# QUALITY SCHOOL



## Structural Integrity Depends on

- **Grade** of the reinforcing steel
- **Size** of the reinforcing steel
- **Spacing** of the reinforcing steel
- **Positioning** of the reinforcing steel

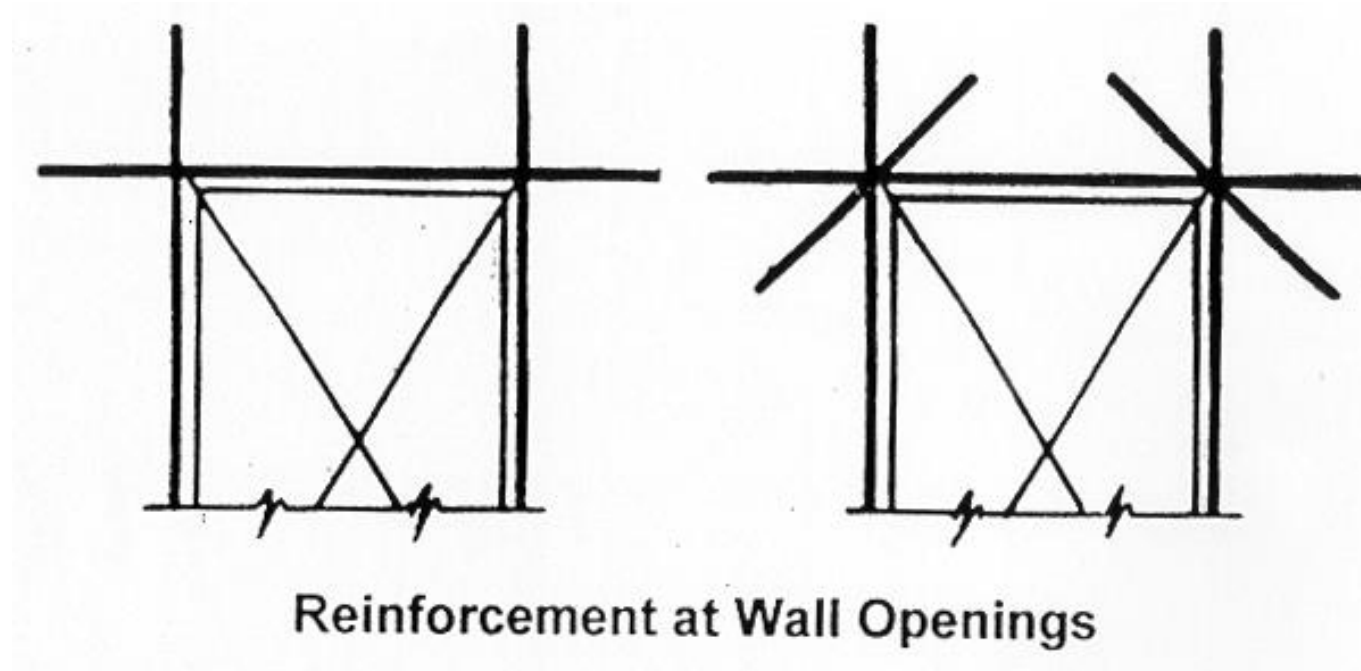




# QUALITY SCHOOL



## Positioning Reinforcement

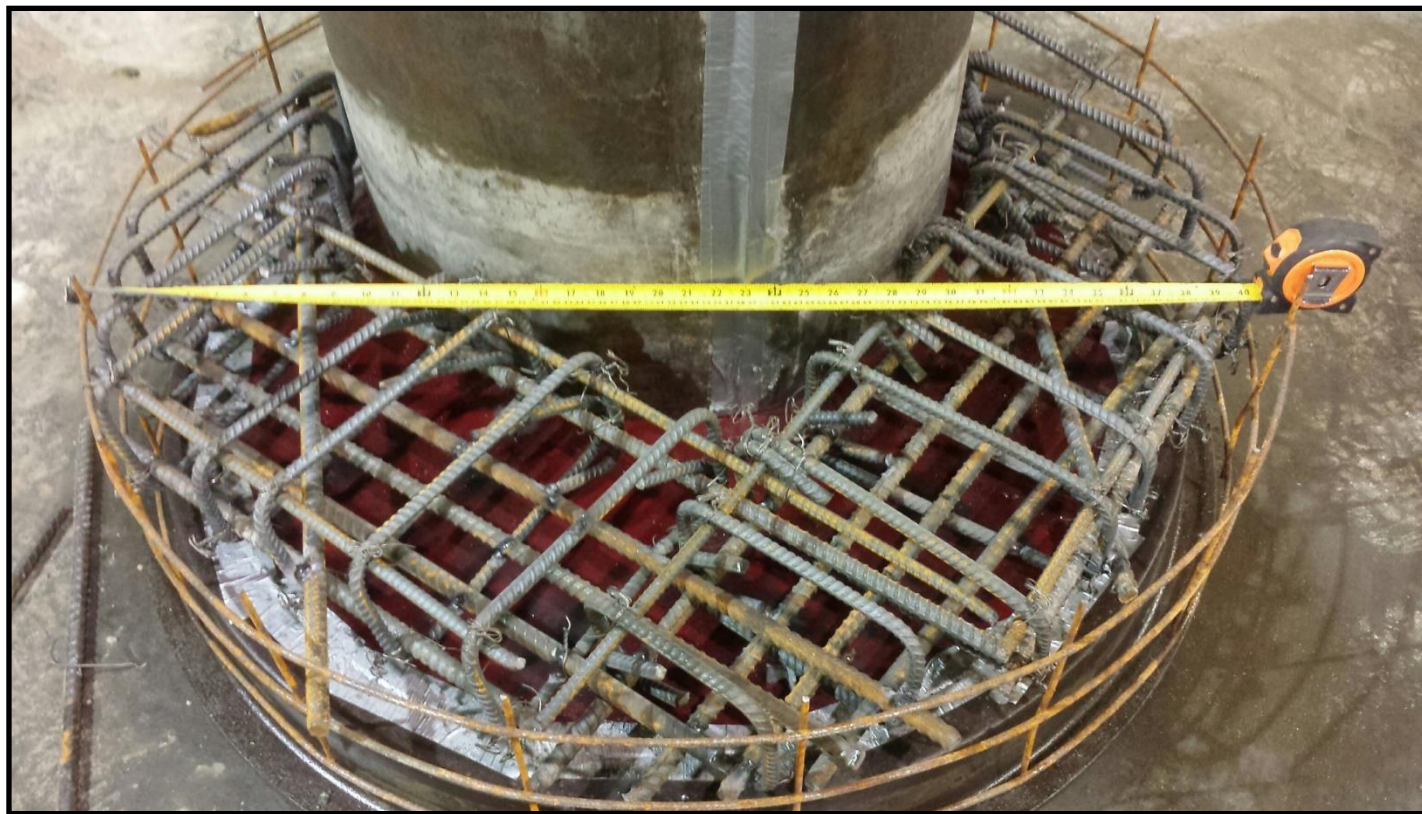




# QUALITY SCHOOL



## Positioning Reinforcement











# QUALITY SCHOOL



## Welding



# QUALITY SCHOOL



## Welding Requirements

### Welding of reinforcement

- Maintain product integrity
- Two weldability limits
  - Max. Carbon content (0.30%) [AWS D1.4]
  - Carbon equivalent (CE)
- ACI 318 And AWS D1.4, CE are:
  - For #6 And smaller - 0.55%
  - For #7 And larger - 0.45%
- The lower The CE, The better The weldability
- For larger CE values, The rebar must be preheated





# QUALITY SCHOOL



## ASTM A615 Reinforcement

### ASTM A615 rebar

- Must be used with extreme caution
- Generally not acceptable
- Check  $CE = \%C + \%Mn / 6$





SOLD TO: [REDACTED] **CERTIFIED MILL TEST REPORT**  
 TO: [REDACTED] **NUCOR STEEL SEATTLE, INC.**

Ship from: [REDACTED]

SHIP TO: [REDACTED]

Date: 30-Apr-2008  
 B.L. Number: 359150  
 Load Number: 205372

Material Safety Data Sheets are available at [www.nucorbar.com](http://www.nucorbar.com) or by contacting your inside sales representative.

NBMG-08 December 4, 2007

HEAT NUM. *	DESCRIPTION	PHYSICAL TESTS					CHEMICAL TESTS							
		YIELD P.S.I.	TENSILE P.S.I.	ELONG % IN 8"	BEND	WT% DEF	C Ni	Mn Cr	P Mo	S V	Si Cb	Cu Sn	C.E.	
PO# => SE0810110105	ROB - MAR,APR,MAY Nucor Steel Seattle, Inc. 19/#6 Rebar 20' A615M Gr 420 (Gr60) ASTM A615/A615M-08 GR 60[420]	95,930 661MPa	129,680 894MPa	9.4%	OK	-4.8%	.33 .09	1.30 .11	.019 .020	.043 .143	.23 .003	.44	.56	
PO# => SE0810163201	JULY-SEPT TONS Nucor Steel Seattle, Inc. 10/#3 Rebar 20' A615M GR 420 (Gr60) ASTM A615/A615M-08 GR 60[420]	70,181 484MPa	110,090 759MPa	16.4%	OK	-1.6%	.42 .10	.65 .13	.018 .030	.029 .006	.20 .012	.32	.55	
PO# => SE0810163301	JULY-SEPT TONS Nucor Steel Seattle, Inc. 10/#3 Rebar 20' A615M GR 420 (Gr60) ASTM A615/A615M-08 GR 60[420]	67,090 463MPa	106,409 734MPa	15.6%	OK		.41 .10	.63 .12	.015 .020	.036 .005	.20 .012	.34	.54	
PO# => SE0810168101	ROB - MAR,APR,MAY Nucor Steel Seattle, Inc. 16/#5 Rebar 20' A615M Gr 420 (Gr60) ASTM A615/A615M-08 GR 60[420]	68,838 475MPa	95,978 662MPa	14.8%	OK	-4.6%	.40 .12	.70 .14	.016 .030	.046 .005	.19 .016	.37	.54	
PO# => SE0810168203	ROB - MAR,APR,MAY Nucor Steel Seattle, Inc. 19/#6 Rebar 20' A615M Gr 420 (Gr60) ASTM A615/A615M-08 GR 60[420]	68,770 474MPa	92,910 641MPa	15.6%	OK	-3.8%	.28 .14	.77 .12	.015 .040	.034 .035	.21 .004	.39	.43	

All steel products produced at Nucor Steel Seattle are manufactured with over 98% recycled materials.

I HEREBY CERTIFY THAT THE ABOVE FIGURES ARE CORRECT AS CONTAINED IN THE RECORDS OF THE CORPORATION.

ALL MANUFACTURING PROCESSES OF THE STEEL MATERIALS IN THIS PRODUCT, INCLUDING MELTING, HAVE OCCURRED WITHIN THE UNITED STATES. ALL PRODUCTS PRODUCED ARE WELD FREE. MERCURY, IN ANY FORM, HAS NOT BEEN USED IN THE PRODUCTION OR TESTING OF THIS MATERIAL.

QUALITY ASSURANCE: [REDACTED]



# QUALITY SCHOOL



## ASTM A706 Reinforcement

### ASTM A706 rebar

- Is a low-alloy weldable grade
- Check CE =

$$\%C + \%Mn/6 + \%Cu/40 + \%Ni/20 + \%Cr/10 - \%Mo/50 - \%V/10$$





SOLD TO:



**CERTIFIED MILL TEST REPORT**

Page: 1

NUCOR STEEL SEATTLE, INC.

Ship from:



SHIP TO:



*(Handwritten signature: KAY)*

206-933-2222

Date: 29-Jul-2008

B.L. Number: 363694

Load Number: 209828



NUCOR SEATTLE

Material Safety Data Sheets are available at [www.nucorbar.com](http://www.nucorbar.com) or by contacting your inside sales representative.

REVISION 16, 2008

HEAT NUM. *	DESCRIPTION	PHYSICAL TESTS					CHEMICAL TESTS									
		YIELD P.S.I.	TENSILE P.S.I.	ELONG % IN 8"	BEND	WT% DEF	C	Ni	Mn	Cr	P	S	Si	Cu	Sn	C.E.
PO# => 9297 SE0810245201	Nucor Steel Seattle, Inc. 16/#5 Rebar 20' A706M(A706) ASTM A706/A706M-06a TEN/YD = 1.49	65,096 449MPa	96,818 668MPa	18.0%	OK	-3.6% .049	.26 .11	.76 .10	.014 .030	.042 .037	.19 .003	.37	.41			
PO# => 9297 SE0810276301	Nucor Steel Seattle, Inc. 13/#4 Rebar 20' A706M(A706) ASTM A706/A706M-06a TEN/YD = 1.33	66,237 457MPa	88,094 607MPa	16.4%	OK	-4.2% .038	.28 .11	.74 .10	.012 .030	.041 .032	.21 .003	.35	.42			
PO# => july, aug, sept SE0810386702	Nucor Steel Seattle, Inc. 19/#6 Rebar 20' A615M Gr 420 (Gr60) ASTM A615/A615M-08 GR 60[420]	65,034 448MPa	105,911 730MPa	14.1%	OK	-5.1% .049	.46 .09	.86 .07	.010 .020	.032 .005	.19 .019	.34	.62			

Received:

Jul 29 2008 00:48pm  
7 29 2008 12:43/ST 12:42/NO. 5560030413 P 1

I HEREBY CERTIFY THAT THE ABOVE FIGURES ARE CORRECT AS CONTAINED IN THE RECORDS OF THE CORPORATION.

ALL MANUFACTURING PROCESSES OF THE STEEL MATERIALS IN THIS PRODUCT, INCLUDING MELTING, HAVE OCCURRED WITHIN THE UNITED STATES. ALL PRODUCTS PRODUCED ARE WELD FREE. MERCURY, IN ANY FORM, HAS NOT BEEN USED IN THE PRODUCTION OR TESTING OF THIS MATERIAL.

QUALITY ASSURANCE:  Winky Lai



# Arc Welding

**Table 5.2**  
**Minimum Preheat and Interpass Temperatures<sup>(1), (2)</sup> (see 5.2.1)**

AWS D1.4		SMAW with Low-Hydrogen Electrodes, GMAW, or FCAW	
		Minimum Temperature	
Carbon Equivalent (C.E.) Range, % <sup>(3), (4)</sup>	Size of Reinforcing Bar	°F	°C
Up to 0.40	Up to 11 [36] inclusive	none <sup>(5)</sup>	none <sup>(5)</sup>
	14 and 18 [43 and 57]	50	10
Over 0.40 to 0.45 inclusive	Up to 11 [36] inclusive	none <sup>(5)</sup>	none <sup>(5)</sup>
	14 and 18 [43 and 57]	50	10
Over 0.45 to 0.55 inclusive	Up to 6 [19] inclusive	none <sup>(5)</sup>	none <sup>(5)</sup>
	7 to 11 [22 to 36]	50	10
	14 to 18 [43 to 57]	200	90
Over 0.55 to 0.65 inclusive	Up to 6 [19] inclusive	100	40
	7 to 11 [22 to 36]	200	90
	14 to 18 [43 to 57]	300	150
Over 0.65 to 0.75	Up to 6 [19] inclusive	300	150
	7 to 18 [22 to 57] inclusive	400	200
Over 0.75	Up to 6 [19] inclusive	300	150
	7 to 18 [22 to 57] inclusive	500	260

**Notes:**

- (1) When reinforcing steel is to be welded to main carbon steel, the preheat requirements of the structural steel shall also be considered (see AWS D1.1, table titled "Prequalified Minimum Preheat and Interpass Temperature.") The minimum preheat requirement to apply in this situation shall be the higher requirement of the two tables. However, extreme caution shall be exercised in the case of welding reinforcing steel to quenched and tempered steels, and such measures shall be taken as to satisfy the preheat requirements for both. If not possible, welding shall not be used to join the two base metals.
- (2) Welding shall not be done when the ambient temperature is lower than 0°F [-18°C]. When the base metal is below the temperature listed for the welding process being used and the size and carbon equivalent range of the bar being welded, it shall be preheated (except as otherwise provided) in such a manner that the cross section of the bar for not less than 6 in. [150 mm] on each side of the joint shall be at or above the specified minimum temperature. Preheat and interpass temperatures shall be sufficient to prevent crack formation.
- (3) After welding is complete, bars shall be allowed to cool naturally to ambient temperature. Accelerated cooling is prohibited.
- (4) Where it is impractical to obtain chemical analysis, the carbon equivalent shall be assumed to be above 0.75%. See also 1.3.4.3.
- (5) When the base metal is below 32°F [0°C], the base metal shall be preheated to at least 70°F [20°C], or above, and maintained at this minimum temperature during welding.



## Pre-Heating Guidelines

If the chemical compositions of the rebars are not known, the following preheat guidelines are offered by ANSI/AWS D1.4.

1. For bars number 6 or less, use a minimum preheat of 300°F
2. For bars number 7 or larger, use a minimum preheat of 400°F
3. For all ASTM A706 bars sizes, use tabulated values for CE values of "over 0.45% to 0.55% inclusive."



# QUALITY SCHOOL



# Fabrication

















# QUALITY SCHOOL



## ACI 318 – Details of Reinforcement

- Standard Hooks
- Minimum Bend Diameters



# QUALITY SCHOOL



## Minimum Bend Diameters – ACI 318

Bar Size	Minimum Diameter
No.3 - No.8	$6d_b$
No.9, No.10, No.11	$8d_b$
No.14 and No.18	$10d_b$

$d_b$  = diameter of the bar  
Not for Hooks or Stirrups



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# QUALITY SCHOOL



## Minimum Bend Diameters – ASTM A1064

- All bends described in terms of inside diameter
- Factors affecting minimum bend diameters
  - Feasibility of bending without breaking
  - Avoidance of concrete crushing inside the bend
- Welded wire fabric
  - W7 and smaller  $1d_b$
  - Larger than W7  $2d_b$
  - D6 and smaller  $2d_b$
  - Larger than D6  $4d_b$

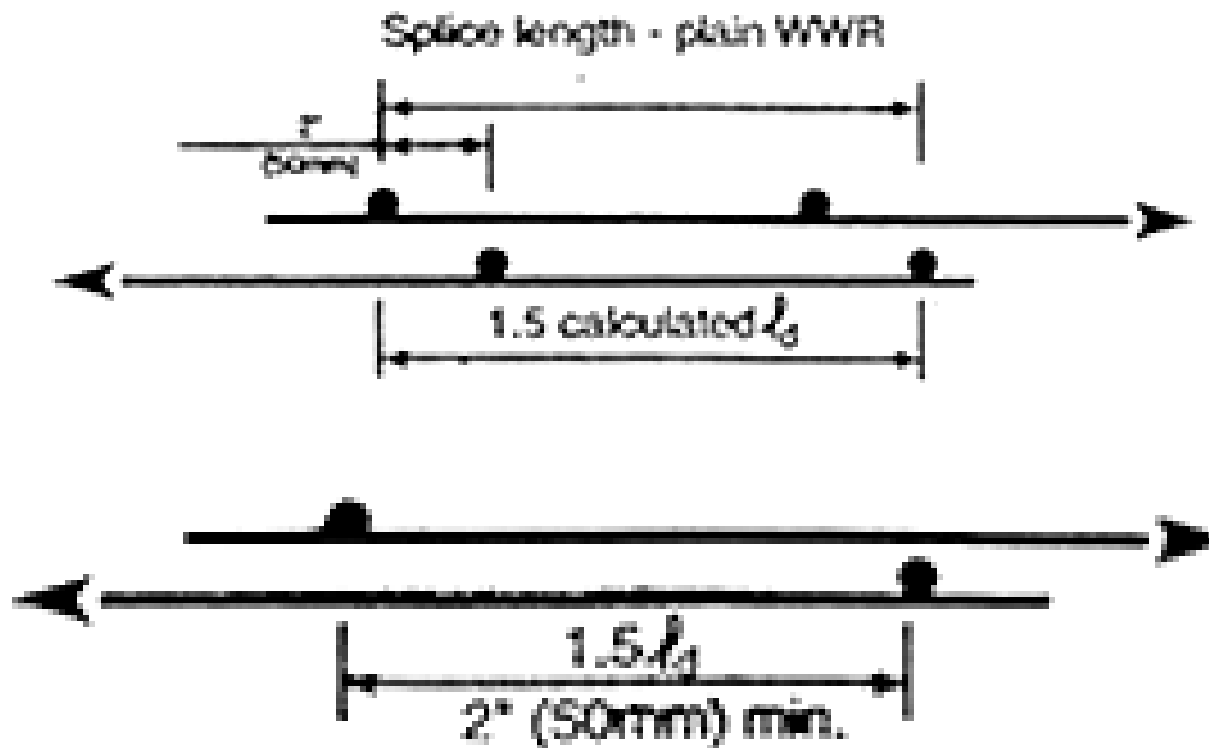




# QUALITY SCHOOL



## Plain Wire Splice Length – ACI 318

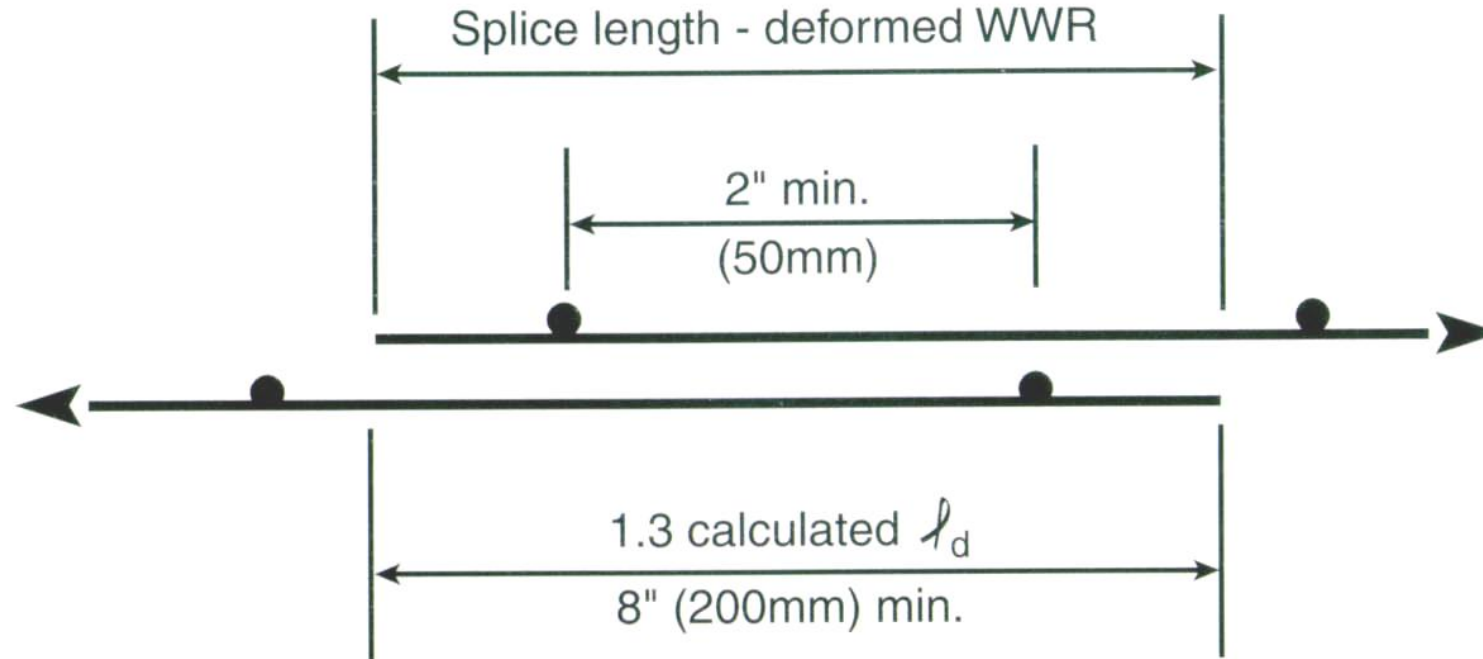




# QUALITY SCHOOL



## Deformed Wire Splice Length – ACI 318





# QUALITY SCHOOL



# Specifications



# QUALITY SCHOOL



## ASTM C76

- Section 7.1 – Design Tables
  - Tables 1 – 5
  - Specify minimum required steel area
- Section 7.2 – Modified/Special Designs
  - Permitted for situations not covered by the design tables
  - Submit proof of adequacy of the design
  - Must be approved by the owner





# QUALITY SCHOOL



## ASTM C76

- Section 8.1.5 – Circ. Wire Spacing
  - Based on wall thickness
  - 4” Max for up to 4” wall thickness
  - Equal to wall thickness for 4” – 6” wall thickness
  - 6” absolute maximum
- **What Is A Proper Number Of Longitudinals?**
- Section 8.2 – Longitudinals
  - Not specified , must contain sufficient longitudinal bars or members, to maintain the reinforcement in shape and in position within the form



# QUALITY SCHOOL



## ASTM C76

- Section 8.1
- What Is A “Line” Of Reinforcement & What Is A “Layer” Of Reinforcement?
  - A “Line” may be made of a single Layer or multiple Layers
  - Two layers allowed for pipe wall less than 7”
  - Three layers allowed for pipe wall 7” or larger
  - Layers separated by maximum thickness of one longitudinal + 1/4”





# QUALITY SCHOOL



## ASTM C76

- Section 8.1.1 - Single Cage
  - Placed 35% - 50% of wall thickness from inside wall
  - Pipe with wall thickness  $< 2 \frac{1}{2}$ " , Cover =  $\frac{3}{4}$ "
- Section 8.1.2 - Double Cage
  - Circular Cages - Concrete cover = 1"
- Section 8.1.3 – Elliptical Cage
  - Elliptical Cages – Cover = 1" from wall in tension ( $\frac{3}{4}$ " for wall  $< 2 \frac{1}{2}$ " )
- Section 8.1.4
  - Location of reinforcement subject to permissible variations of Section 12.5





# QUALITY SCHOOL



## ASTM C76

- Section 12.5 - Permissible Variations
  - Position of reinforcement, +/- 10% of wall thickness, or +/- 1/2" whichever is greater
- **If your cage is outside this permissible variation, is the pipe automatically rejected?**
  - Variations exceeding those above shall be accepted if D-load passes
  - Must maintain minimum cover requirements (1/2" from any surface except: 1/4" from end of spigot, mating surfaces of nonrubber gasket joints or gasket groove)



# QUALITY SCHOOL



## ASTM C76

- Section 8.3 - Joint Reinforcement
- Non-rubber gasket joint
  - For pipe 36" & larger, either the bell or spigot shall contain circumferential reinforcement
- Rubber gasket joint
  - For pipe 12" & larger, the bell ends shall contain circumferential reinforcement





# QUALITY SCHOOL



## ASTM C76

- Section 8.1.8 - Splices
- Welding
  - Lap = min 2", and a weld of sufficient length that pull test = at least 50% of min specified tensile strength of the steel
  - butt-welded splices permitted only with helically wound cages, Strength = 75% of min specified strength of the steel
- Lapping
  - Lap = 20/40 Bar Diameters (Deformed/Plain)
  - WWF lap must contain a longitudinal









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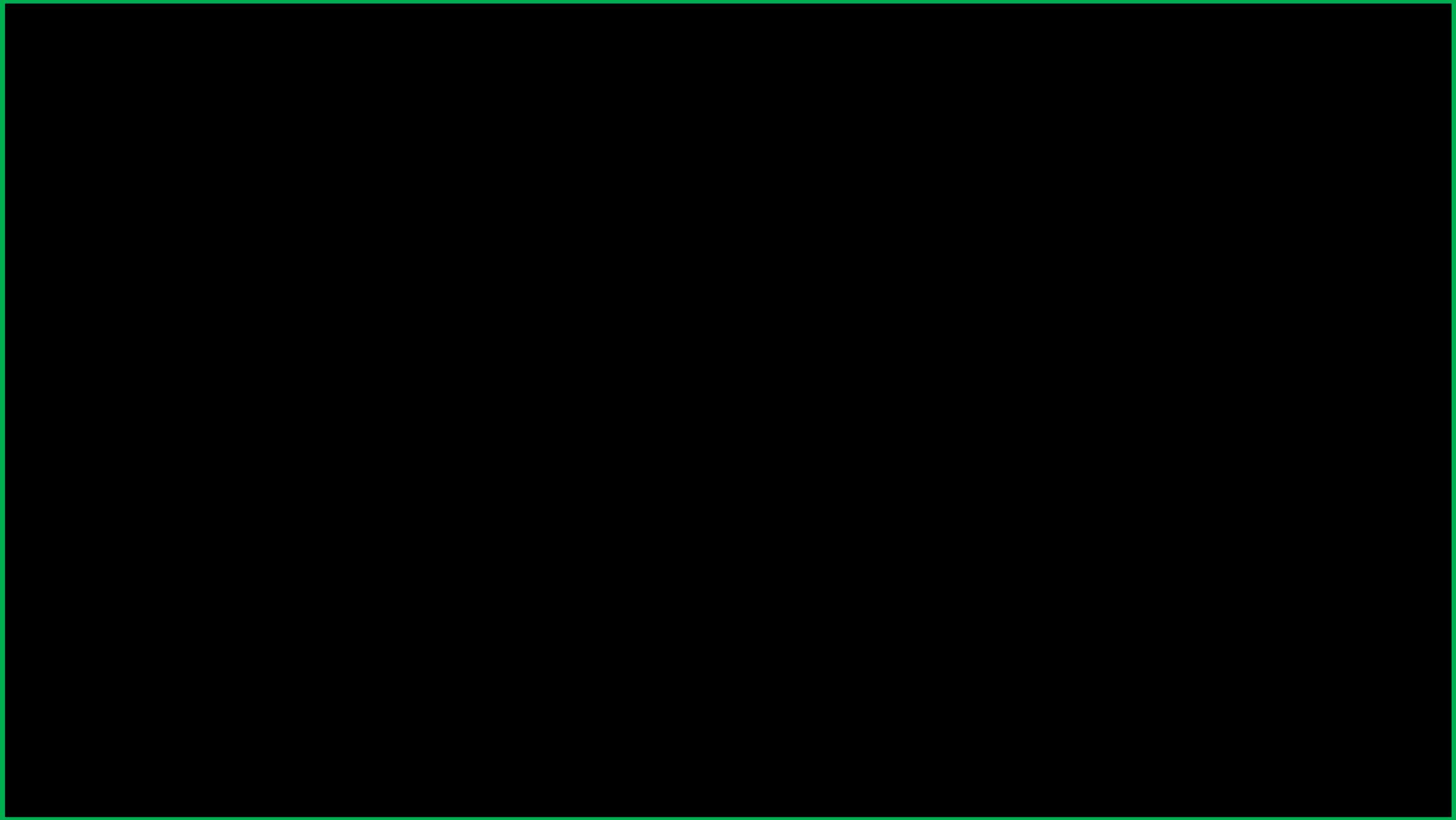
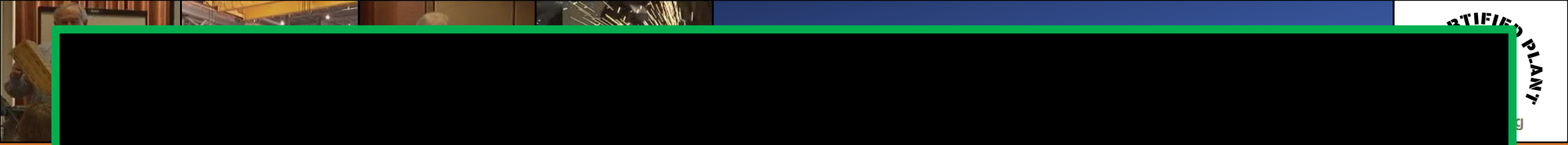


# QUALITY SCHOOL



## ASTM C478

Sections 6.4.1 and 6.4.2 contain the same wording as for Sections 8.1.8 and 8.1.8.1 of ASTM C76





# QUALITY SCHOOL



## ASTM C76

- Spacers & Chairs
- How many spacers/chairs should you have & where should they be placed?
- Section 8.2
  - The exposure of the ends of longitudinals, stirrups, or spacers that have been used to position the cages during the placement of the concrete shall not be a cause for rejection.

**Use enough to maintain the cage in place!**



# QUALITY SCHOOL



## ASTM C1433/1577

- Section 7 – Design
  - Design Tables
  - Modified/Special designs are allowed
  - Circ. Spacing = 2”–4”, Long spacing = 8” max
- Section 7.3 – Placement of Reinforcement
  - Subject to permissible variations of Section 12
- Section 7.4 – Laps & Welds
  - All splices made by lapping
  - Beware the Restricted Welding Zones!





# QUALITY SCHOOL



## ASTM C1433/1577

- Section 7.4 – Laps
  - The overlap measured between the outermost longitudinal wires of each fabric sheet shall not be less than the spacing of the longitudinal wires plus 2 in. but not less than 10 in.





# QUALITY SCHOOL



## ASTM C1433/1577

Do you know the  
Restricted  
Welding Zones?

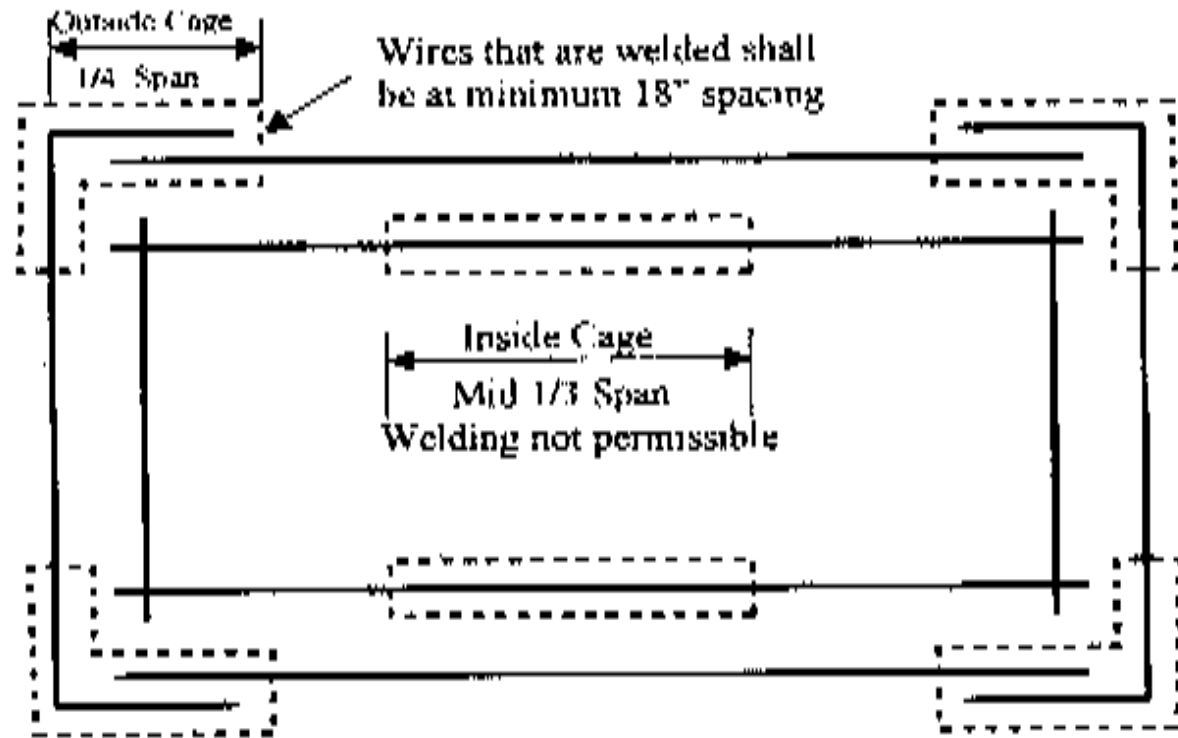


FIG. 9 Critical Zones of High Stress Where Welding is Restricted



# QUALITY SCHOOL



## What Makes a Good Cage?

- Right Steel Areas (Circumferential & Longitudinal)
- Correct Cage Dimensions
- Proper Lap &/or Good Welds
- Proper Spacers & Chairs
- Meet Specifications





## Two New Fiber Pipe ASTM Standards

### 1. C1765 – Steel Fiber Reinforced Concrete Culvert, Storm Drain, and Sewer Pipe (SFRCP) - 2013

- a) 12" – 48"
- b) Class I, II, III, IV, V
- c)  $D_{service}$  and  $D_{test}$  loads –  $D_{test}$  is 1.5 times  $D_{service}$
- d) Proof of Design Test to  $D_{ultimate}$

### 2. C1818 – Synthetic Fiber Reinforced Concrete Culvert, Storm Drain, and Sewer Pipe (Syn-FRCP) - 2015

- a) 12" – 48"
- b) Class I, II, III, IV, V
- c)  $D_{service}$ ,  $D_{test}$  and  $D_{reload}$  loads –  $D_{test}$  is 1.5 times  $D_{service}$
- d)  $D_{reload} = D_{service}/\alpha$
- e)  $\alpha$  is a long-term serviceability factor



# Questions?

Mel Marshall

Mel@[mcmconsultants.ca](mailto:mcmconsultants.ca)