Myth and Misinterpretation of "Overdesign"

Ken Hover
Disciple of, and Reader of Stuff written by,
Bruce Suprenant

Bruce Suprenant

Our Friend, Coach, Mentor, and Grounding-Rod to Keep us Real

Popular Acclaim

"For many years, Suprenant was a fixture at the World of Concrete, often appearing as the master of ceremonies for the Mega-Demos in jeans, work boots, and a tuxedo shirt, jacket, and bow tie. "

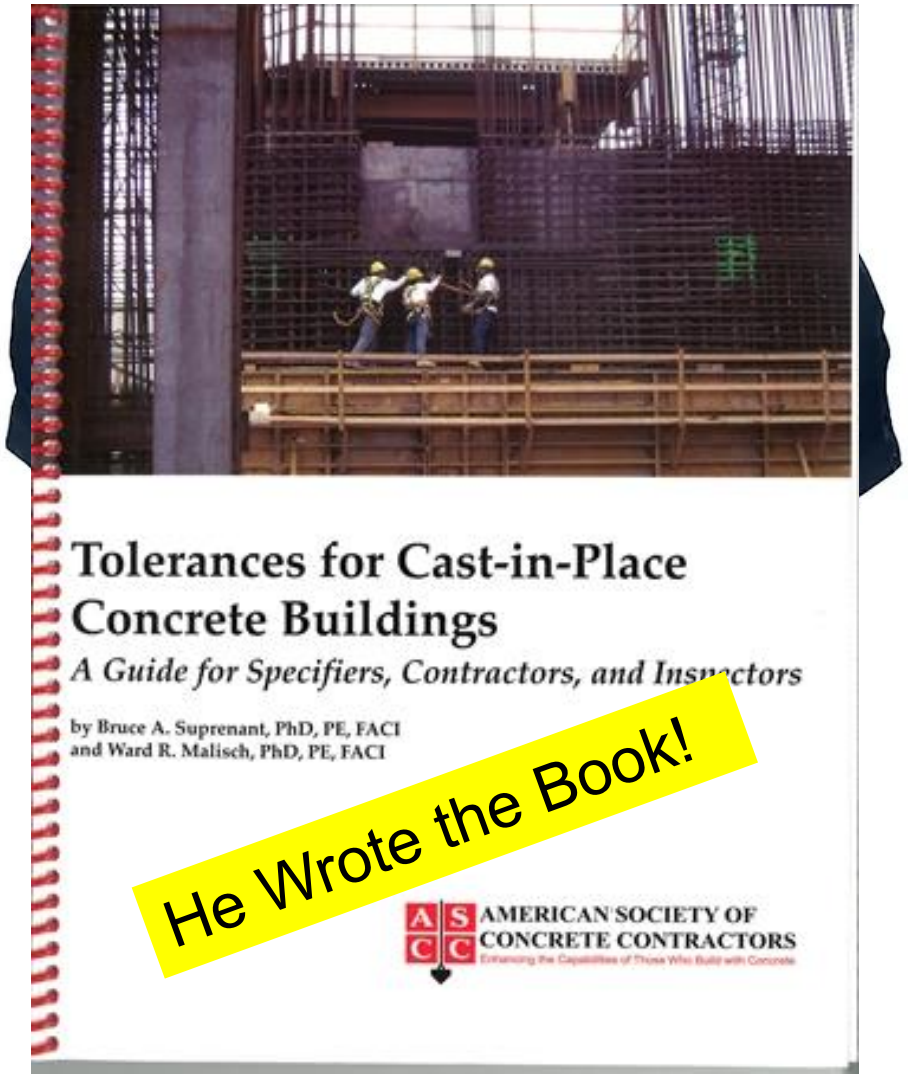
BLACK TIE & BLUE JEANS

Bruce is a man of many moods

aci CONCRETE CONVENTION

Bruce’s Wardrobe beyond Black Tie & Jeans:

Bruce's Wardrobe beyond Black Tie & Jeans:




Concrete too thick!
University of Tennessee


Pavement too wide!
Gomaco


Too much Rebar!
Concrete Construction


Baker Concrete

OVERDESIGN?


Too much concrete!
RepublicBank Center


Way too much Rebar!
Concrete Construction


The Constructor

Myth and Misinterpretation of "Overdesign"

- **Focus on Concrete Cylinder Strength, f'_c**

Example:

Specified Compressive Strength, f'_c = 5000 psi

Required Average Cylinder Strength, f'_{cr} = 5470 psi

470 psi = *"^*&%%^&*" Overdesign"*

Insert colorful or (off-colorful) sarcastic adjective

Misinterpretations of “Overdesign”

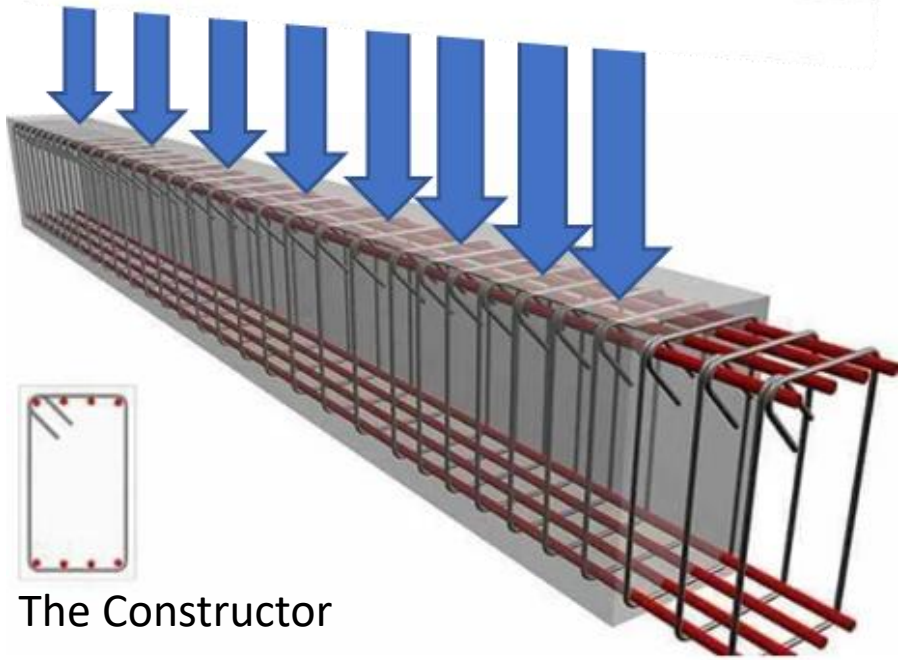
- *“Costs Money, Consumes Resources, Carbon Footprint.”*
- *“Arbitrary, Conservative, Building-Code Imposition.”*
- *“Convoluted way to get higher strength than specified.”*
- *“Specifications Bait and Switch.”*
- *“Why didn’t they just specify*

  5470 instead of 5000 psi in the first place?”

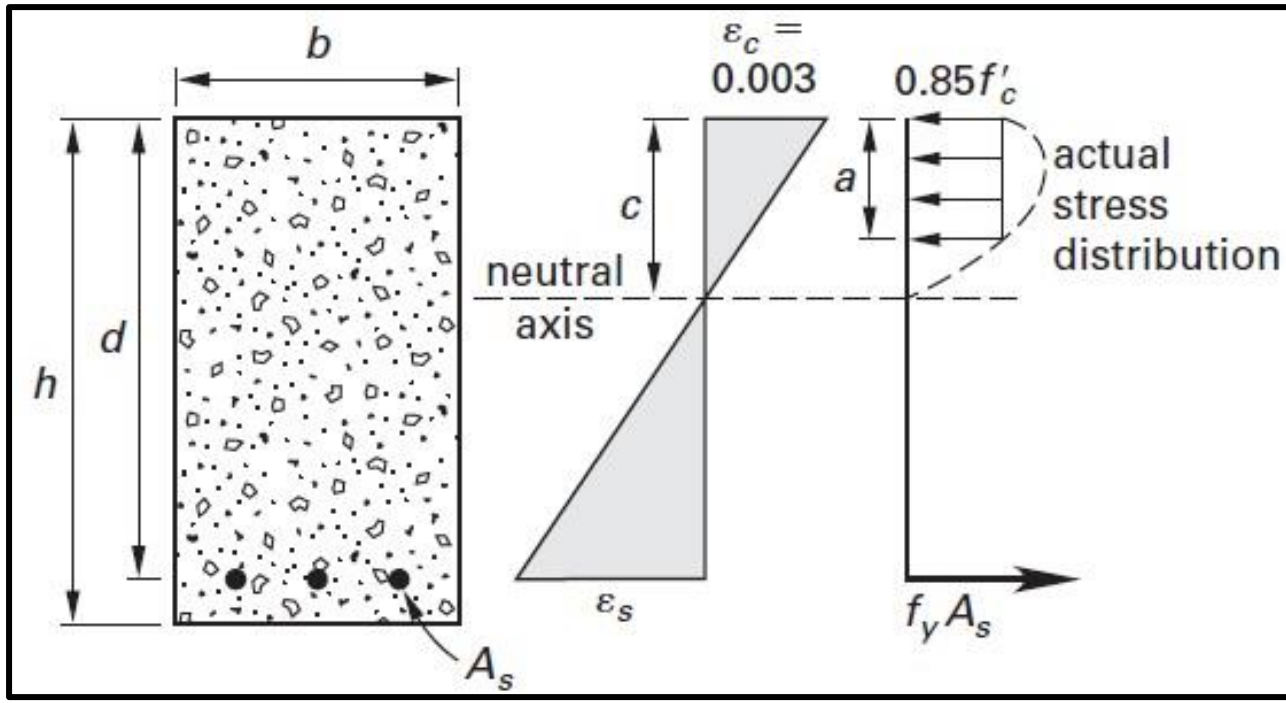
Constructive interpretations of “Overdesign”

- *Increases safety & reliability of concrete structures.*
- *Defines tolerance for strength tests.*
- *Reduces time spent dealing with apparent low breaks.*

f'_c Based on Resistance to Load



The Constructor



Civil Engineering Bible.com

$$Bending\ Moment\ Capacity = \emptyset M_n = \emptyset A_s f_y \left(d - \frac{A_s f_y}{1.7 f'_c b}\right)$$

Cross sectional area of rebar

Yield strength of rebar

Depth from compression face to center of rebar

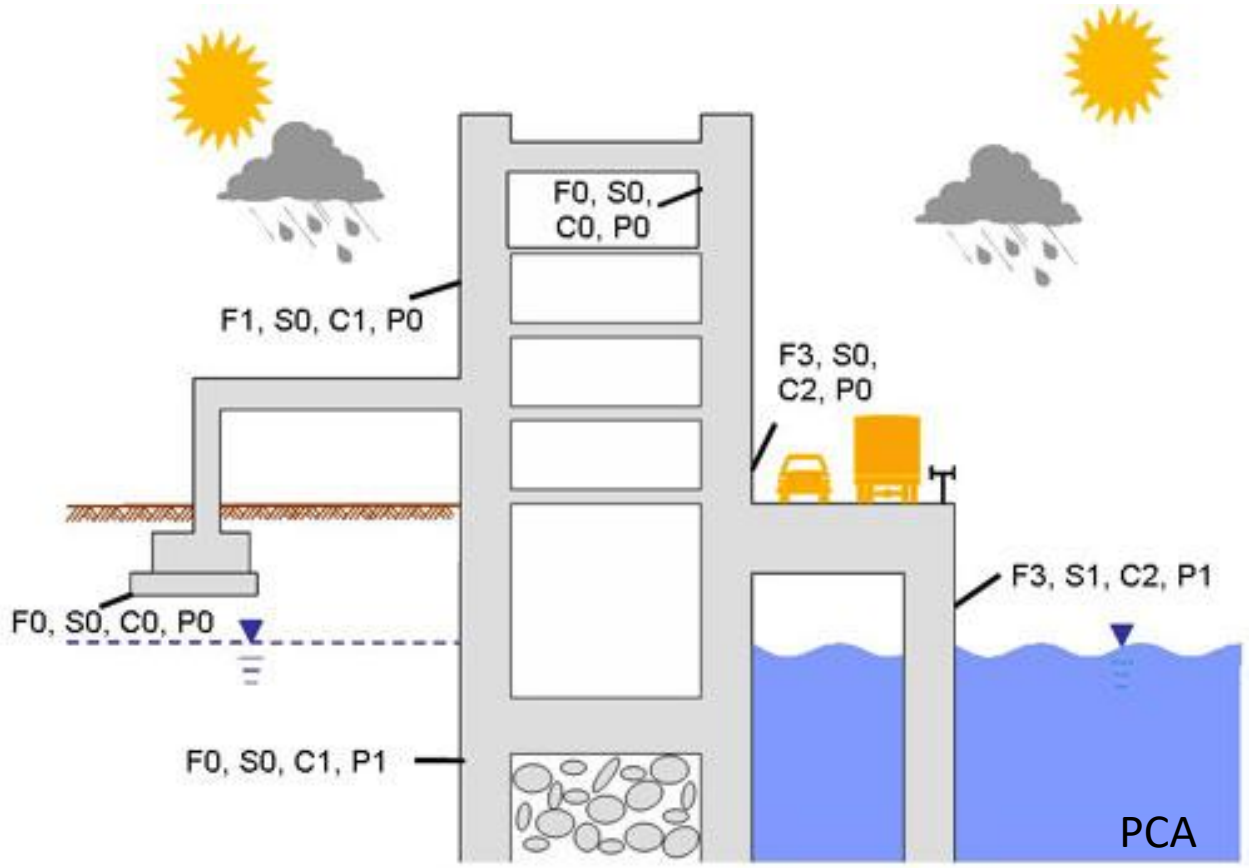
Specified compression strength of concrete

Width of beam

f'_c Based on Resistance to Environmental Exposure

ACI 318-19

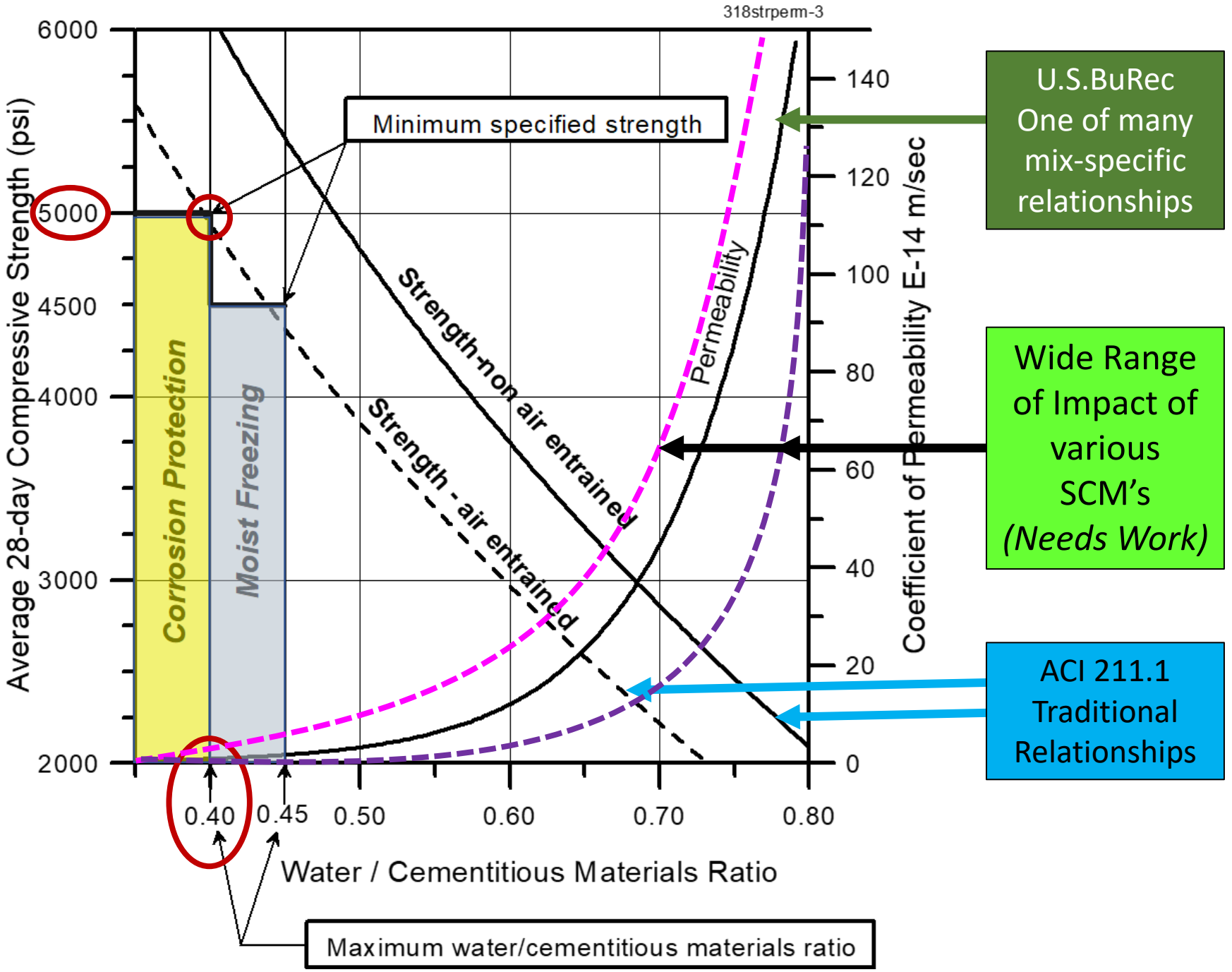
Exposure	
F0	Not exposed to freezing & thawing cycles
F1	Exposed to freezing-and-thawing cycles with limited exposure to water
F2	Exposed to freezing-and-thawing cycles with frequent exposure to water
F3	Exposed to freezing-and-thawing cycles with frequent exposure to water and exposure to deicing chemicals
C0	Concrete dry or protected from moisture
C1	Exposed to moisture but not external source of chlorides
C2	Exposed to moisture and external source of chlorides from deicing chemicals, salt, brackish water, seawater, or spray from these sources



f'_c Based on Resistance to Environmental Exposure

ACI 318-19

Exposure		Maximum w/cm	Minimum *f'c* *(psi)*
F0	Not exposed to freezing & thawing cycles	N/A	2500
F1	Exposed to freezing-and-thawing cycles with limited exposure to water	0.55	3500
F2	Exposed to freezing-and-thawing cycles with frequent exposure to water	0.45	4500
F3	Exposed to freezing-and-thawing cycles with frequent exposure to water and exposure to deicing chemicals	0.40	5000
C0	Concrete dry or protected from moisture	N/A	2500
C1	Exposed to moisture but not external source of chlorides	N/A	2500
C2	Exposed to moisture and external source of chlorides from deicing chemicals, salt, brackish water, seawater, or spray from these sources	0.40	5000


318strperm-3
Average 28-day Compressive Strength (psi)
6000
5000
4500
4000
3000
2000
Coefficient of Permeability E-14 m/sec
140
120
100
80
60
40
20
0
Minimum specified strength
Strength-non air entrained
Strength - air entrained
Permeability
Corrosion Protection
Moist Freezing
0.40
0.45
0.50
0.60
0.70
0.80
Water / Cementitious Materials Ratio
Maximum water/cementitious materials ratio
U.S.BuRec
One of many
mix-specific
relationships
Wide Range
of Impact of
various
SCM's
(Needs Work)
ACI 211.1
Traditional
Relationships

Example: C2 (Corrosion) & F3 (F-T Deicing Salt) Exposure

f'_c Based on Resistance to Load & Structural Performance

4500 psi

f'_c Based on Resistance to Environmental Exposure

C2: 5000 psi

F3: 5000 psi

Minimum "Specifiable" Value: 5000 psi

Dwngs & Specs:

f'c = 5000 psi


Demcon Concrete Contractors


Cornell, October –April

So far , so Good. No "Overdesign" Yet!

Dwngs & Specs:

f'c = 5000 psi

If specified cylinder strength = 5000 psi,
is it OK if average cylinder strength = 5000 psi?

If AVERAGE Cylinder Strength = 5000 psi:

Good News: Half your breaks are stronger than required!

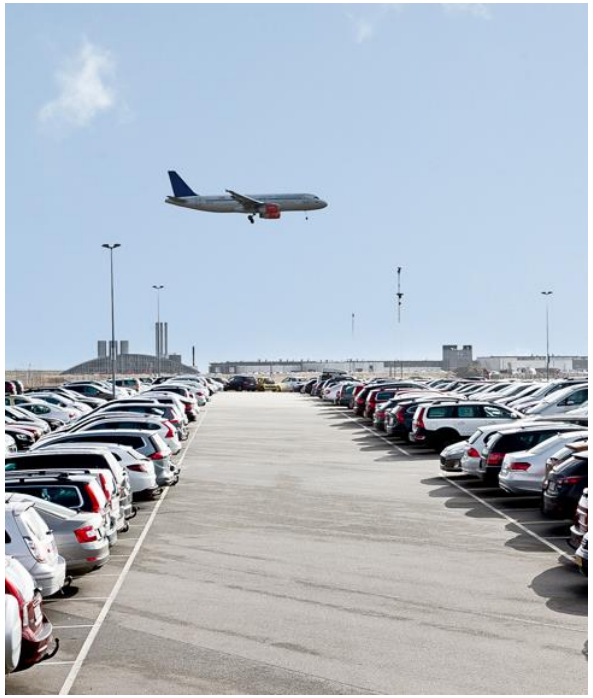
Bad News: Half your breaks are weaker than required!

If AVERAGE cylinder strength = 5000 psi
50% chance of meeting specs!

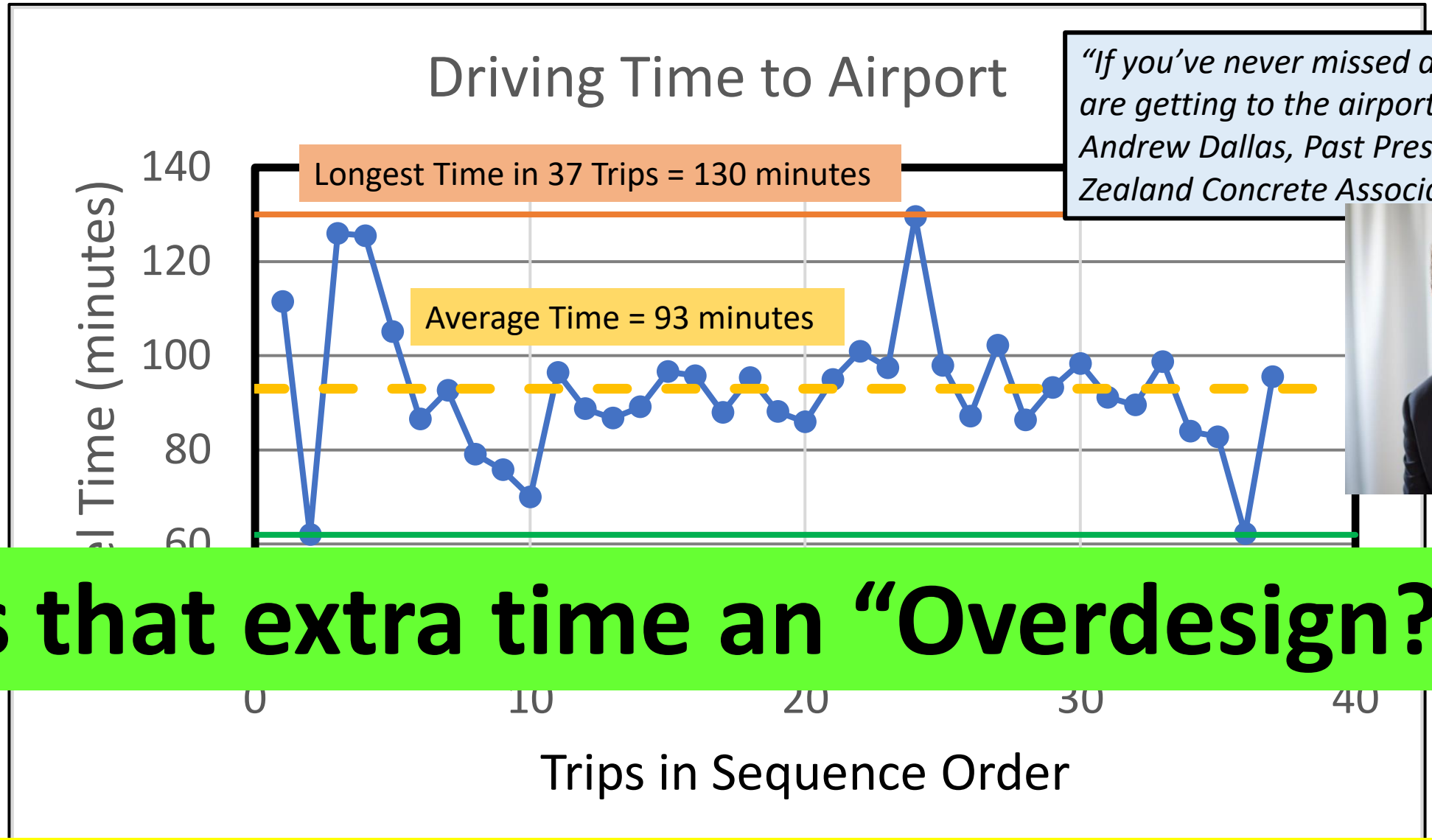
What's the lowest average strength consistent with 99% specification compliance?

A Related “Overdesign” Problem:

How much extra time do you allow to get to airport?



If you plan for exactly the average, you'll be late 50% of time



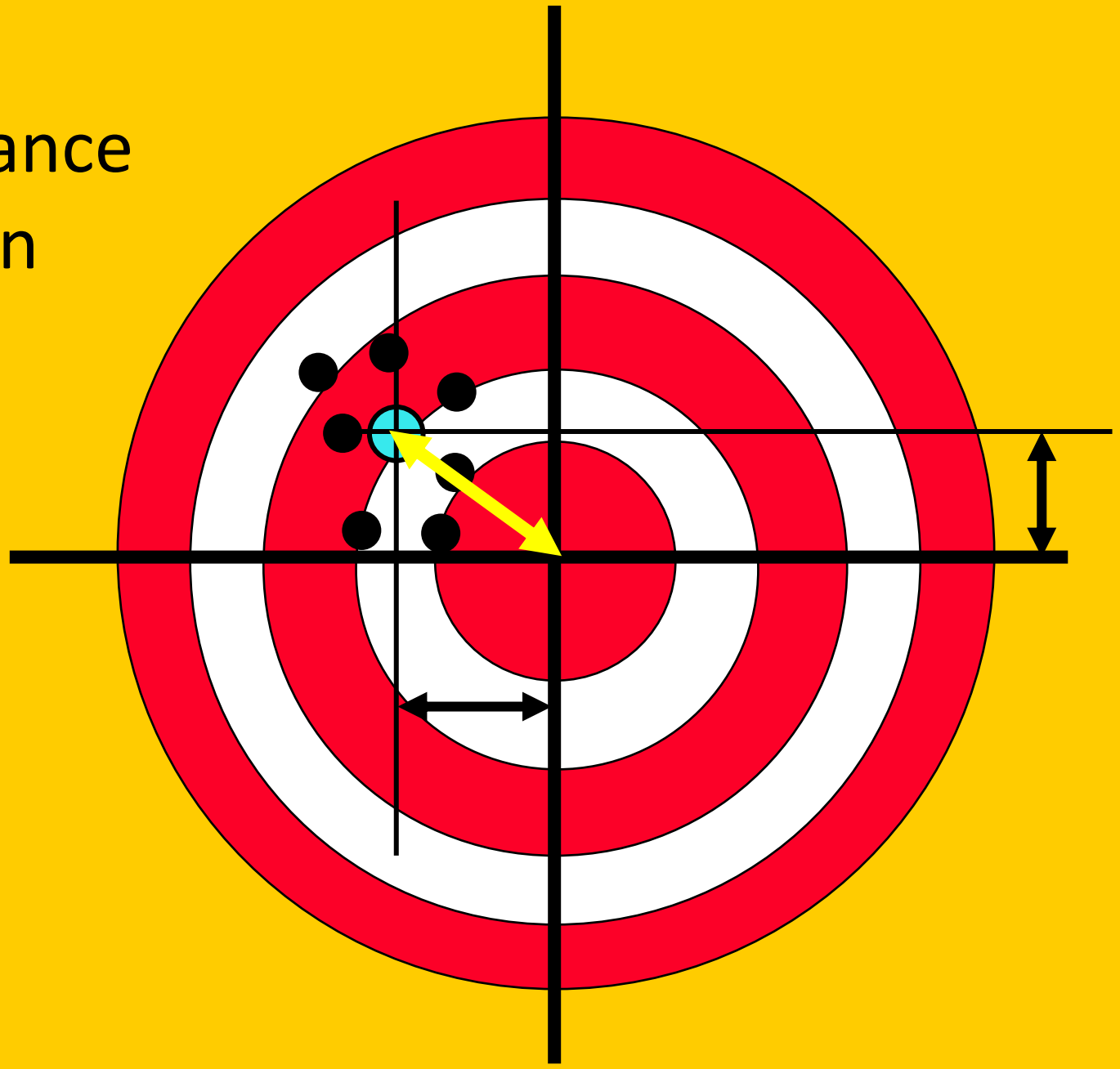
"If you've never missed a plane, you are getting to the airport too early!" Andrew Dallas, Past President, New Zealand Concrete Association

Is that extra time an "Overdesign?"

How much extra time do you allow to get to airport?

Target Analogy

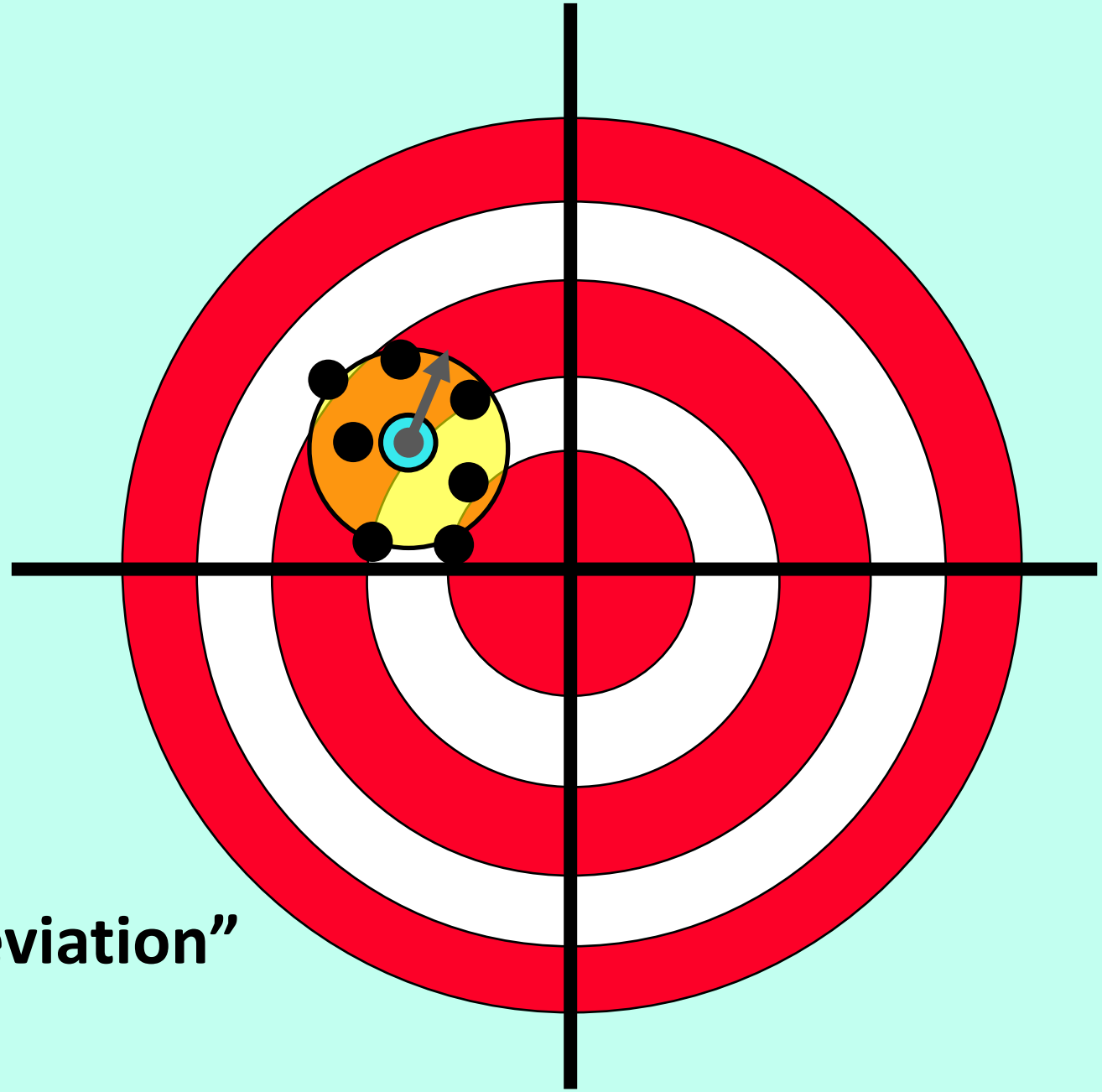
“Accuracy” indicates distance
from Center of Shot Pattern
(= “Average”)
to
Center of Target



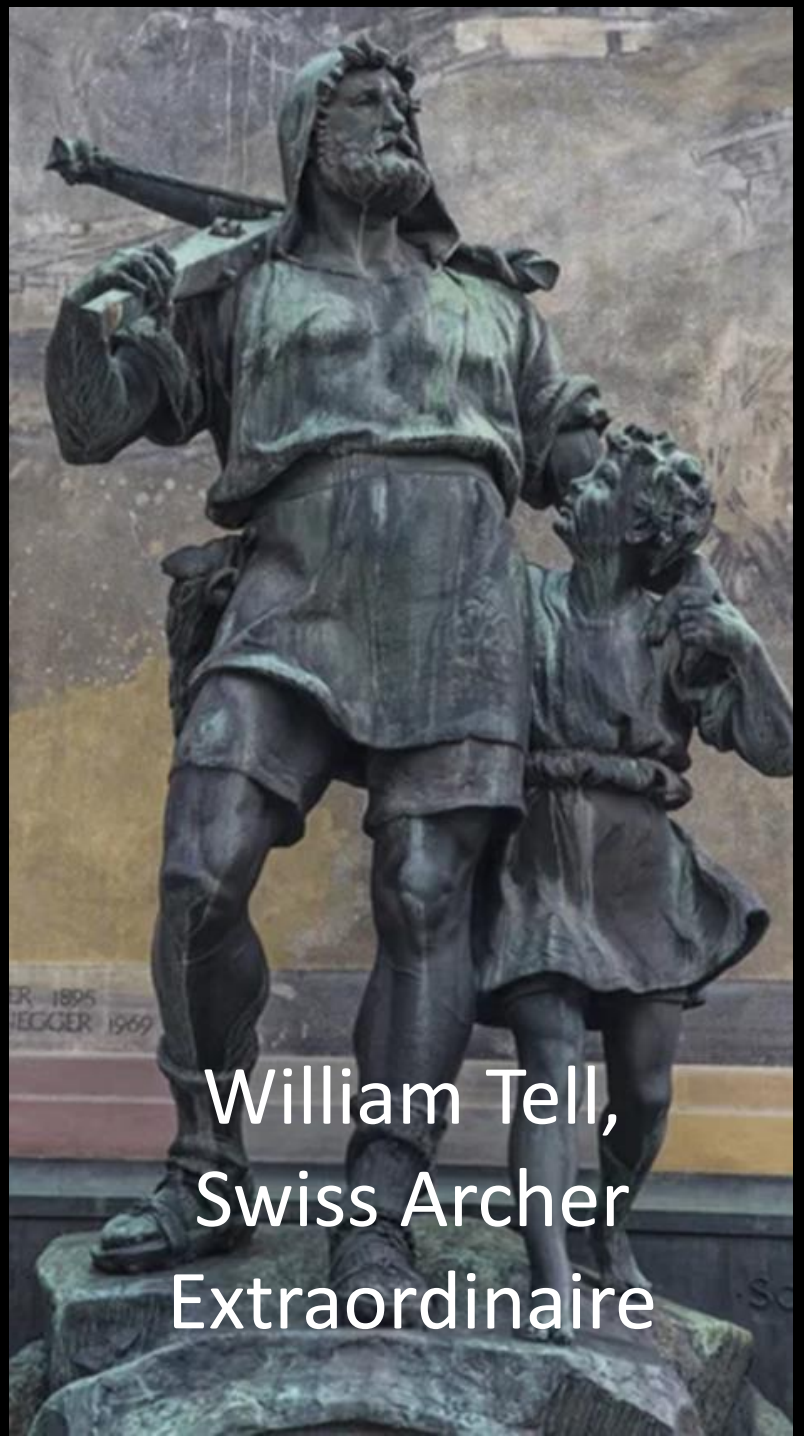
“Precision” indicates
Tightness,
Consistency,
Scatter, or Spread
of Shot Pattern

Common measure of “Precision”

Distance from
center of
shot pattern
that includes 68%
(Call it 2/3)
of all shots



Also known as: “Standard Deviation”



Another related problem:

Measuring Performance

About 2/3 of shots are within 5 inches of "Average" = center of shot pattern!

About 1/3 are more than 5 inches high, low, or wide.

Standard Deviation = 5 inches

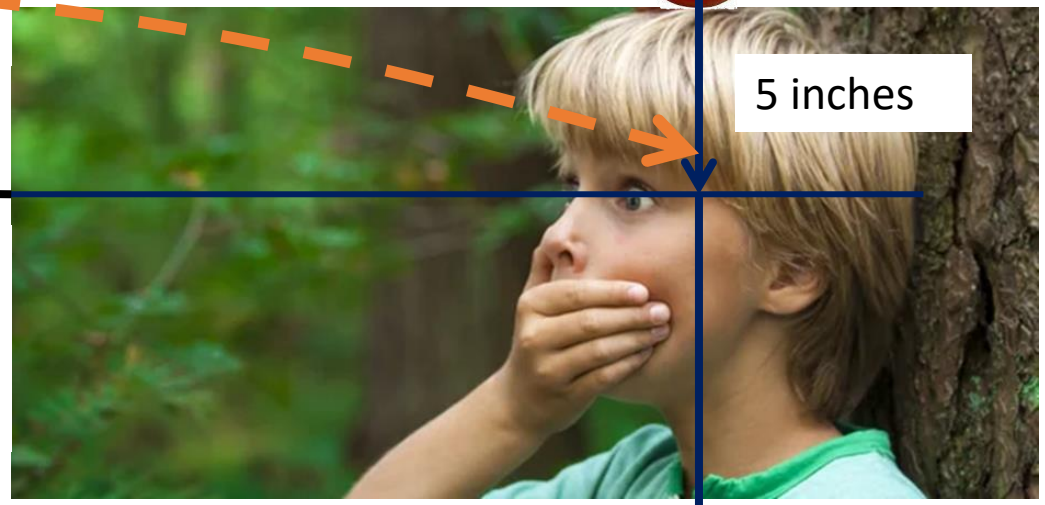
1/6
chance

2/3
chance

1/6
chance

5 inches

5 inches



Now back to William Tell & Son

Raise the Apple!

How far we raise the apple…

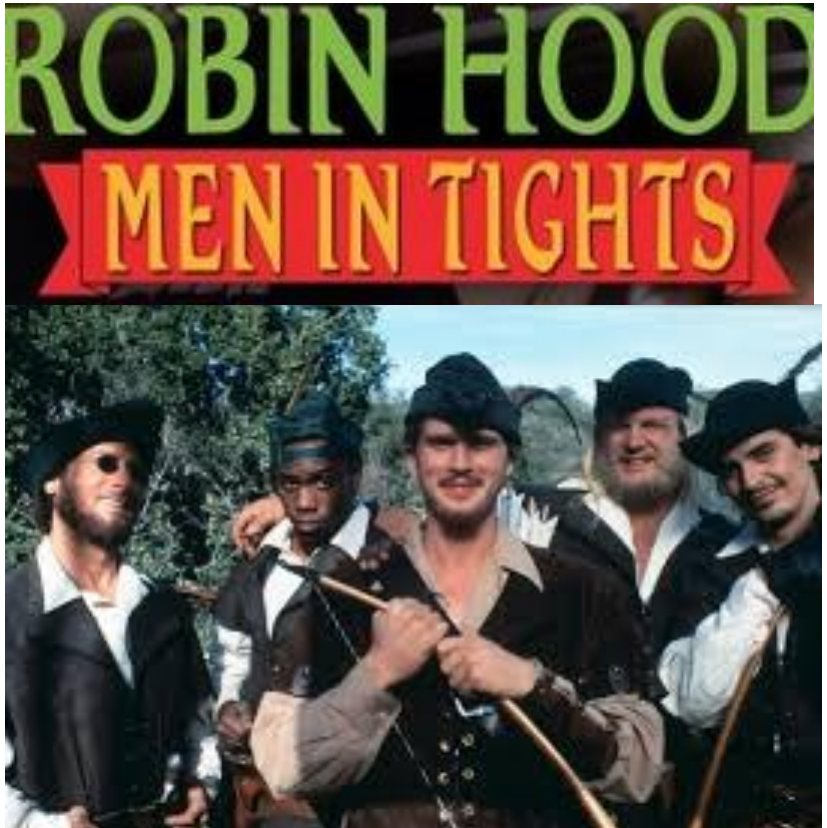
…Depends on the skill of the Archer

How far we raise the apple…

…Depends on the skill of the Archer

How far we raise the apple…

…Depends on the skill of the Archer



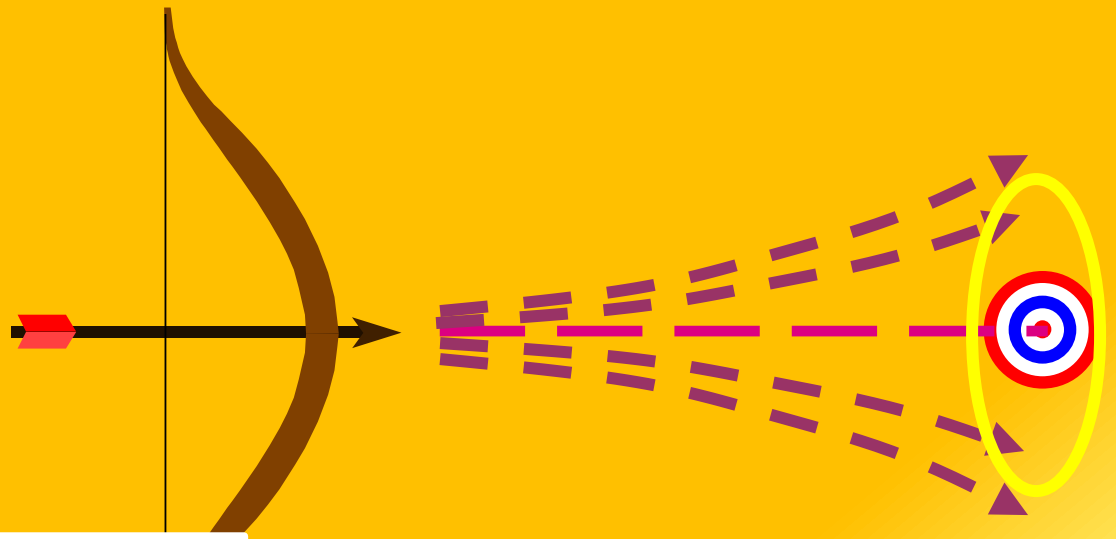
How far we raise the apple…

…Depends on the skill of the Archer

How High we set the target depends on how good the shooter is!

Specified Value: What the designer really needs

People whose safety depends on the reliability of your structure



“S value” =“Standard Deviation”

Describes “Producer’s” concrete-making precision

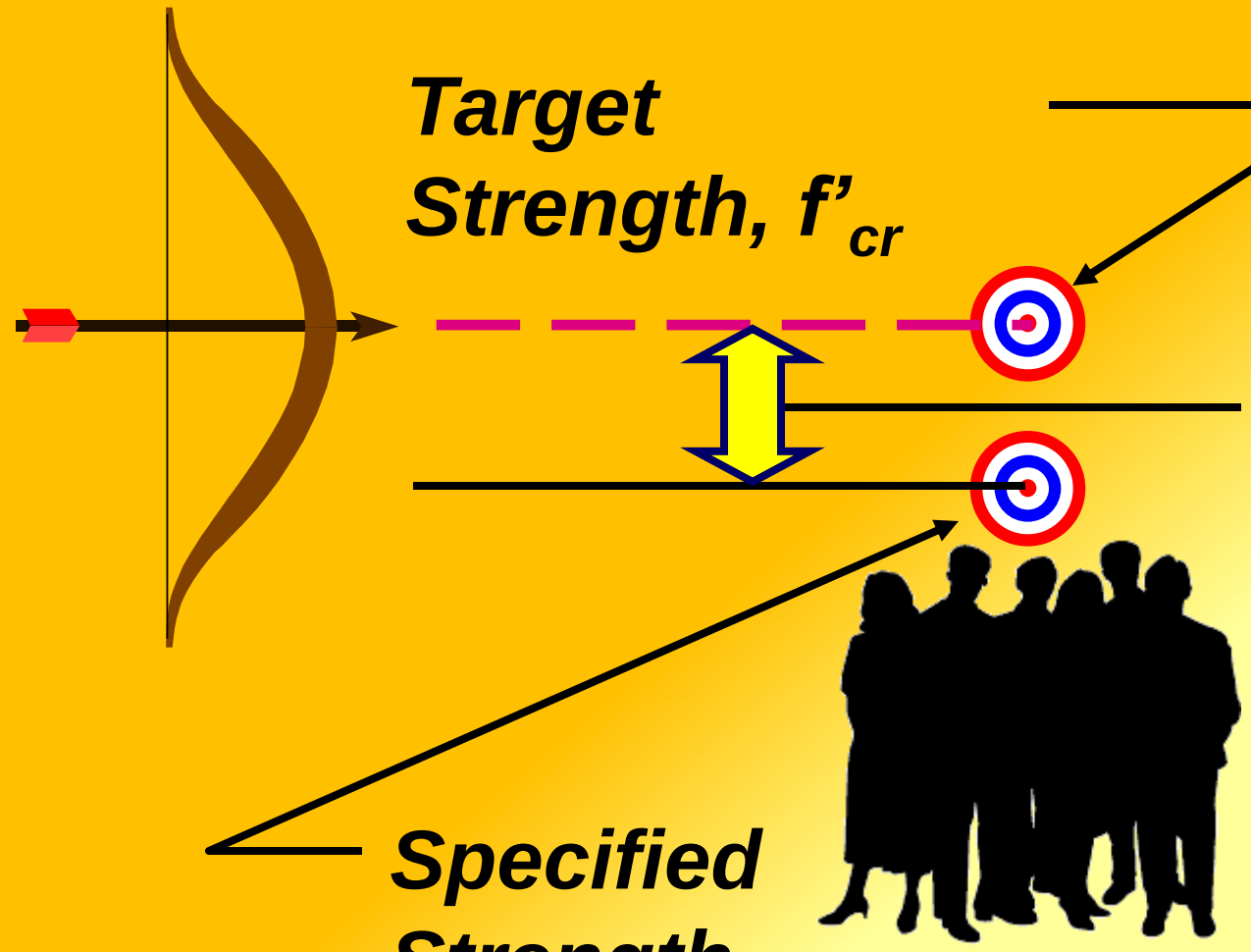
BREAKING NEWS

S depends on:

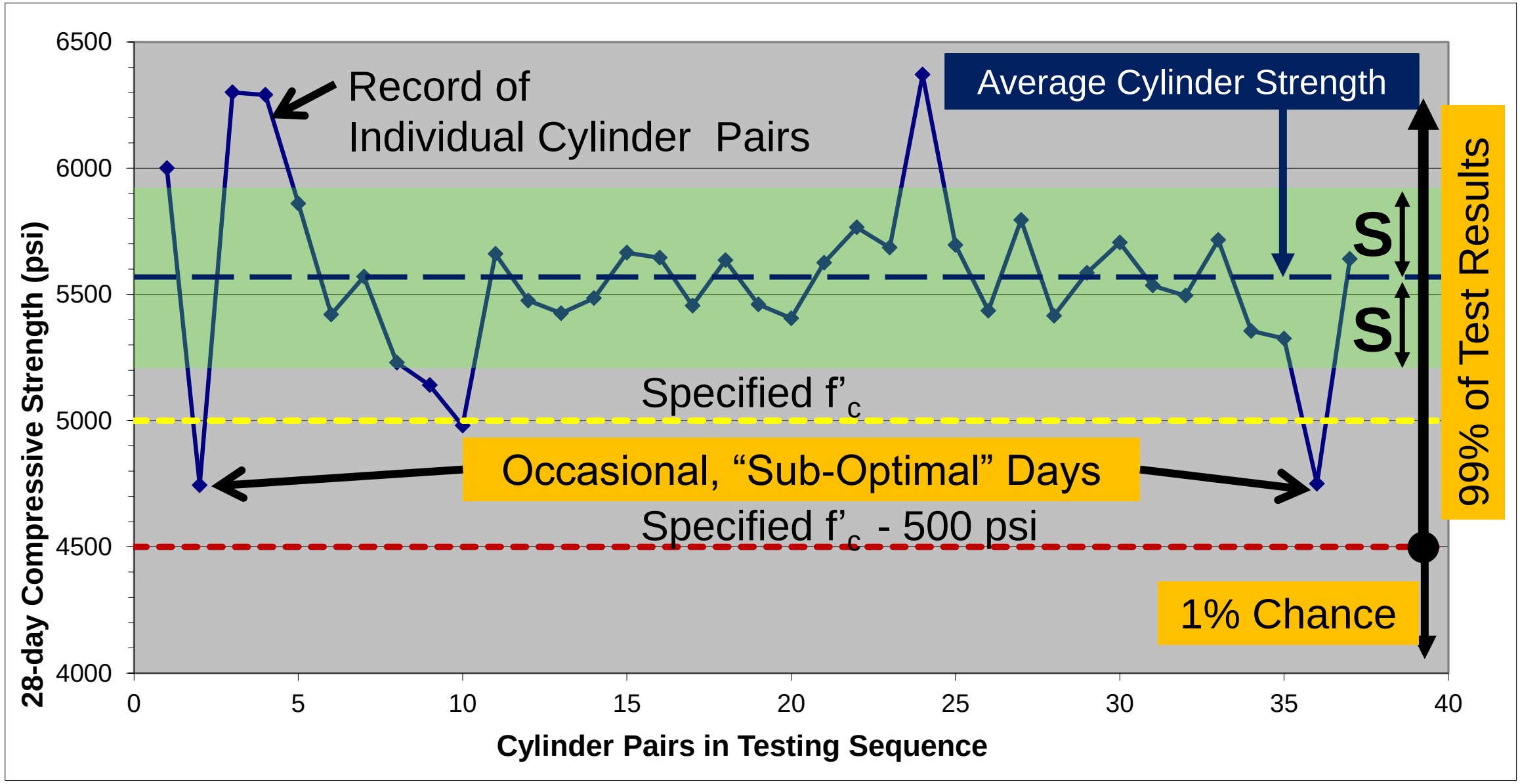
Precision of concrete production

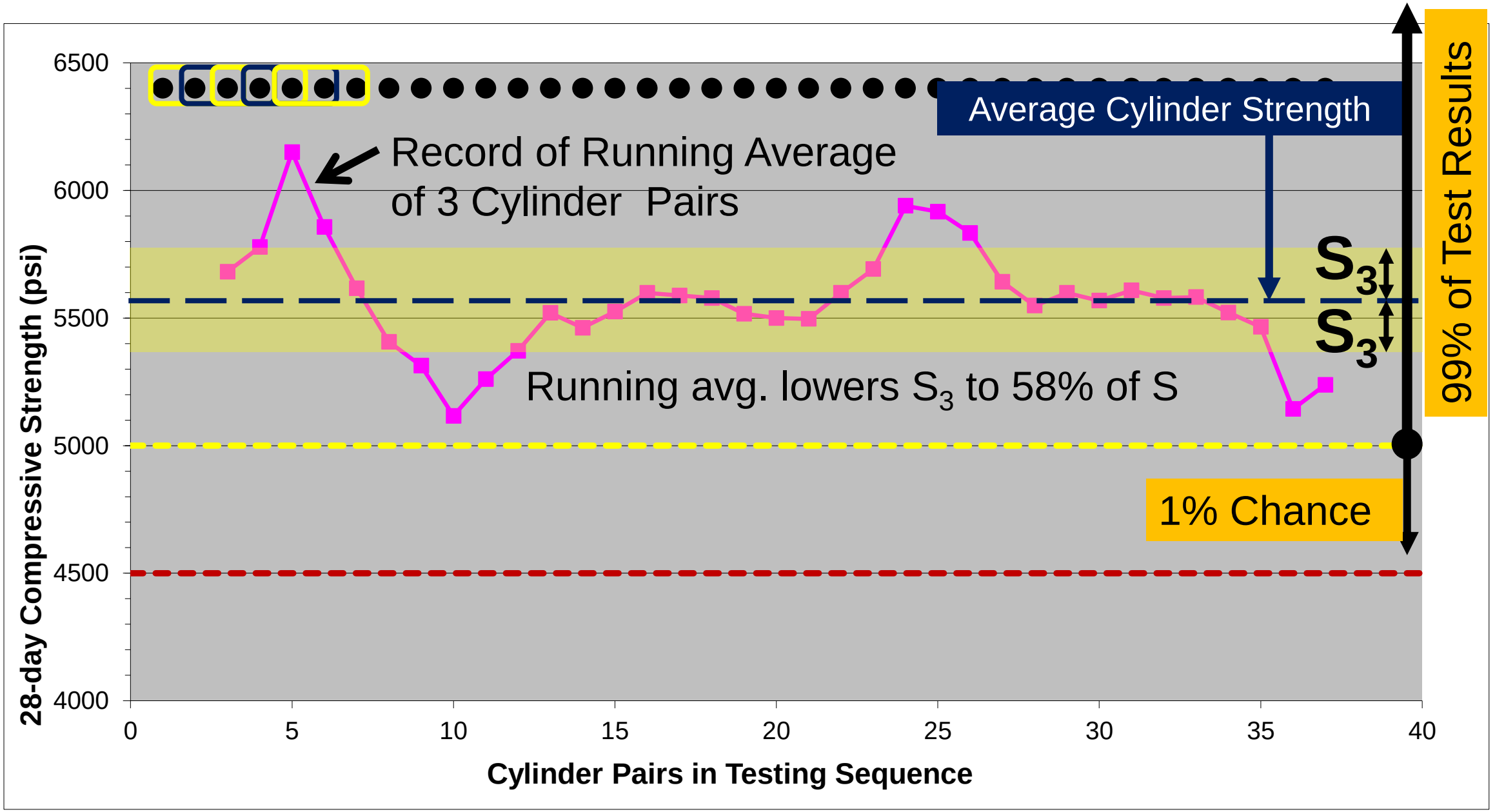
COMBINED WITH

Precision of concrete testing!



Required "overdesign" depends on Individual Producer's Unique Value of S


6500
6000
5500
5000
4500
4000
28-day Compressive Strength (psi)
0
5
10
15
20
25
30
35
40
Cylinder Pairs in Testing Sequence
Record of
Individual Cylinder Pairs
Average Cylinder Strength
S
S
99% of Test Results
Specified f'c
Occasional, "Sub-Optimal" Days
Specified f'c - 500 psi
1% Chance


6500
6000
5500
5000
4500
4000
28-day Compressive Strength (psi)
0
5
10
15
20
25
30
35
40
Cylinder Pairs in Testing Sequence
Average Cylinder Strength
Record of Running Average
of 3 Cylinder Pairs
S_3
S_3
Running avg. lowers S_3 to 58% of S
99% of Test Results
1% Chance

Dwngs & Specs:

f'c = 5000 psi

Data from concrete producer for this or "similar" mixture:

Average Concrete Strength = 5560 psi

Standard Deviation for Cylinder Pairs = 350 psi

Coef. of Variation = S/Average = 6.3% → "Excellent" (ACI 214)

Standard Deviation for running avg. of 3 Cylinder Pairs = 202 psi

What's the lowest average strength that signals 99% specification compliance?

We need to use probability and statistics…

2,554 4x8 Cylinders
could be made from 11 CY.

Volume of two 4x8 cylinders = 0.04% Volume of concrete in 11 CY truck

Statistics helps us estimate strength of vast majority of the concrete in structure THAT WAS NOT TESTED.

We use the same mathematical principles of risk, chance, and probability that keep the lights on in Las Vegas

You only know for sure the five cards you are holding.
There are 47 others that you do not know about .

50.1%

High Card

42.3%

One Pair

4.75%

Two Pairs

2.11%

Three of a Kind

0.39%

Straight

0.20%

Flush

0.14%

Full House

0.02%

Four of a Kind

0.0011%

Straight Flush

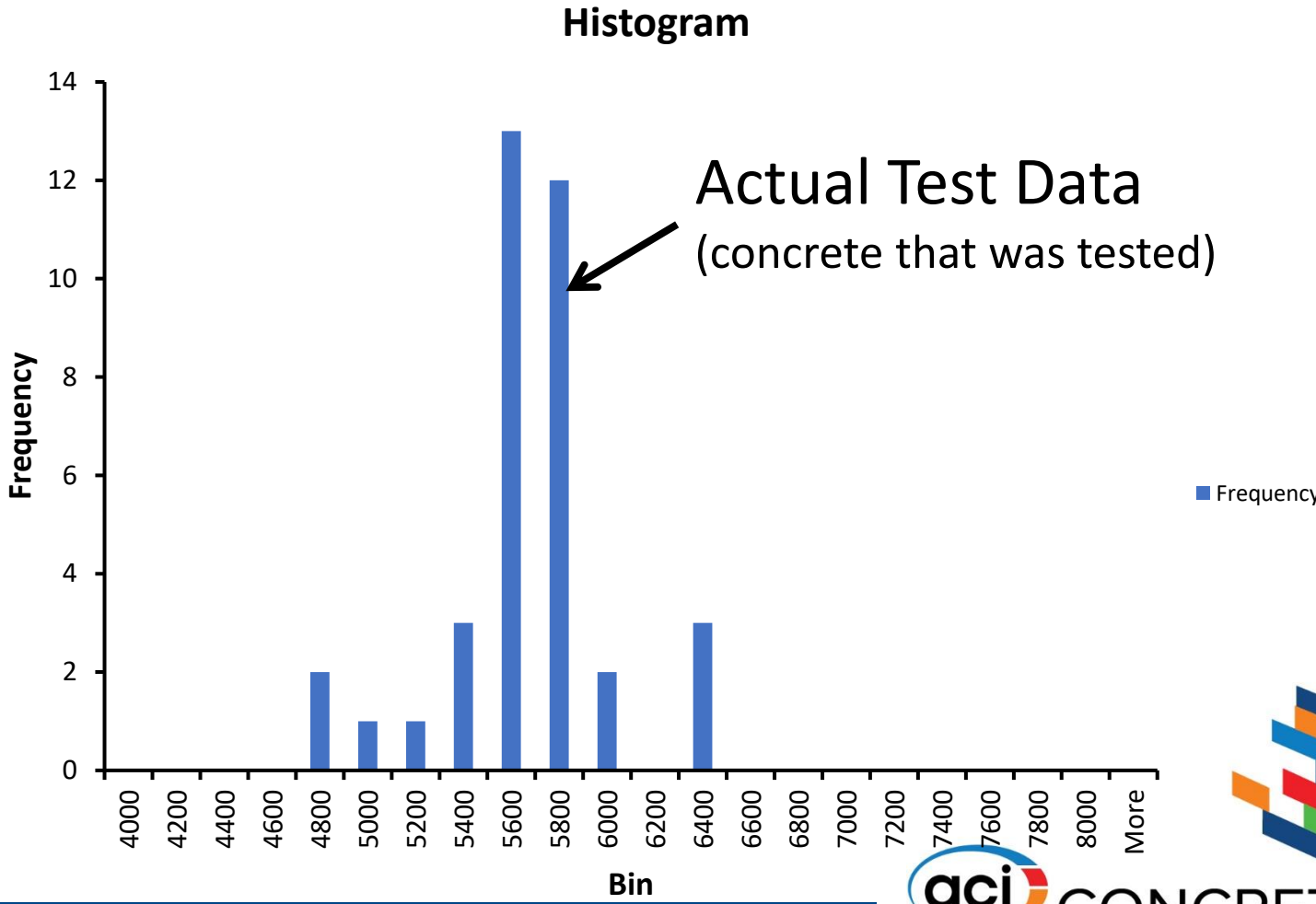
0.00015%

Royal Flush

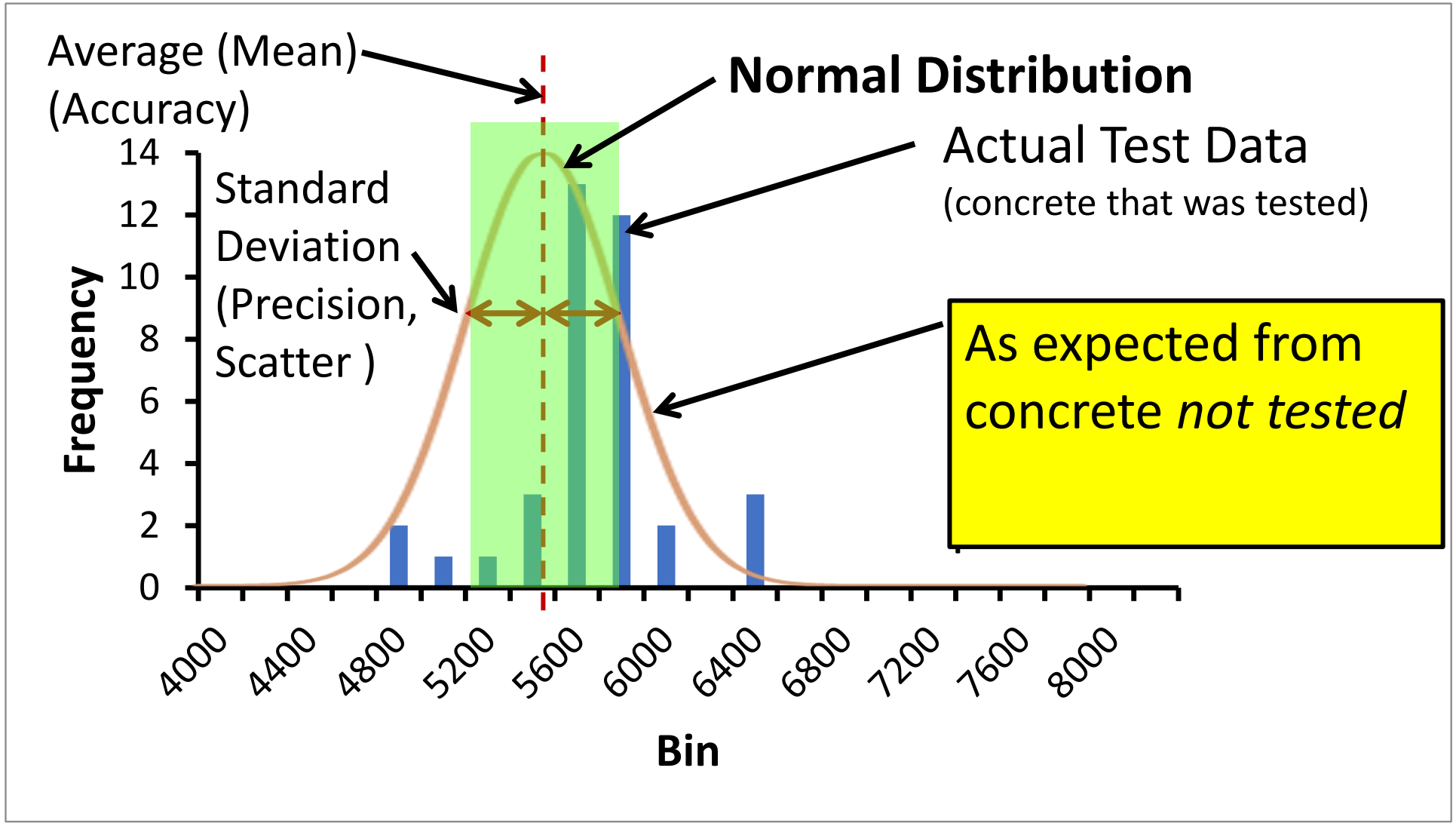
Analyzing the Concrete Actually Tested

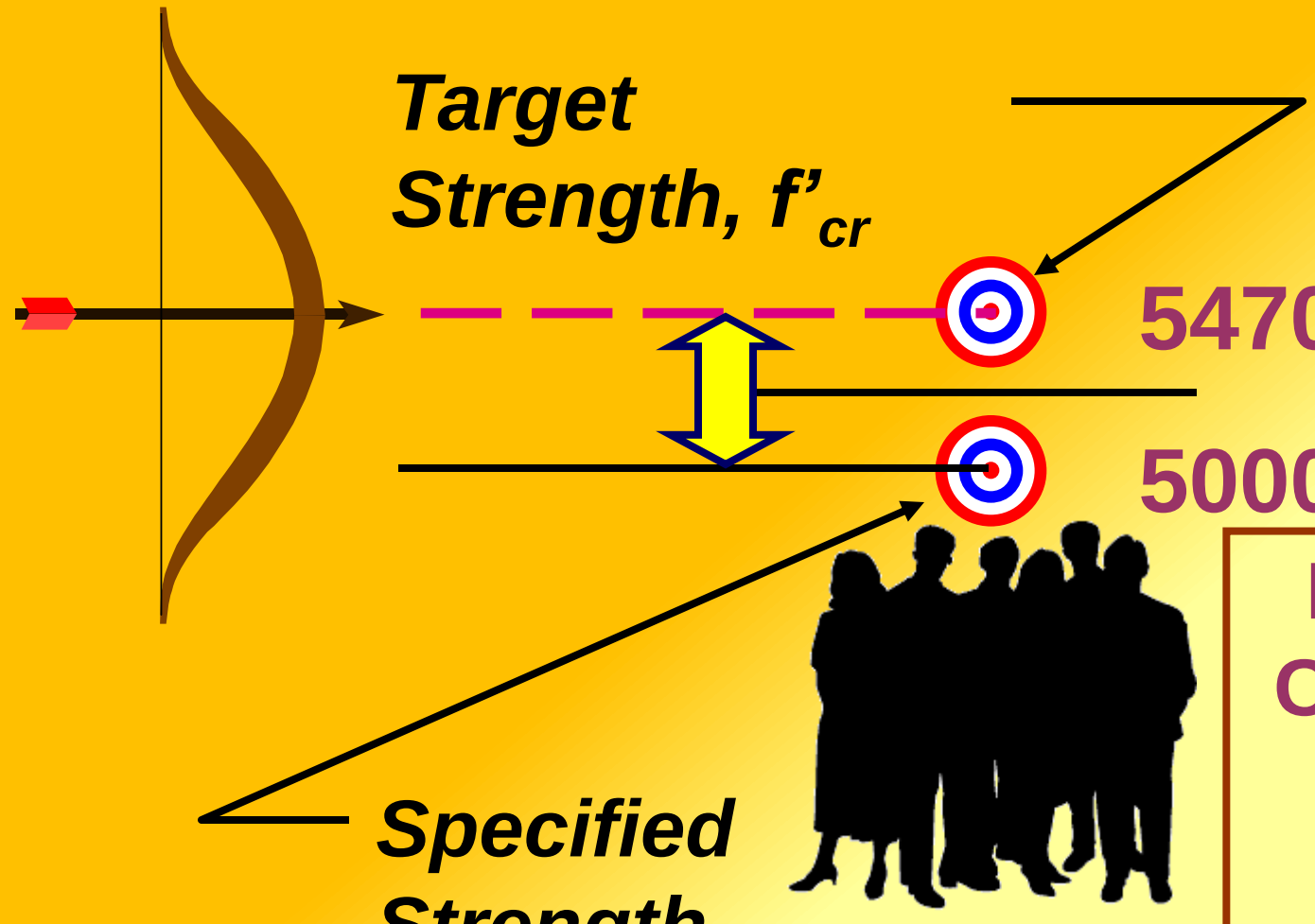
Cyl pair No.	Average of Cyl. Pair,psi	Cyl pair No.	Average of Cyl. Pair,psi
1	**6000**	21	**5625**
2	**4744**	22	**5765**
3	**6300**	23	**5685**
4	**6290**	24	**6370**
5	**5860**	25	**5695**
6	**5420**	26	**5435**
7	**5570**	27	**5795**
8	**5230**	28	**5415**
9	**5140**	29	**5585**
10	**4980**	30	**5705**
11	**5660**	31	**5535**
12	**5475**	32	**5495**
13	**5425**	33	**5715**
14	**5485**	34	**5355**
15	**5665**	35	**5325**
16	**5645**	36	**4750**
17	**5455**	37	**5640**
18	**5635**		
19	**5460**		
20	**5405**		

Cylinder Strength Data



Estimating the Strength of Concrete Not Tested



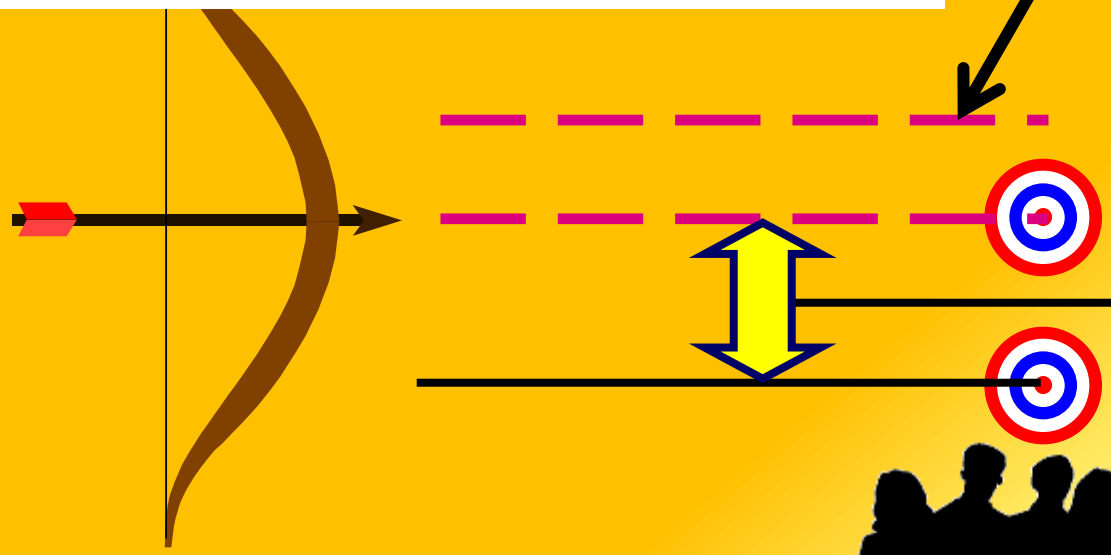


Lowest Average Cylinder Strength consistent with 99% Reliability

$f'_{cr} =$	f'_c	+	2.33S – 500	1% Risk of single test< (f'_c-500) psi
$f'_{cr} =$	f'_c	+	1.34S psi	1% Risk Running Avg. (3)< (f'_c) psi

Average Strength of Mixture = 5560 psi

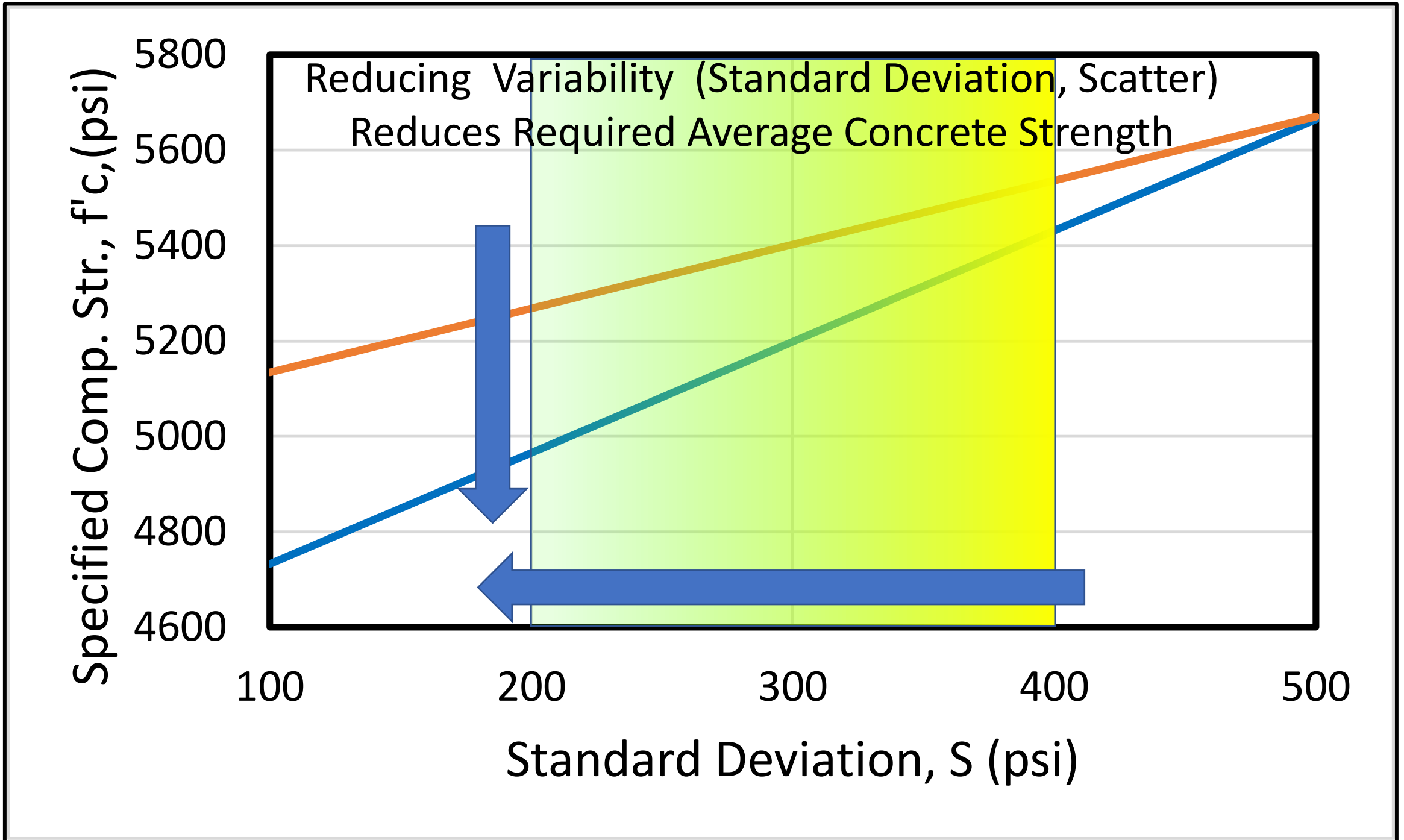
Target Strength, f'_{cr}



5470 psi

5000 psi

Specified Strength

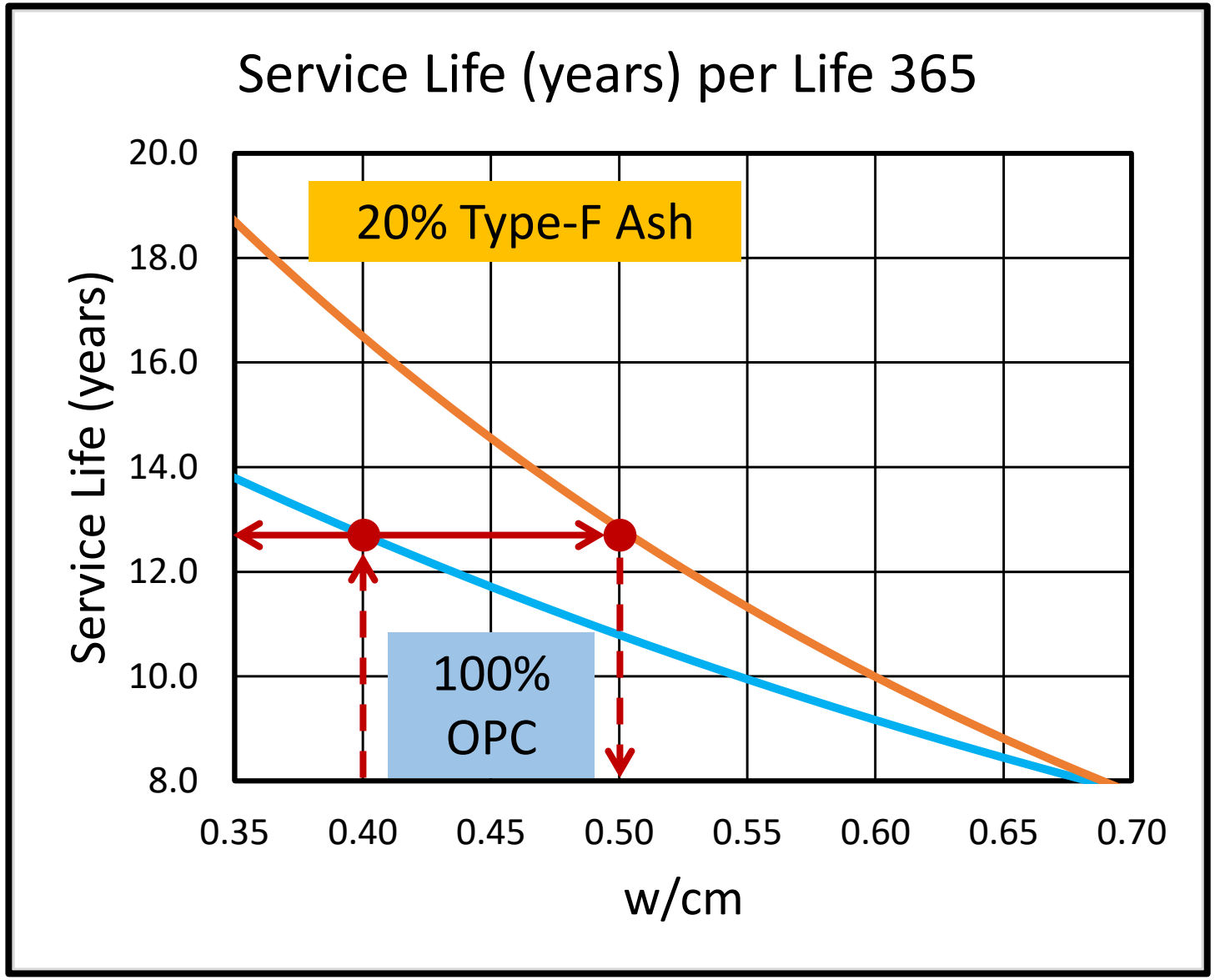

Reducing Variability (Standard Deviation, Scatter)
Reduces Required Average Concrete Strength
Specified Comp. Str., f'c,(psi)
5800
5600
5400
5200
5000
4800
4600
100
200
300
400
500
Standard Deviation, S (psi)

Myth and Misinterpretation of "Overdesign"

Some Conclusions:

- So-called “Overdesign” has a solid, rational basis.
- So-called “Overdesign” is not arbitrarily conservative.
- Greater precision in concrete production and testing can reduce Target Strength and Cementitious Materials.
- It is an honor to help recognize Bruce’s Influence on the Built-Environment, our Industry, and our Institute!

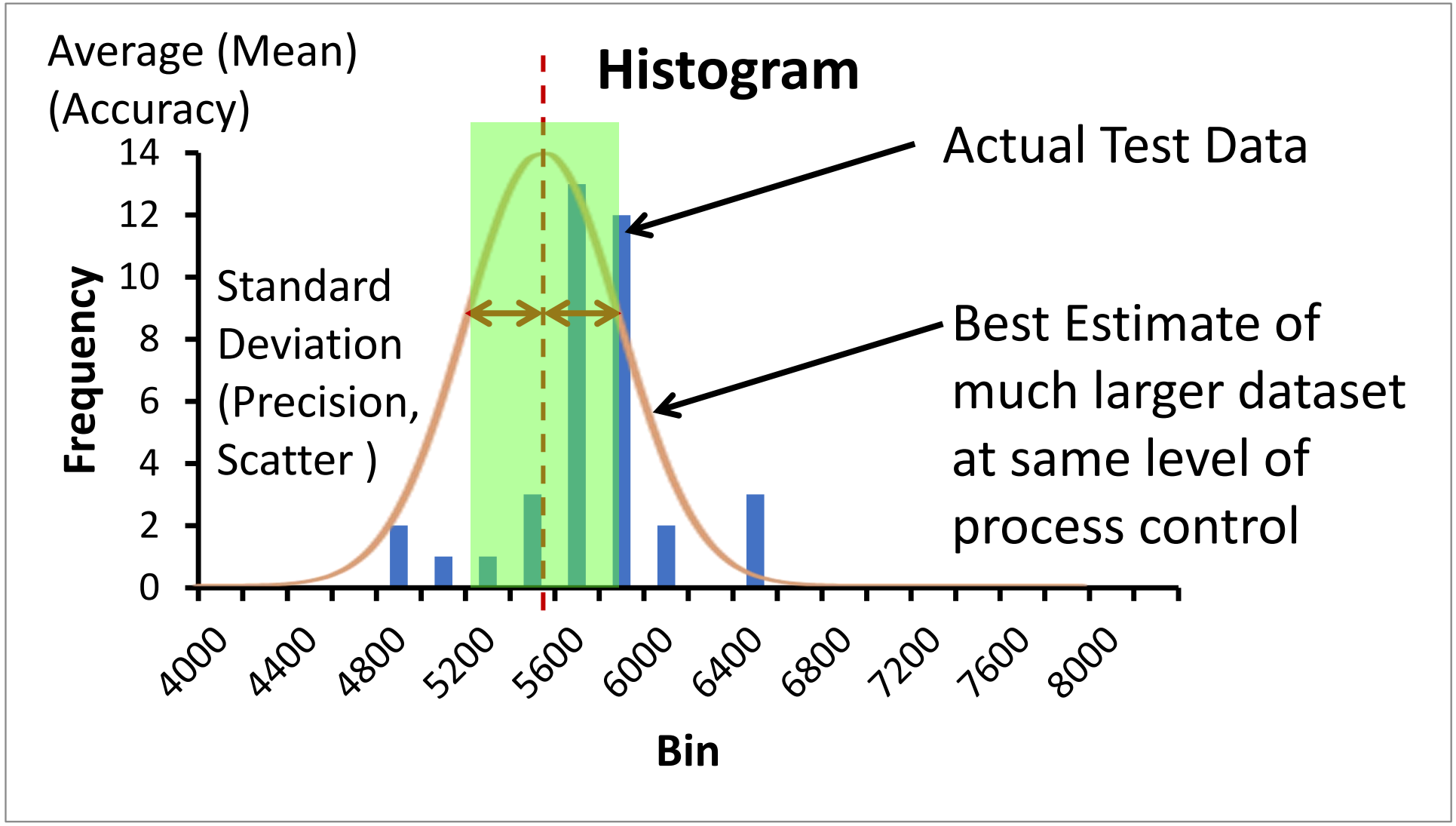
Service Life Based on Corrosion of Reinforcing Steel



12.8-year
Service Life

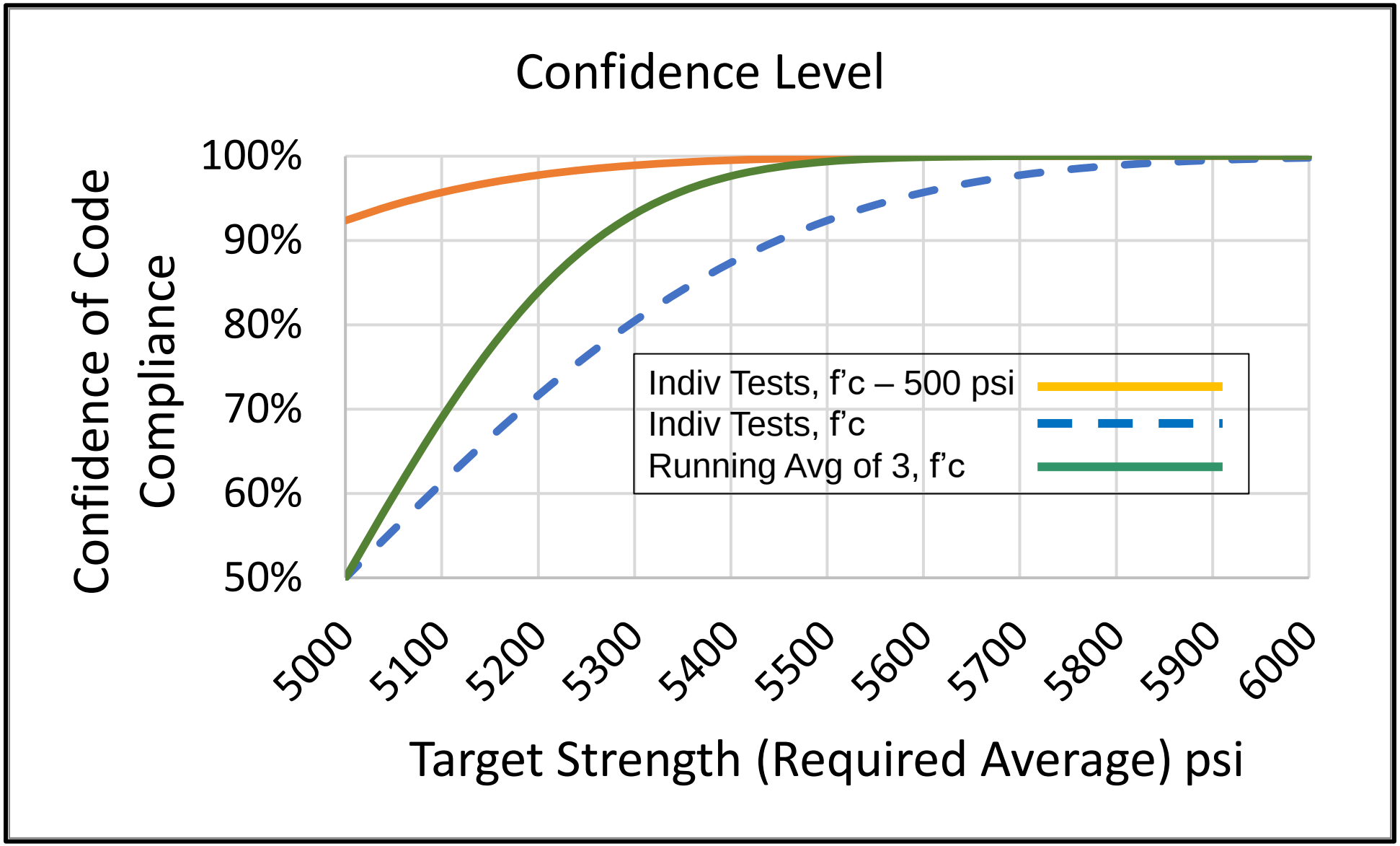
6-inch slab
1-1/2 inch
cover
Exposure C2
St. Louis, Mo.

"Normal" Distribution



Specified Strength (psi)	Standard Deviation (Scatter) (psi)	Average Cylinder Strength	Level of Risk of cylinder pair < f'c	Level of Risk of cylinder pair < f'c – 500 psi
5000	350	6000	0.2%	0.001%
5000	350	5500	7.7%	0.21%
5000	350	5300		
5000				
5000				

Specified Strength = 5000 psi Standard Deviation = S = 350 psi



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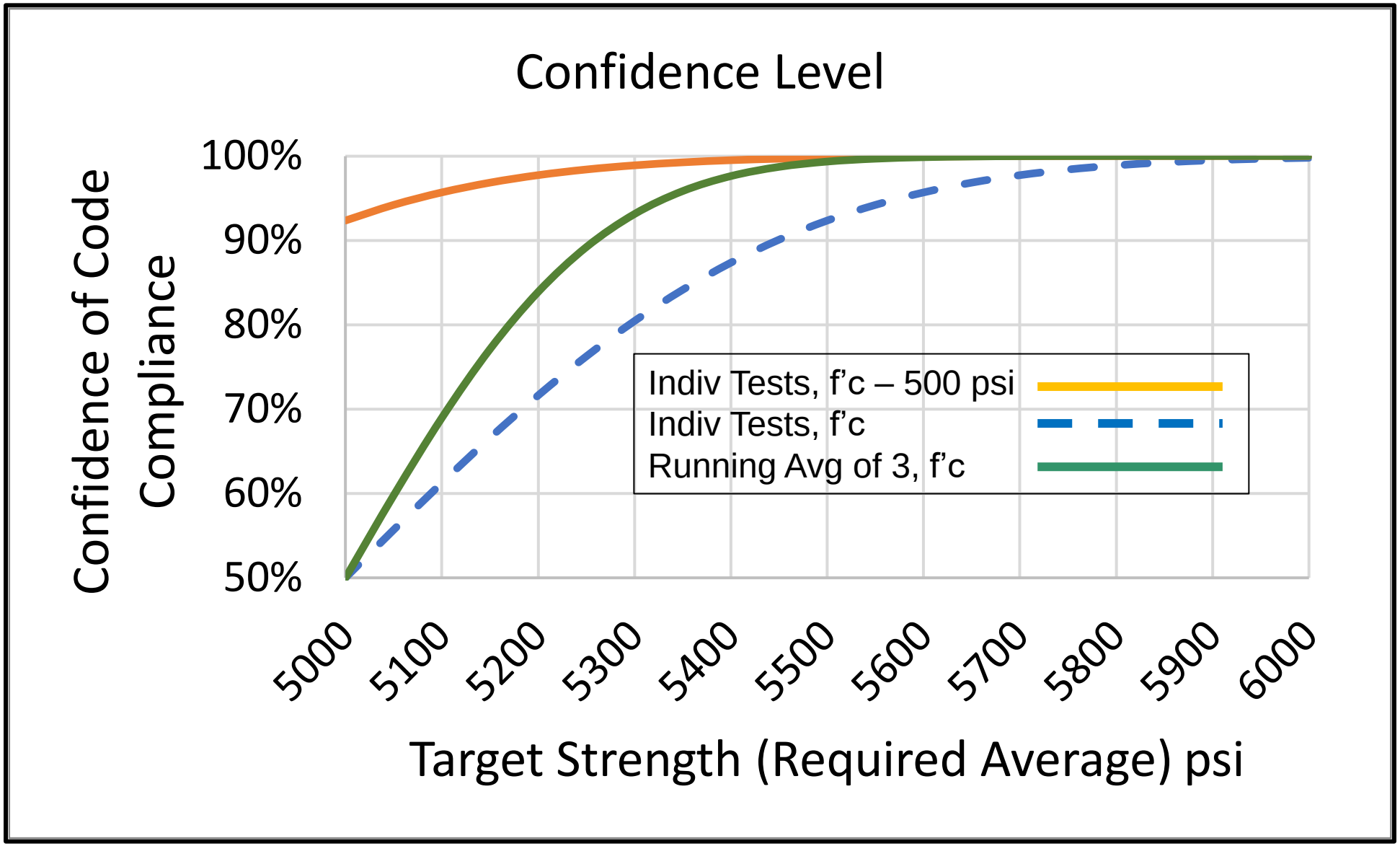

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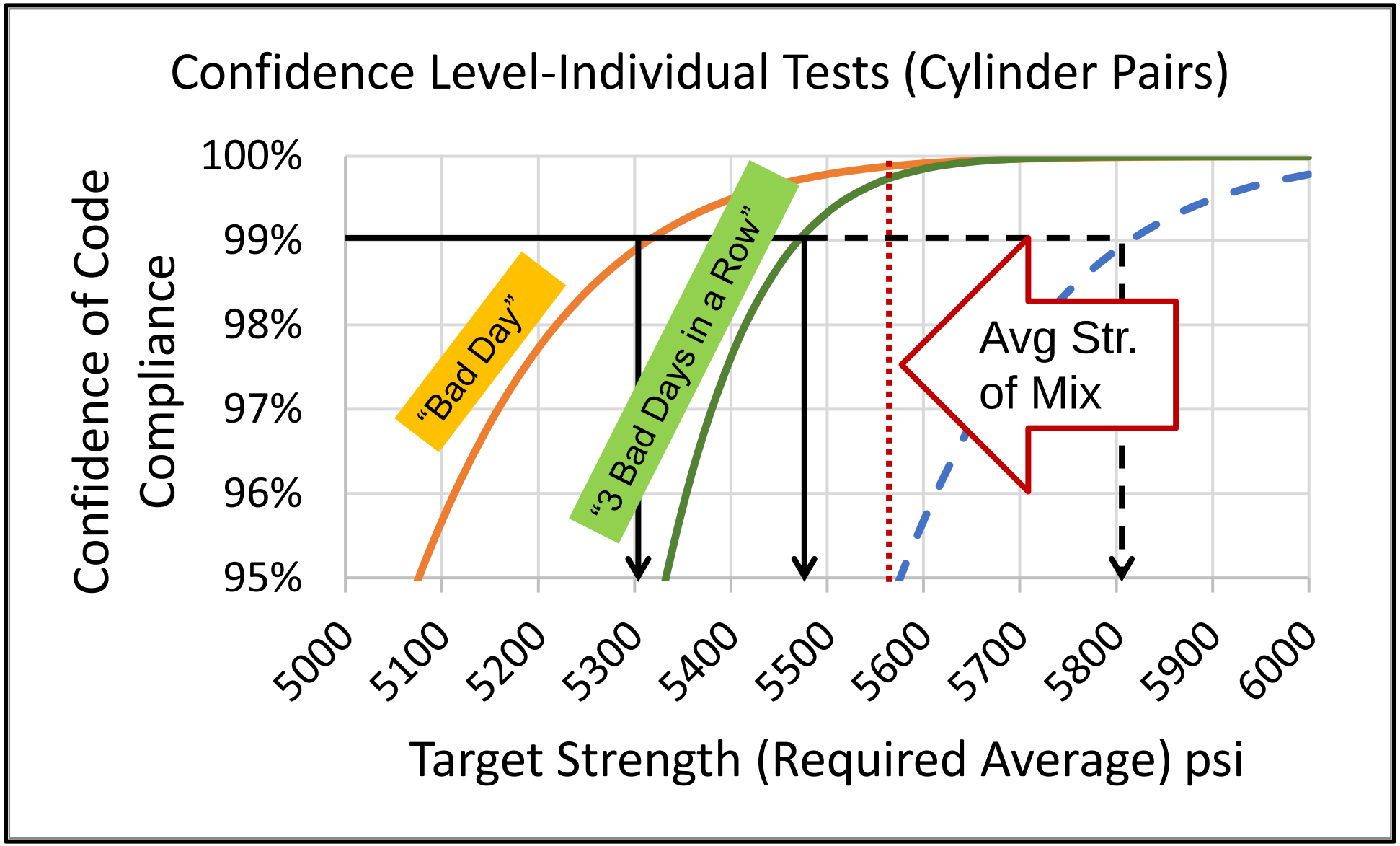


From Specification

Worksheet for evaluating compressive strength of proposed mixture

Specified 28-day compressive strength, f'c	4500	psi
Calculation of Target Strength		
Standard deviation, S psi	350	psi
f'c + 1.34 S psi *4500 + 1.34 x 350 =*	4969	psi
f'c + 2.33 S - 500 psi *4500 + 2.33 x 350 - 500 =*	4816	psi

Producer's records

Figuring required *"over-design"*

Maximum Value


Poker Analogy

Low Cylinder Breaks are expensive—Cost more than high cyl. Breaks

How LOW can you go?

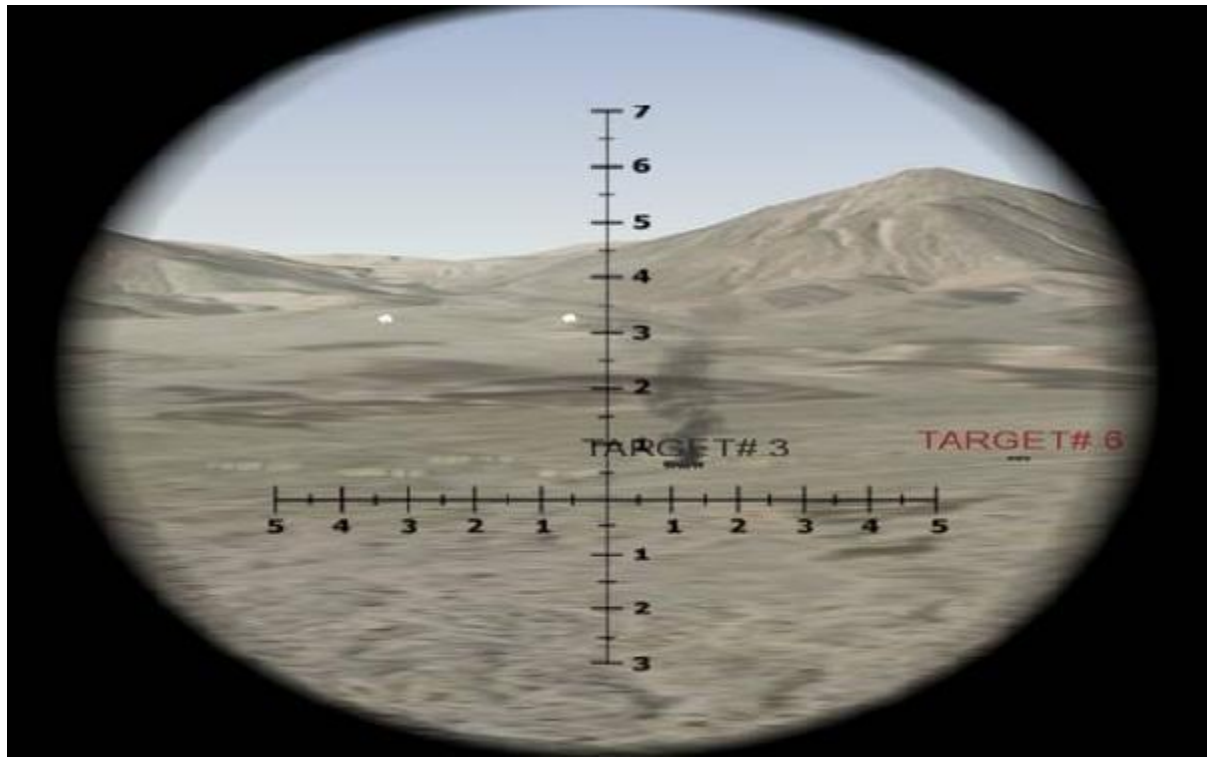
Estimate the strength of concrete NOT tested

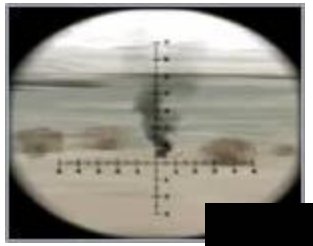
2 4 x 8 cyls in a 9 CY truck = 0.0004 = 0.04% of concrete Volume

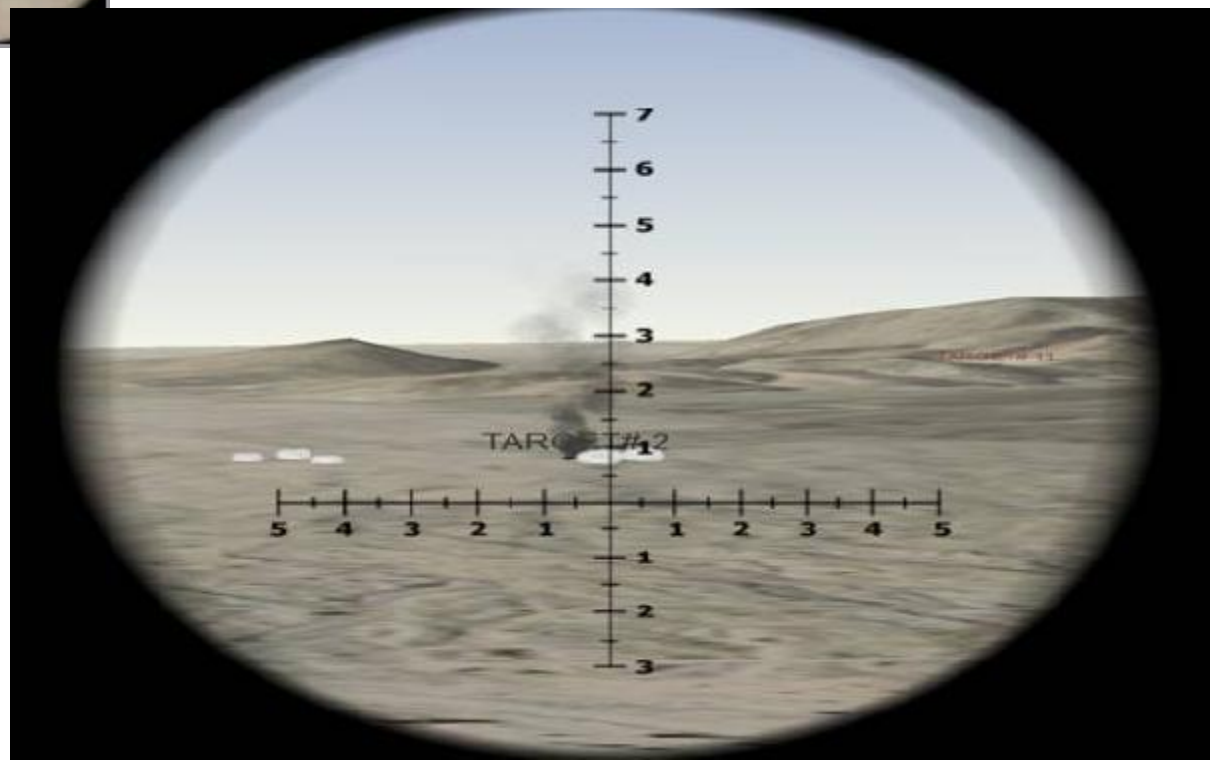
Who is placing the bet: Public?

CULLS

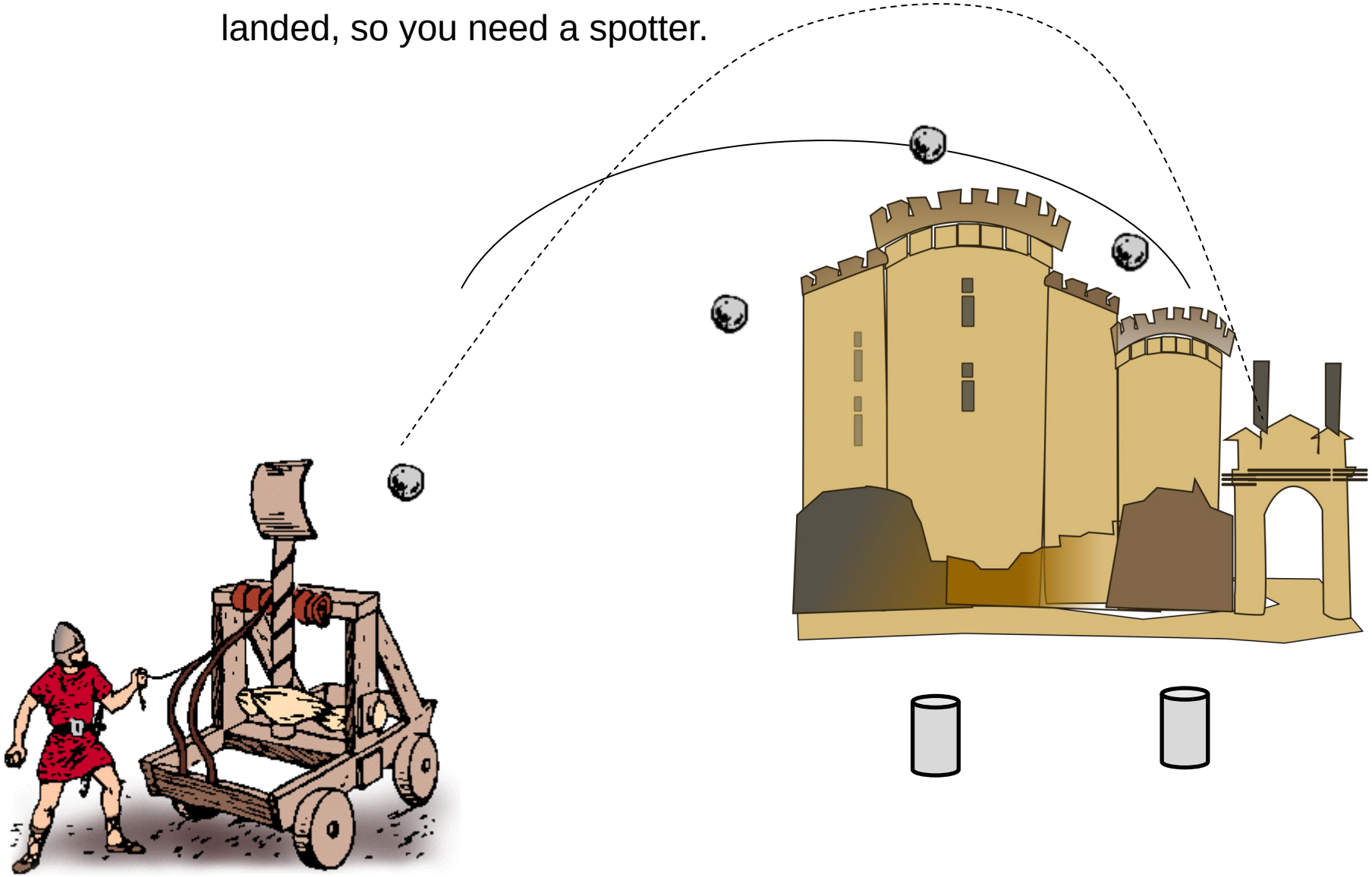
From a mountain perch, a U.S. 34th Infantry Division officer scans German movements on Cassino.


7
6
5
4
3
2
TARGET# 3
TARGET# 6
5 4 3 2 1 1 2 3 4 5
1
2
3




7
6
5
4
3
2
1
5 4 3 2 1 1 2 3 4 5
1
2
3

Replace the Hill with a Castle.
You cannot see where it
landed, so you need a spotter.



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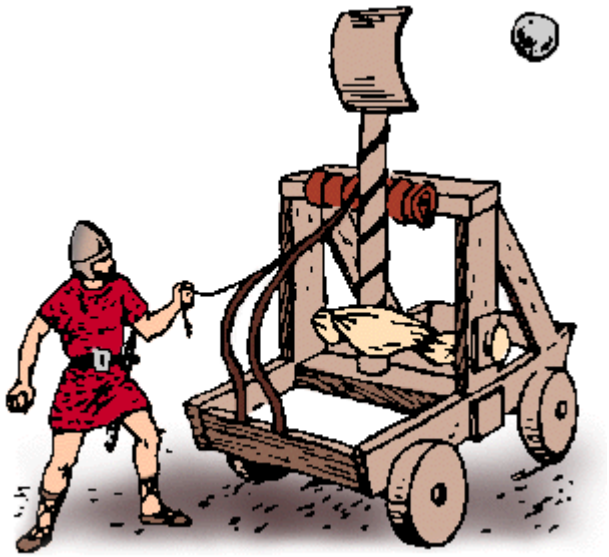
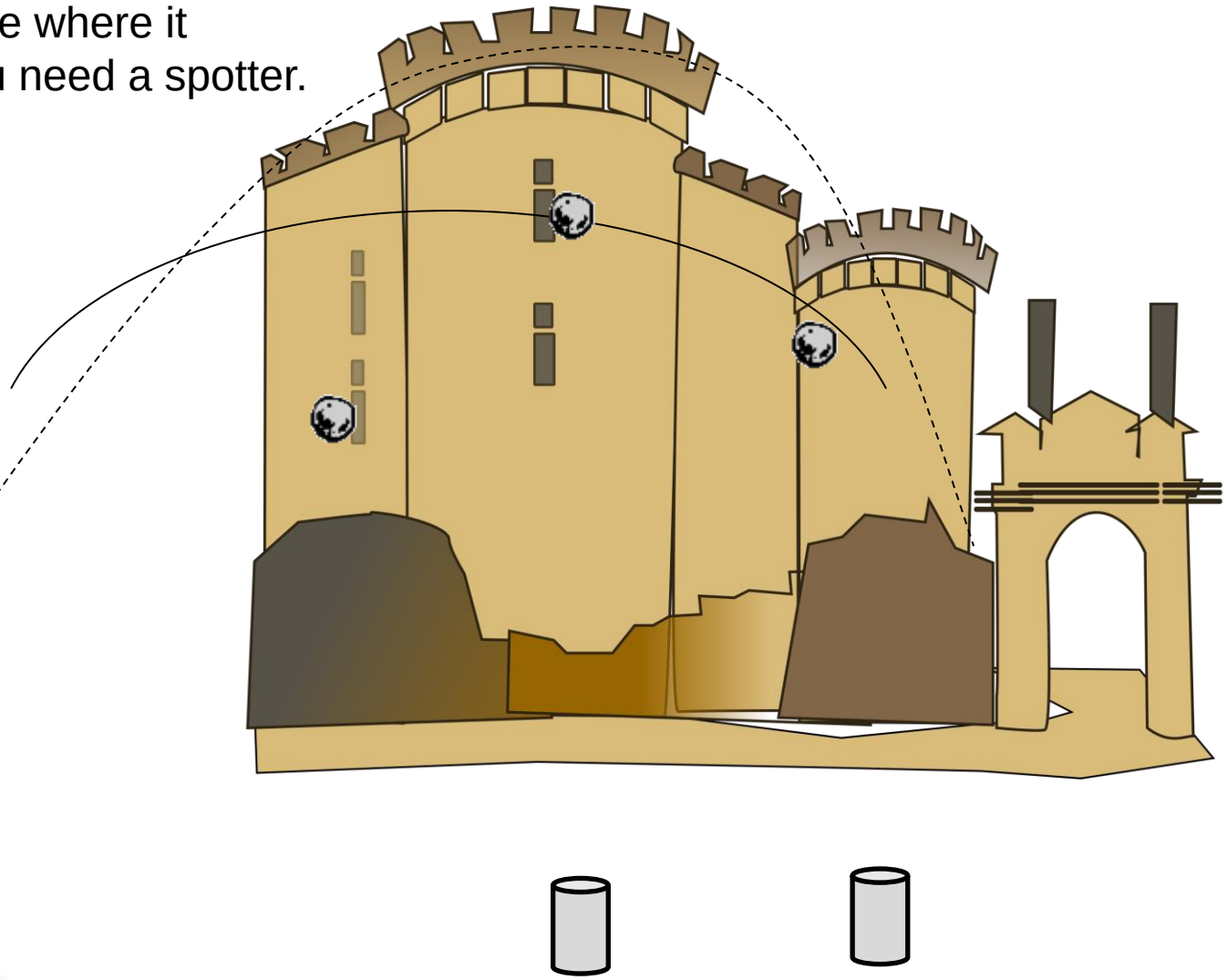
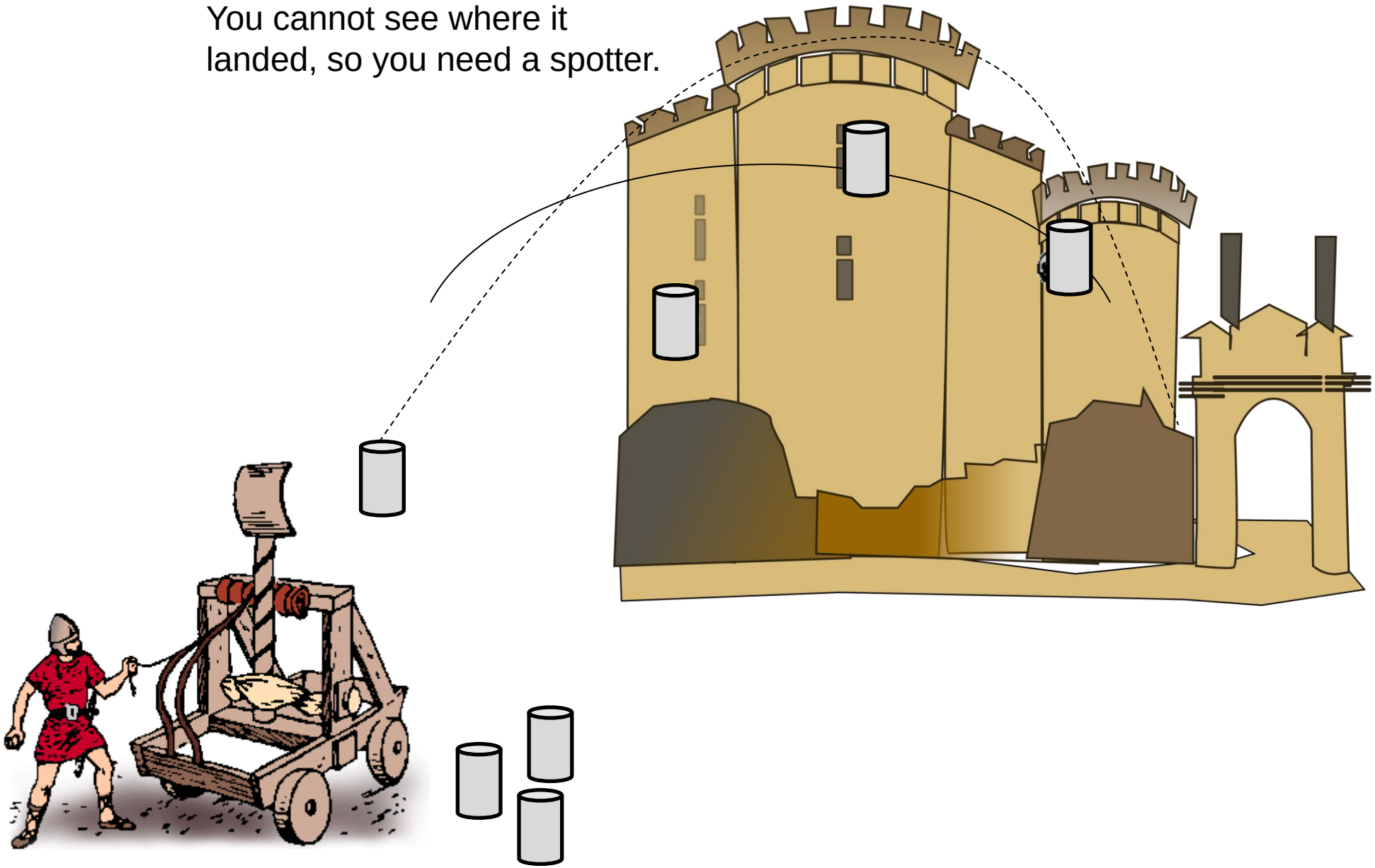
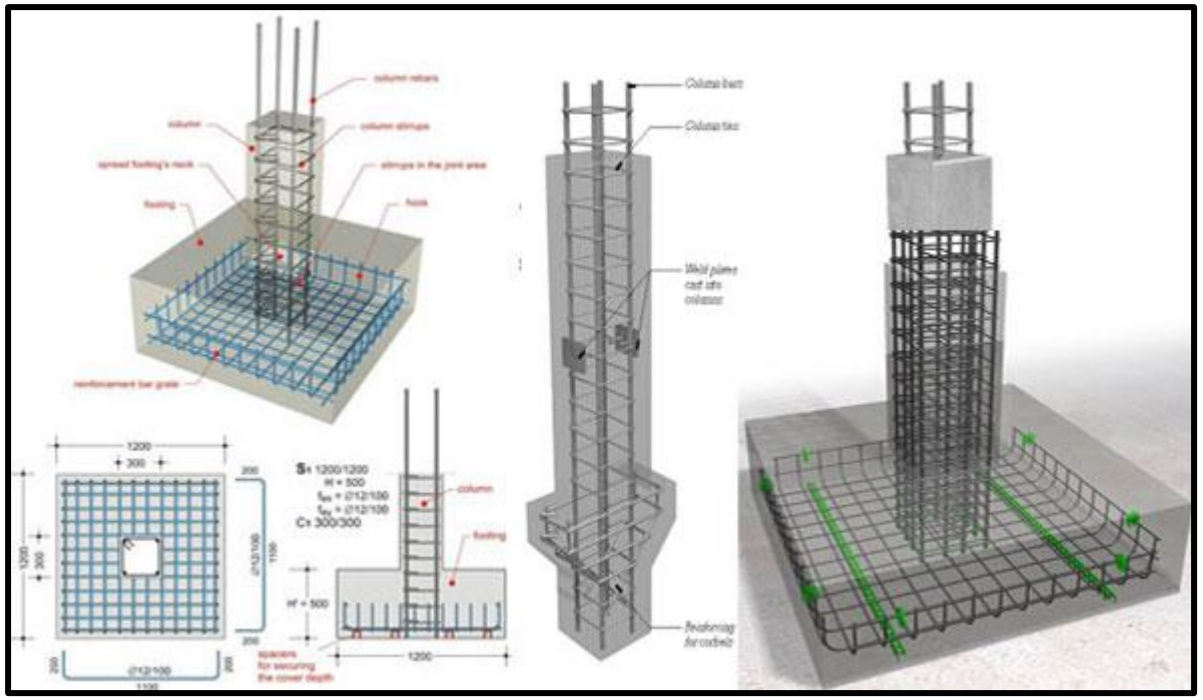




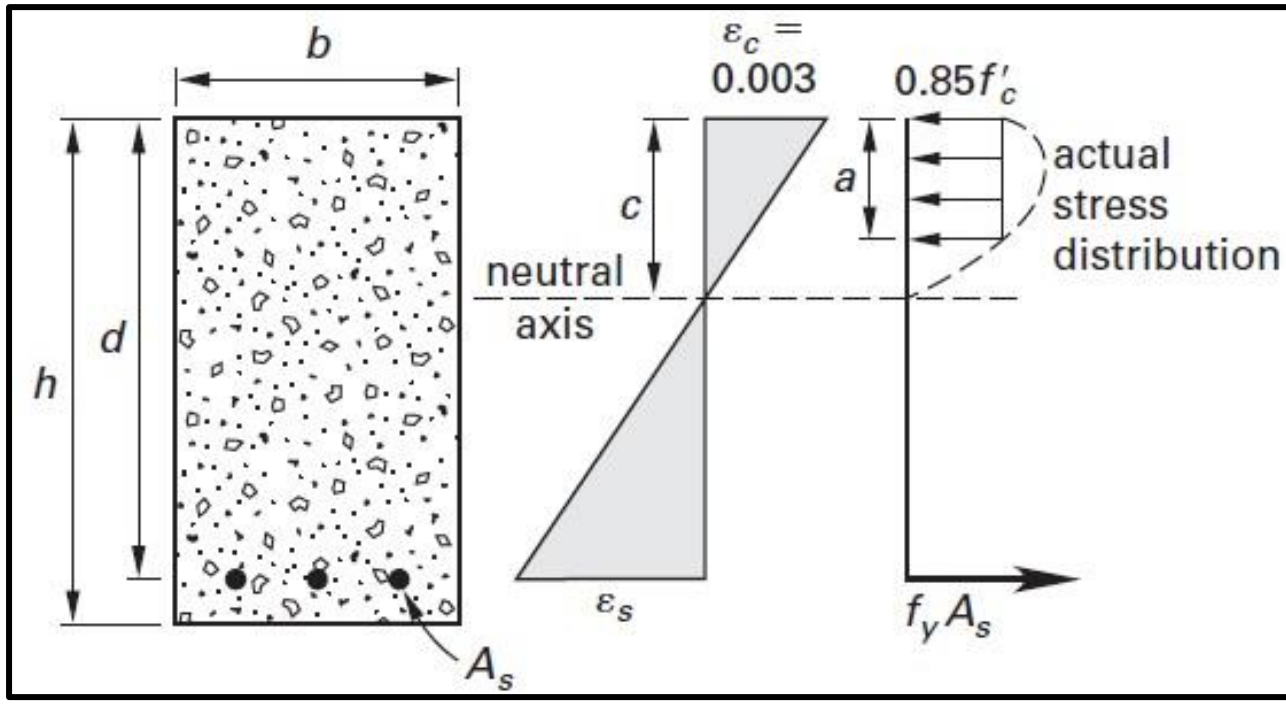
Replace the Hill with a Castle.
You cannot see where it
landed, so you need a spotter.



- For many years, Suprenant was a fixture at the World of Concrete, often appearing as the master of ceremonies for the Mega-Demos in jeans, work boots, and a tuxedo shirt, jacket, and bow tie. “



https://www.aboutcivil.org/reinforced-cement-concrete-design.html



Civil Engineering Bible.com

$$Bending\ Moment\ Capacity = \emptyset M_n = \emptyset A_s f_y \left(d - \frac{A_s f_y}{1.7 f'_c b}\right)$$

Cross sectional area of rebar

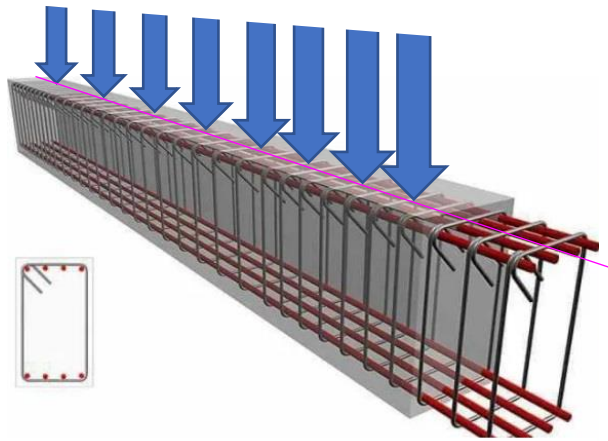
Yield strength of rebar

Depth from compression face to center of rebar

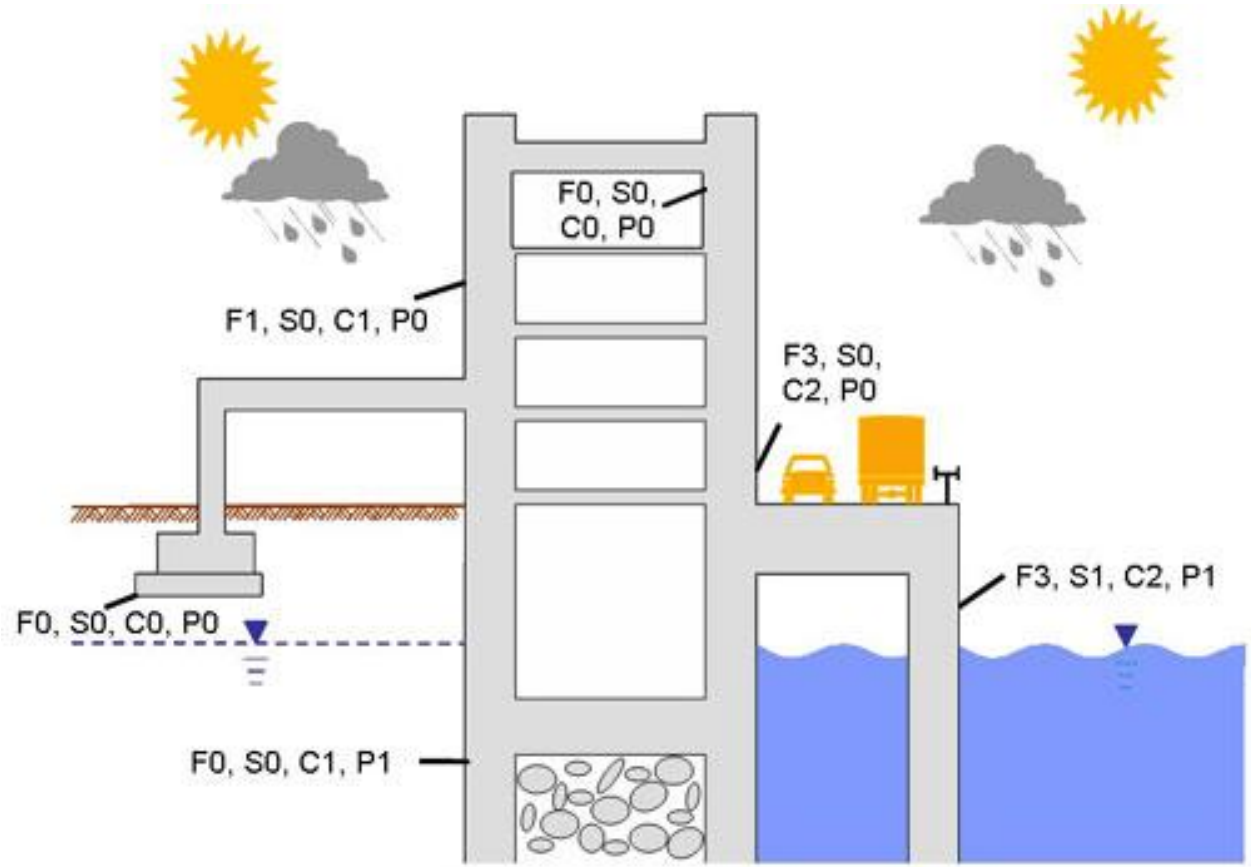
Specified compression strength of concrete

Width of beam

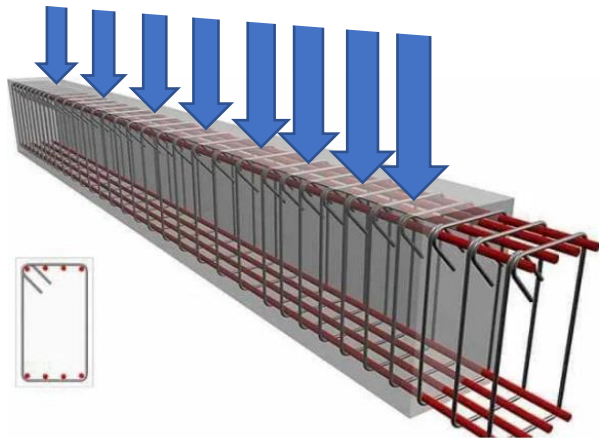
f'_c based on Resistance to Load

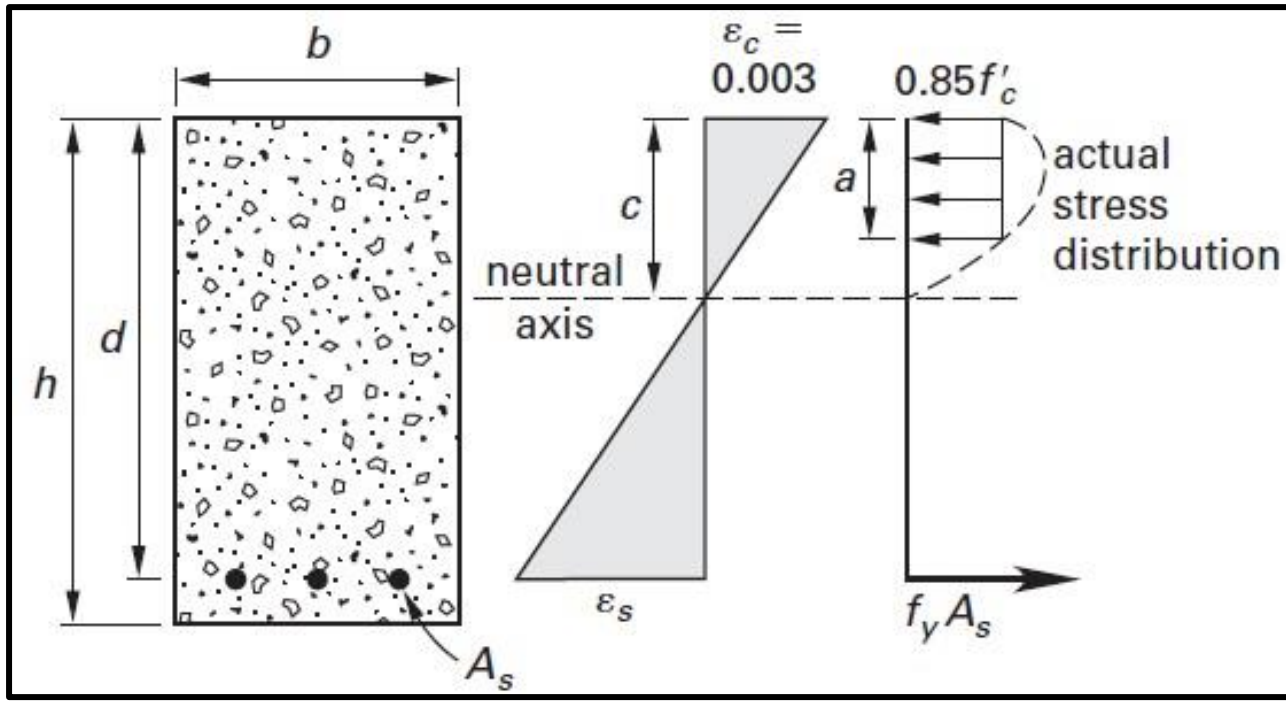


f'_c based on Resistance to Environmental Exposure



f'_c Based on Resistance to Load





Civil Engineering Bible.com

$$Bending\ Moment\ Capacity = \emptyset M_n = \emptyset A_s f_y \left(d - \frac{A_s f_y}{1.7 f'_c b}\right)$$

Cross sectional area of rebar

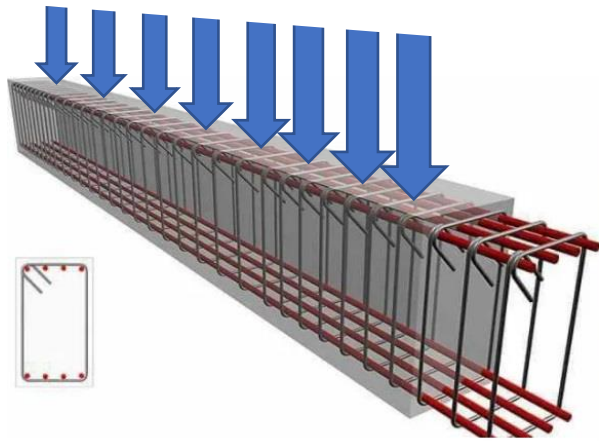
Yield strength of rebar

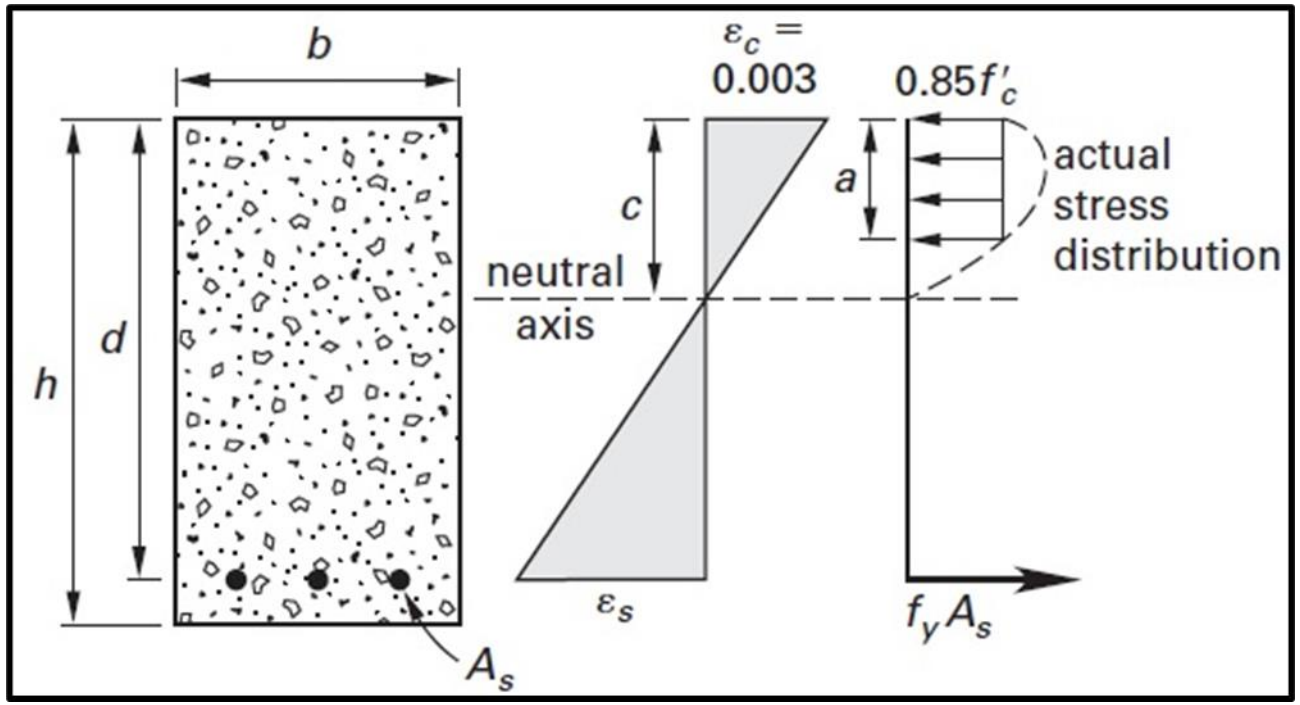
Depth from compression face to center of rebar

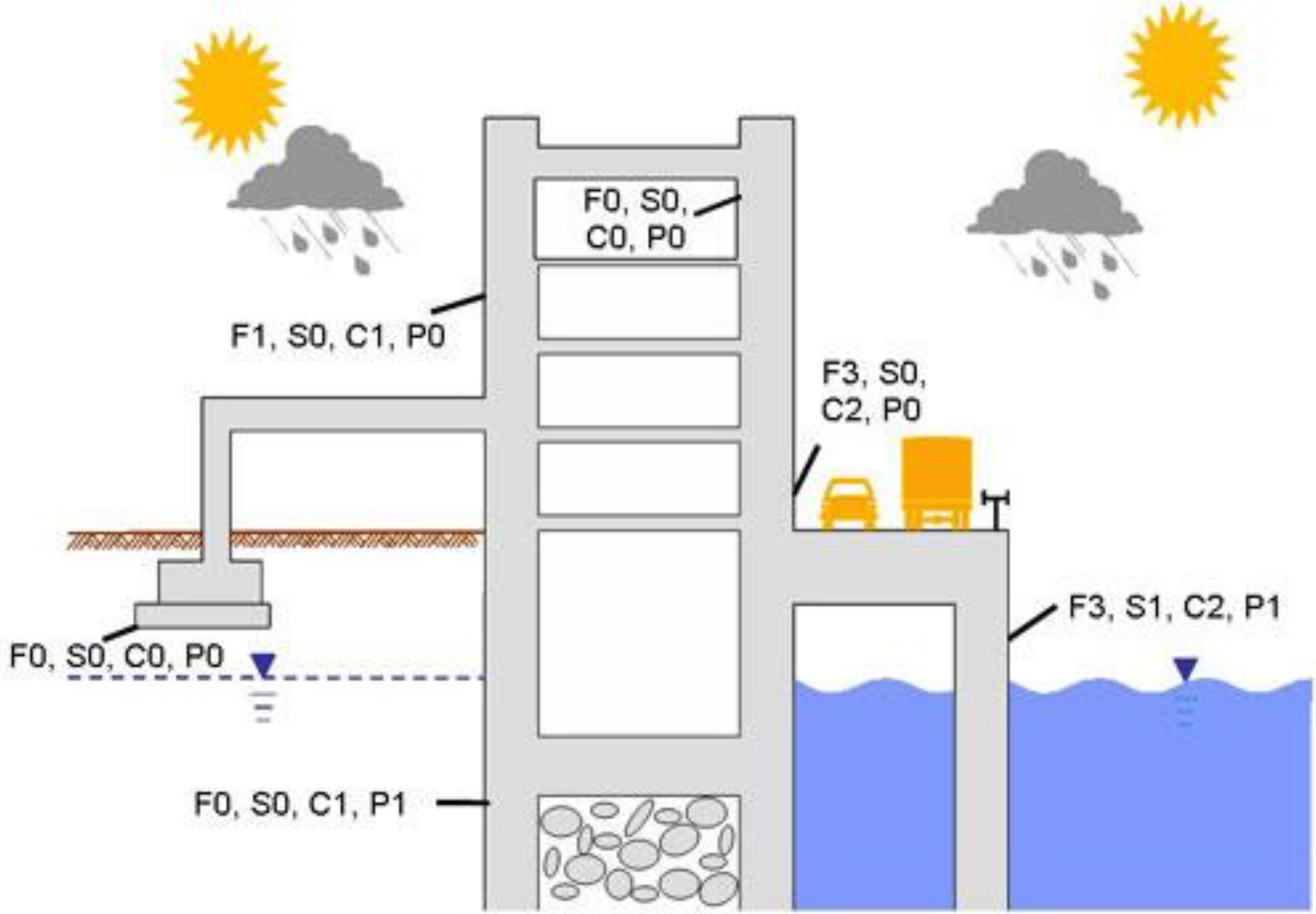
Specified compression strength of concrete

Width of beam

f'_c based on Resistance to Load






F0, S0,
C0, P0
F1, S0, C1, P0
F3, S0,
C2, P0
F3, S1, C2, P1
F0, S0, C0, P0
F0, S0, C1, P1

ACI 318-19 CODE REQUIREMENTS for CONCRETE DURABILITY

19.3—Concrete durability requirements

19.3.1 *Exposure categories and classes*

19.3.1.1 The licensed design professional shall assign exposure classes in accordance with the severity of the anticipated exposure of members for each exposure category in Table 19.3.1.1.

Table 19.3.1.1—Exposure categories and classes

[1]Percent sulfate by mass in soil shall be determined by ASTM C1580.

[2]Concentration of dissolved sulfates in water, in ppm, shall be determined by ASTM D516 or ASTM D4130.

Category	Class	Condition	
Freezing and thawing (F)	F0	Concrete not exposed to freezing-and-thawing cycles	
	F1	Concrete exposed to freezing-and-thawing cycles with limited exposure to water	
	F2	Concrete exposed to freezing-and-thawing cycles with frequent exposure to water	
	F3	Concrete exposed to freezing-and-thawing cycles with frequent exposure to water and exposure to deicing chemicals	
Sulfate (S)		Water-soluble sulfate (SO_4^{2-}) in soil, percent by mass[1]	Dissolved sulfate (SO_4^{2-}) in water, ppm[2]
	S0	$SO_4^{2-} < 0.10$	$SO_4^{2-} < 150$
	S1	$0.10 \le SO_4^{2-} < 0.20$	$150 \le SO_4^{2-} < 1500$ or seawater
	S2	$0.20 \le SO_4^{2-} \le 2.00$	$1500 \le SO_4^{2-} \le 10{,}000$
	S3	$SO_4^{2-} > 2.00$	$SO_4^{2-} > 10{,}000$
In contact with water (W)	W0	Concrete dry in service	
	W1	Concrete in contact with water where low permeability is not required	
	W2	Concrete in contact with water where low permeability is required	
Corrosion protection of reinforcement (C)	C0	Concrete dry or protected from moisture	
	C1	Concrete exposed to moisture but not to an external source of chlorides	
	C2	Concrete exposed to moisture and an external source of chlorides from deicing chemicals, salt, brackish water, seawater, or spray from these sources	



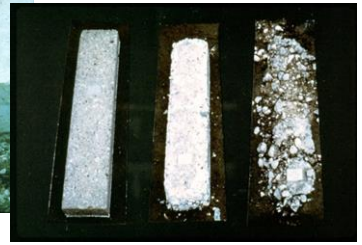


Table 19.3.2.1—Requirements for concrete by exposure class

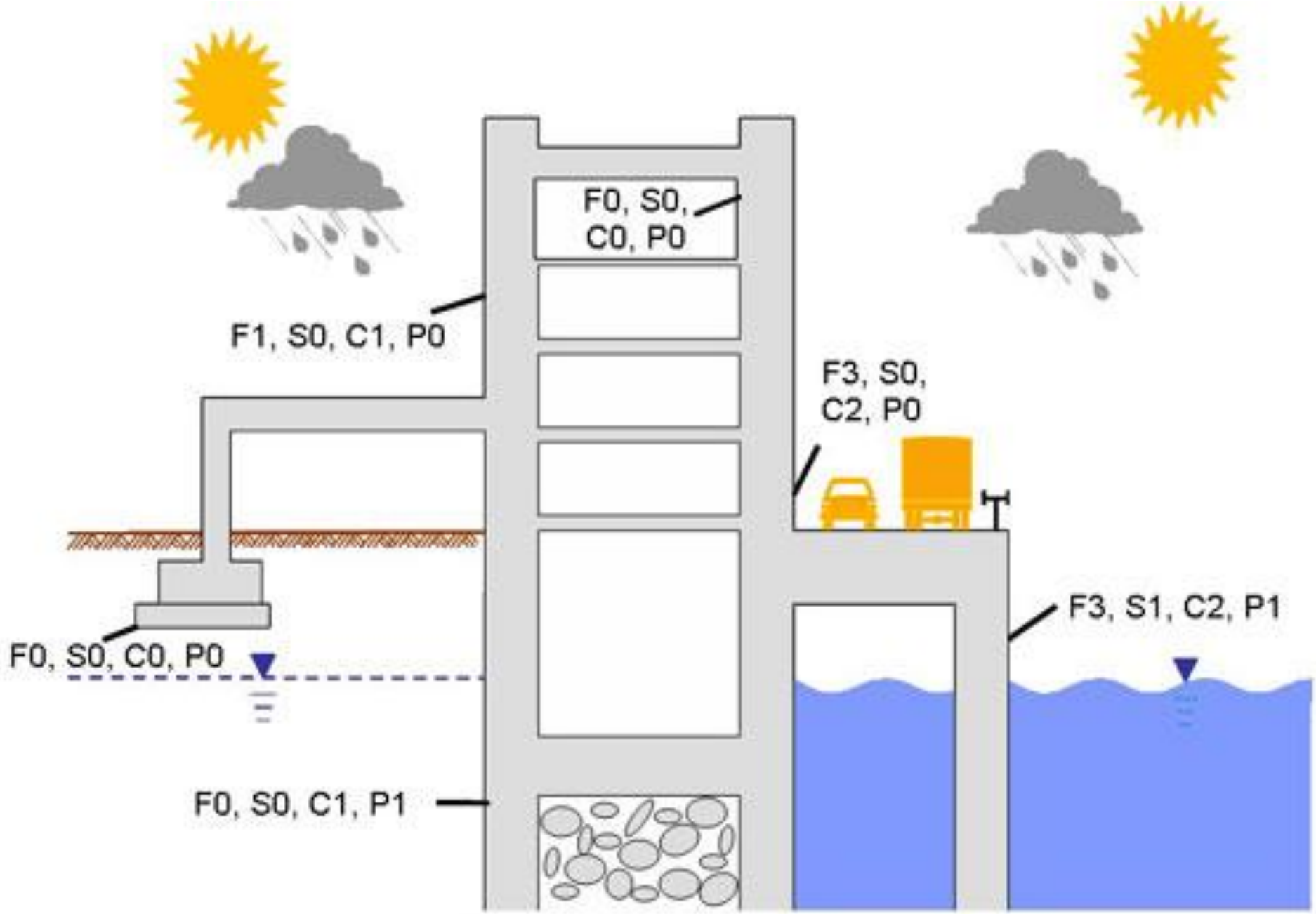
Exposure class	Maximum *w/cm*[1,2]	Minimum f'_c, psi	Additional requirements Air content			Limits on cementitious materials
F0	N/A	2500	N/A			N/A
F1	0.55	3500	Table 19.3.3.1			N/A
F2	0.45	4500	Table 19.3.3.1			N/A
F3	0.40[3]	5000[3]	Table 19.3.3.1			26.4.2.2(b)
			Cementitious materials[4] — Types			Calcium chloride admixture
			ASTM C150	ASTM C595	ASTM C1157	
S0	N/A	2500	No type restriction	No type restriction	No type restriction	No restriction
S1	0.50	4000	II[5][6]	Types with (MS) designation	MS	No restriction
S2	0.45	4500	V[6]	Types with (HS) designation	HS	Not permitted
S3 Option 1	0.45	4500	V plus pozzolan or slag cement[7]	Types with (HS) designation plus pozzolan or slag cement[7]	HS plus pozzolan or slag cement[7]	Not permitted
S3 Option 2	0.40	5000	V[8]	Types IP, IS, or IT with (HS) designation	HS	Not permitted

Table 19.3.2.1—Requirements for concrete by exposure class

Exposure class	Maximum *w/cm*[1,2]	Minimum f'_c, psi	Additional requirements Air content	Limits on cementitious materials
F0	N/A	2500	N/A	N/A

W0	N/A	2500	None		
W1	N/A	2500	26.4.2.2(d)		
W2	0.50	4000	26.4.2.2(d)		
			Maximum water-soluble chloride ion (Cl^-) content in concrete, percent by mass of cementitious materials [9,10]		
			Nonprestressed concrete	**Prestressed concrete**	**Additional provisions**
C0	N/A	2500	1.00	0.06	None
C1	N/A	2500	0.30	0.06	
C2	0.40	5000	0.15	0.06	Concrete cover[11]

[1] The w/cm is [based] on all cementitious and supplementary cementitious materials in the concrete mixture.
[2] The maximum ***w/cm*** limits do not apply to lightweight concrete.
[3] For plain concrete, the maximum ***w/cm*** shall be 0.45 and the minimum f_c' shall be 4500 psi.
[4] Alternative combinations of cementitious materials to those listed are permitted for all sulfate exposure classes when tested for sulfate resistance and meeting the criteria in 26.4.2.2
[5] For seawater exposure, other types of portland cements with tricalcium aluminate (C3A) contents up to 10 percent are permitted if the w/cm does not exceed 0.40.
[6] Other available types of cement such as Type I or Type III are permitted in Exposure Classes S1 or S2 if the C_3A contents are less than 8 percent for Exposure Class S1 or less than 5 percent for Exp
[7] The amount of the specific source of the pozzolan or slag cement to be used shall be at least the amount that has been determined by service record to improve sulfate resistance when used in concre
[8] If Type V cement is used as the sole cementitious material, the optional sulfate resistance requirement of 0.040 percent maximum expansion in ASTM C150 shall be specified.
[9] The mass of supplementary cementitious materials used in determining the chloride content shall not exceed the mass of the cement.
[10] Criteria for determination of chloride content are in 26.4.2.2
[11] Concrete cover shall be in accordance with 20.5.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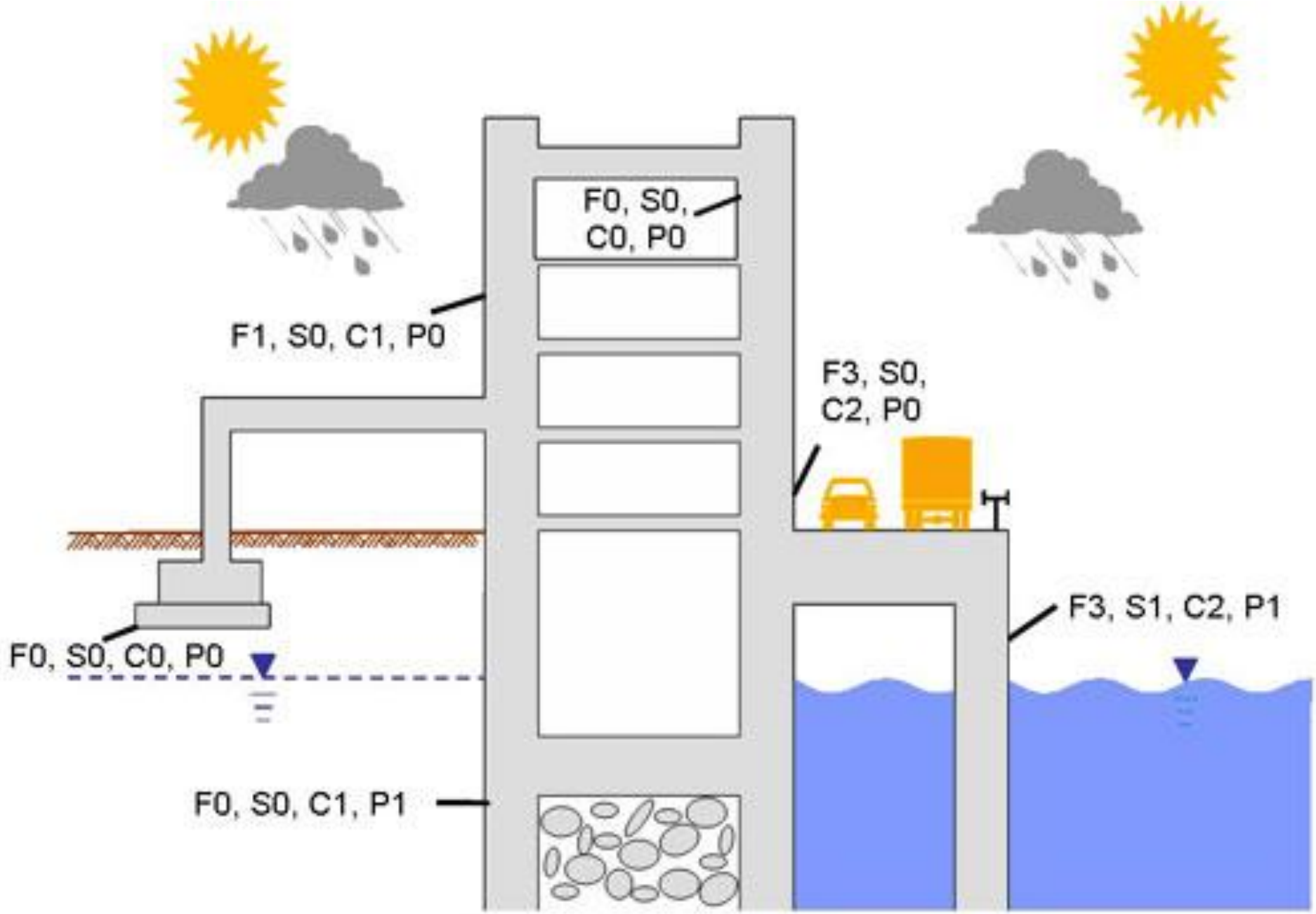
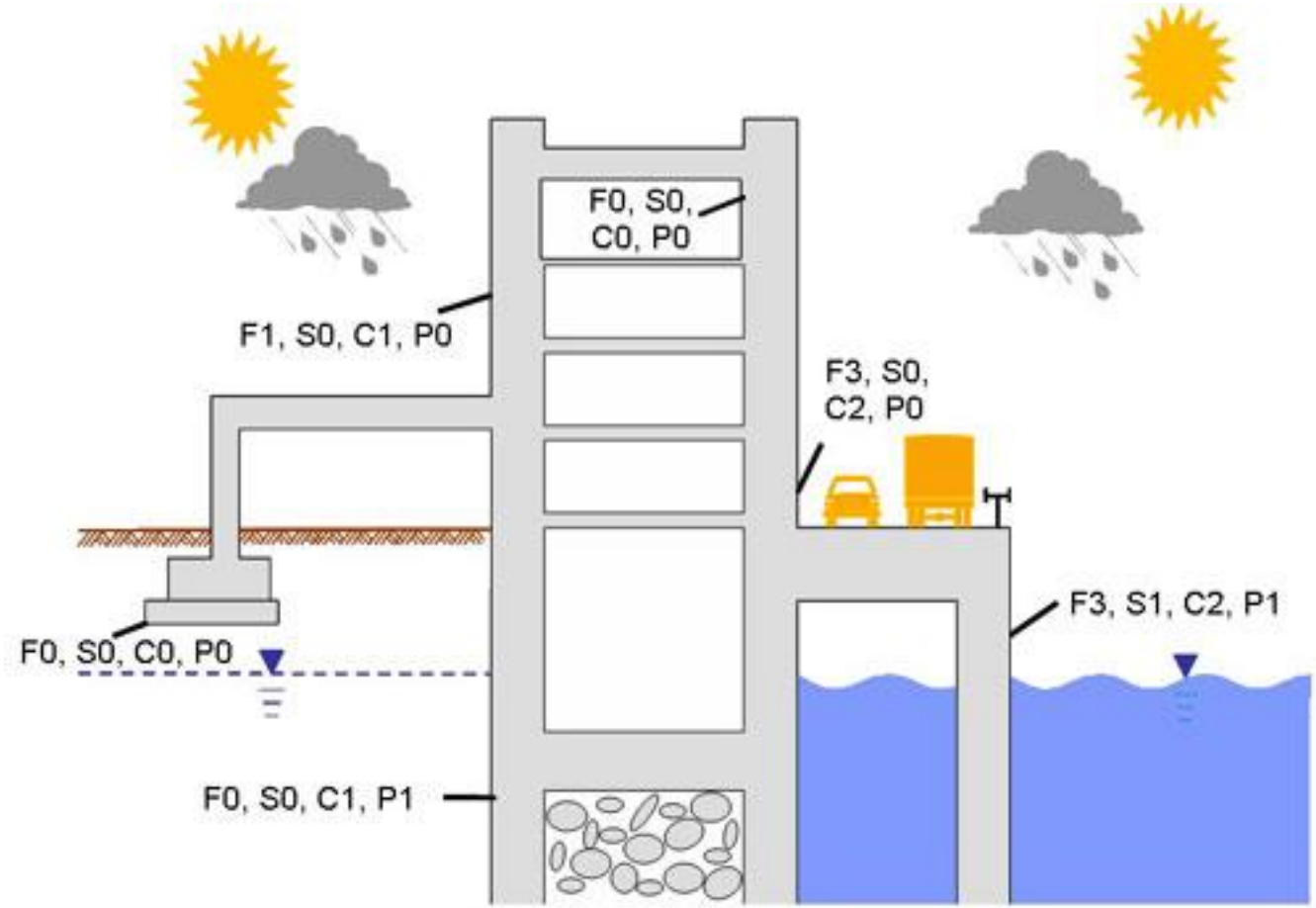
C0, P0
F1, S0, C1, P0
F3, S0,
C2, P0
F3, S1, C2, P1
F0, S0, C0, P0
F0, S0, C1, P1


F0, S0,
C0, P0
F1, S0, C1, P0
F3, S0,
C2, P0
F3, S1, C2, P1
F0, S0, C0, P0
F0, S0, C1, P1


F0, S0,
C0, P0
F1, S0, C1, P0
F3, S0,
C2, P0
F3, S1, C2, P1
F0, S0, C0, P0
F0, S0, C1, P1

- Sometimes concern for Mechanical “Overdesign” is justified:
  - Constructability (congested rebar)
  - Problems associated with Heat of Hydration increase with thicker concrete
- Overall consumption and cost of resources
  - Steel, cement, aggregates
- Sustainability
  - Reduce 10-inch slab to 8-inch slab→
    - 20% reduction in carbon footprint with some reduction in cost
    - Code minimum slab thickness apply *unless calculated deflections ≤ code limits*

Dwngs & Specs:

$f'c = 5000$ psi

"If you've never missed a plane, you are spending too much time in airports! Andrew Dallas, Past President, New Zealand Concrete Association

If specified cylinder strength = 5000 psi

Is it OK

to have an average cylinder

Activity	Shortest s… events		
Drive from home to airport parking	45 r…		
Find Parking space	5 min…		
Enter & check in	15 minut…		
Security	5 minutes		…inutes
Get to Gate	5 minutes	25 minutes	10 minutes
Total Time	75 minutes	280 minutes	140 minutes

Except for time of day for traveling, you have very little control over these random events!

Can you routinely leave for airport 140 minutes before boarding?

Myth and Misinterpretation of "Overdesign"

- Focus on f'c
  - –Specified 28-day, lab-cured, concrete compressive strength
  - –Cast per ASTM C31 and initially stored on site without moisture loss,
    @ 60-80 F (68-78F for ± 6000 psi), shielded from direct sunlight.
  - –Tested in moist condition per ASTM C39
  - –Loaded at 35 ± 7 psi/sec
  - –Until test operator "certain that ultimate capacity has been attained."

The "Apparent" Overdesign Bait & Switch

Dwngs & Specs:

f'c = 5000 psi

If your AVERAGE Cylinder Strength = 5000 psi:

Good News: Half your breaks are stronger than required!

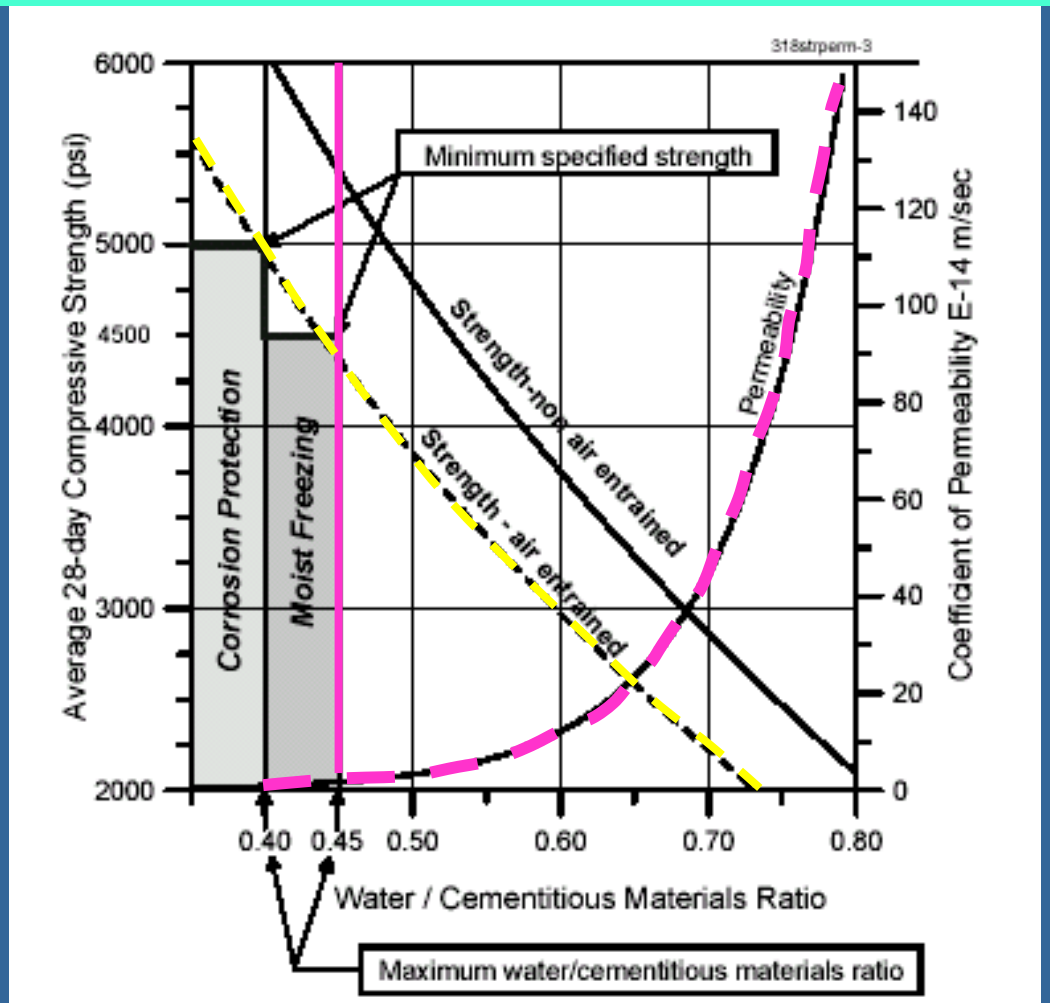
Bad News: Half your breaks are weaker than required!

At an average cylinder strength = 5000 psi
50% chance of meeting specs!

Dwngs & Specs:

For f'c = 5000 psi, Average cylinder strength > 5000 psi

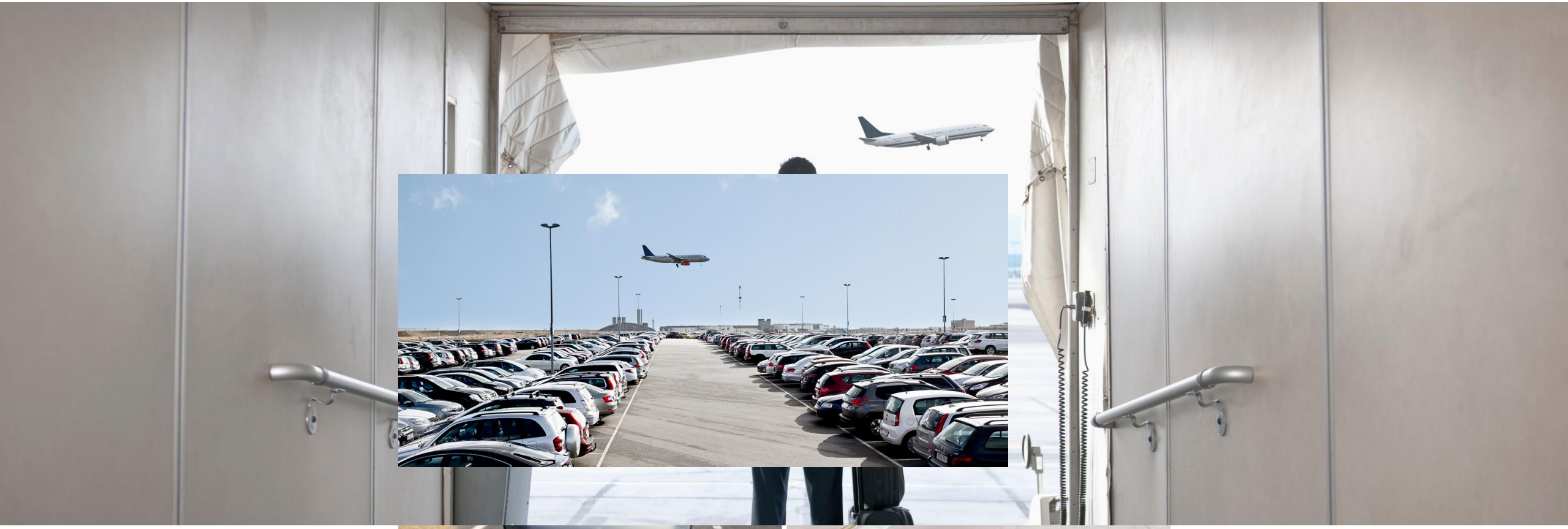
IBC, ACI, and State Building Code Requirements From 1989 to 2019:



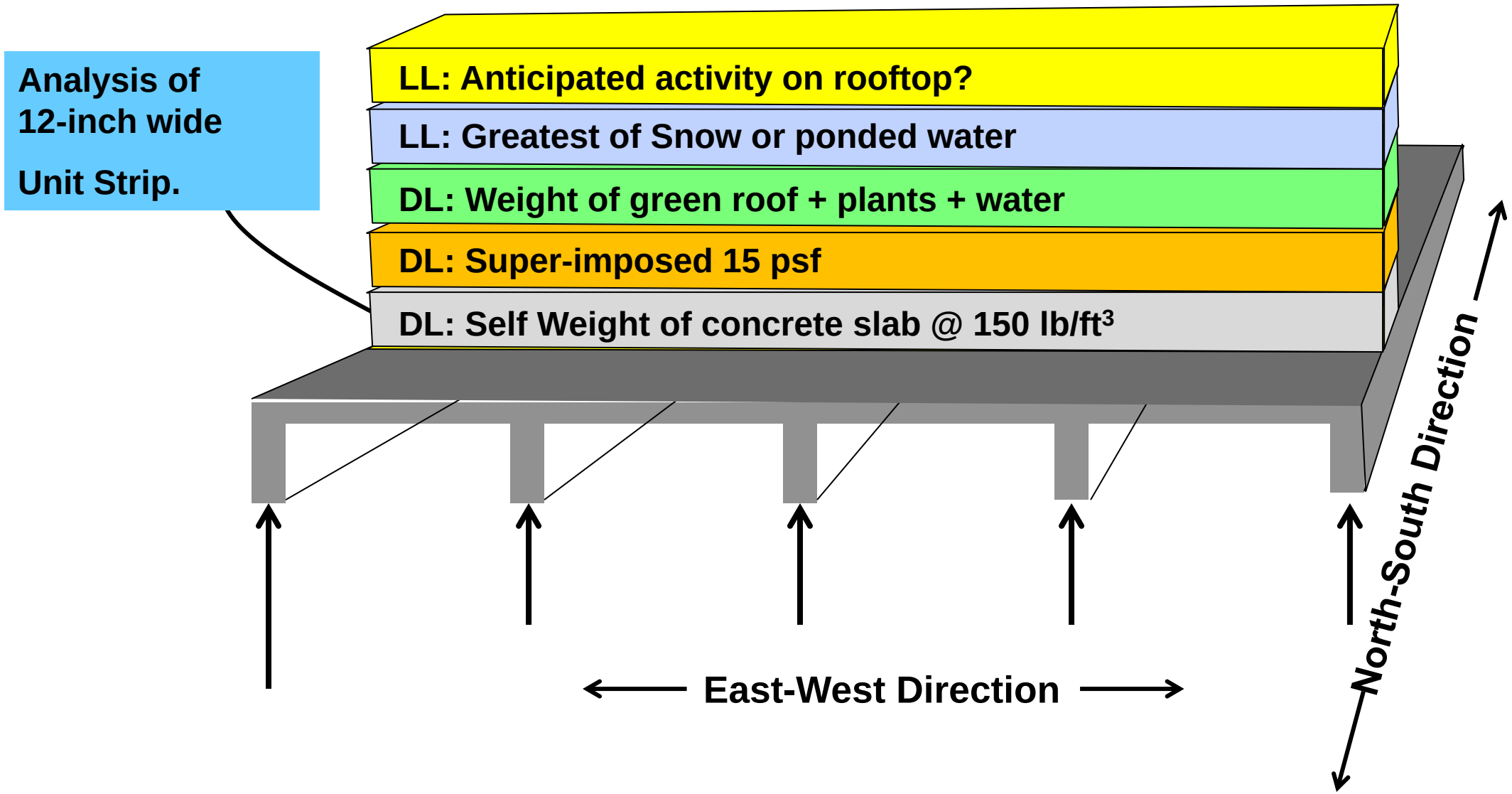
Evaluating compliance with required DURABILITY

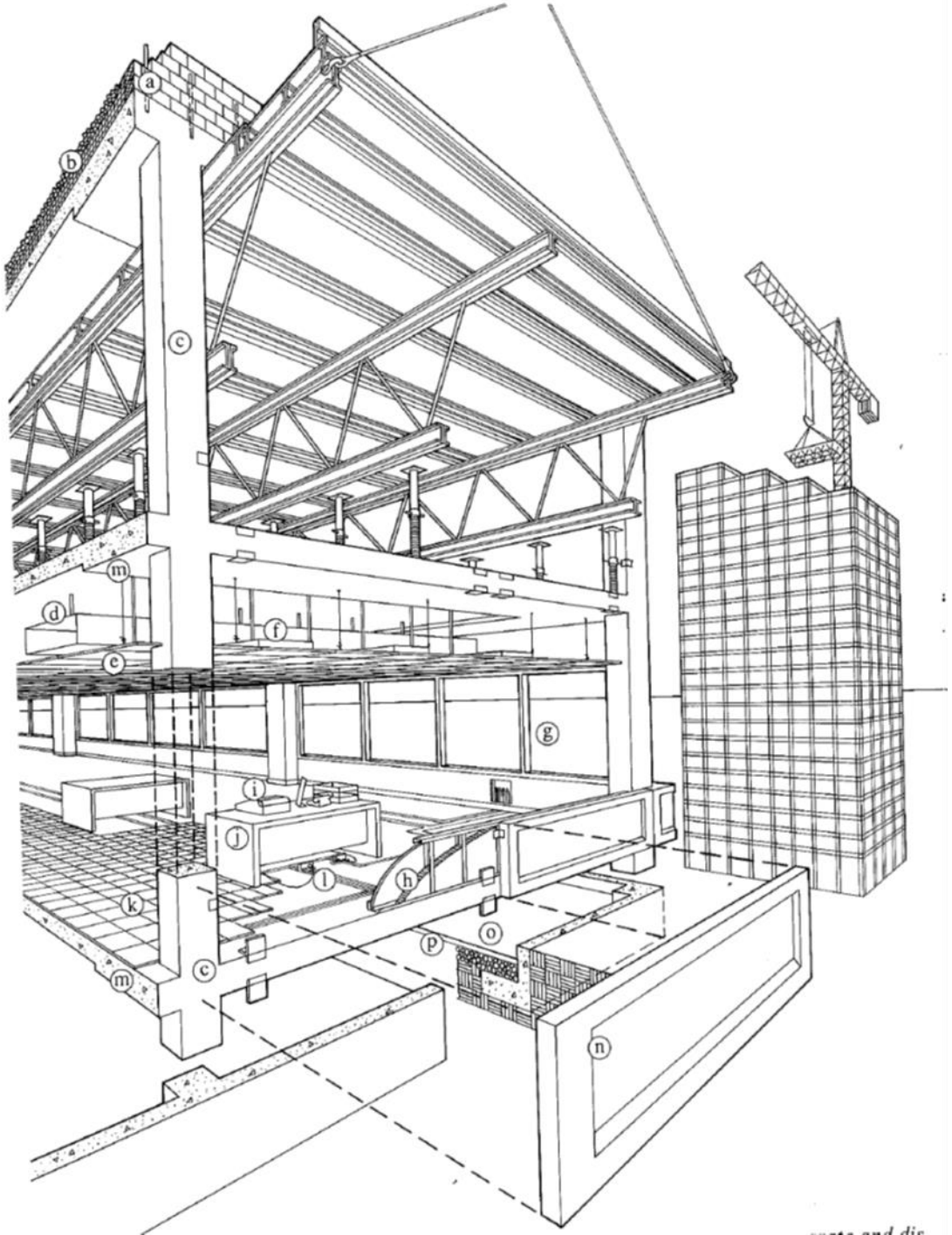
Let’s look at a related problem:

How much extra time do you allow to drive to airport?



A Multi-Span, Continuous Reinforced Concrete Roof Slab

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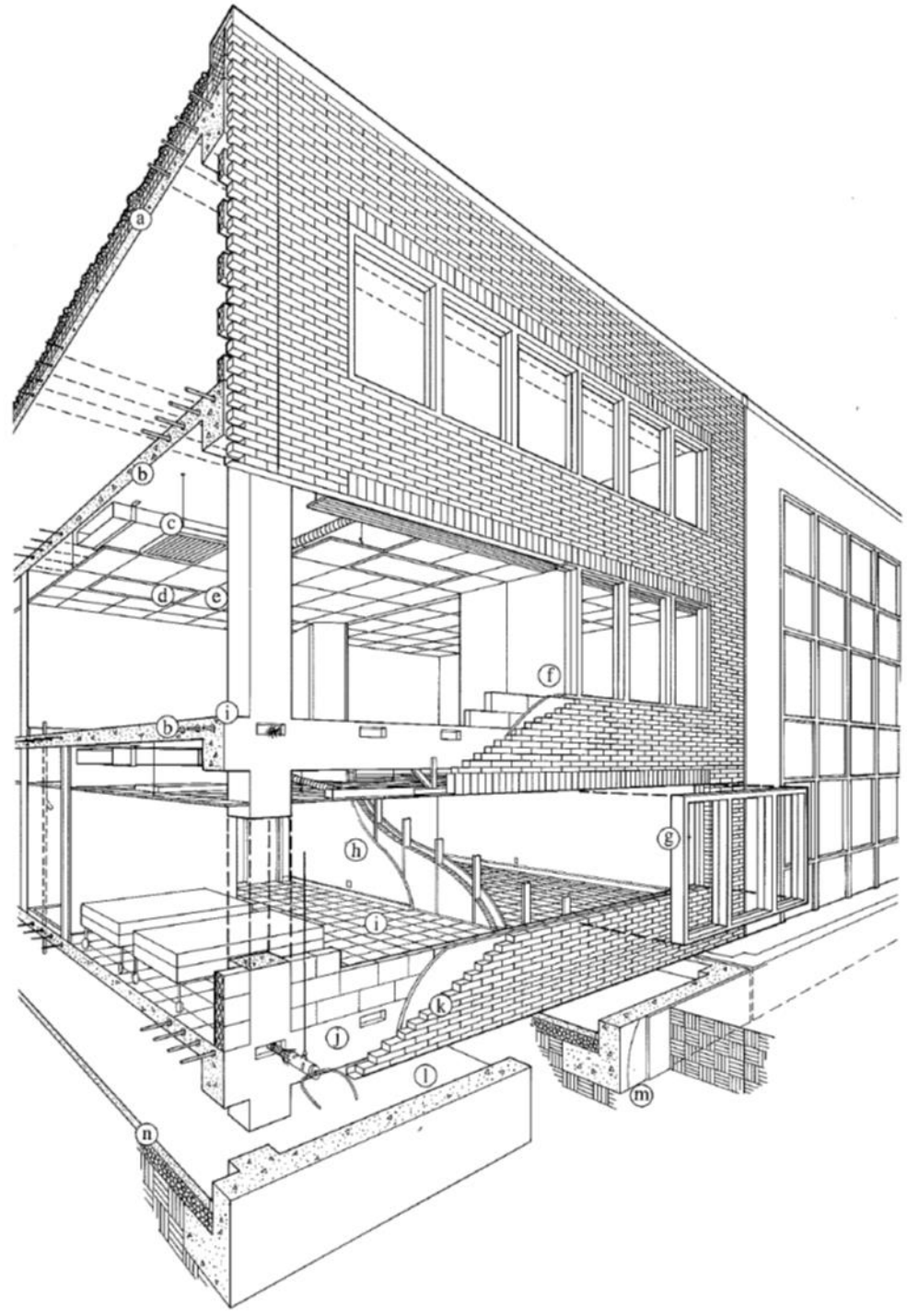
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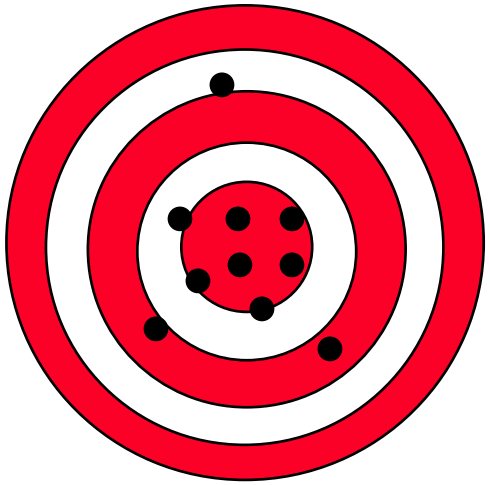
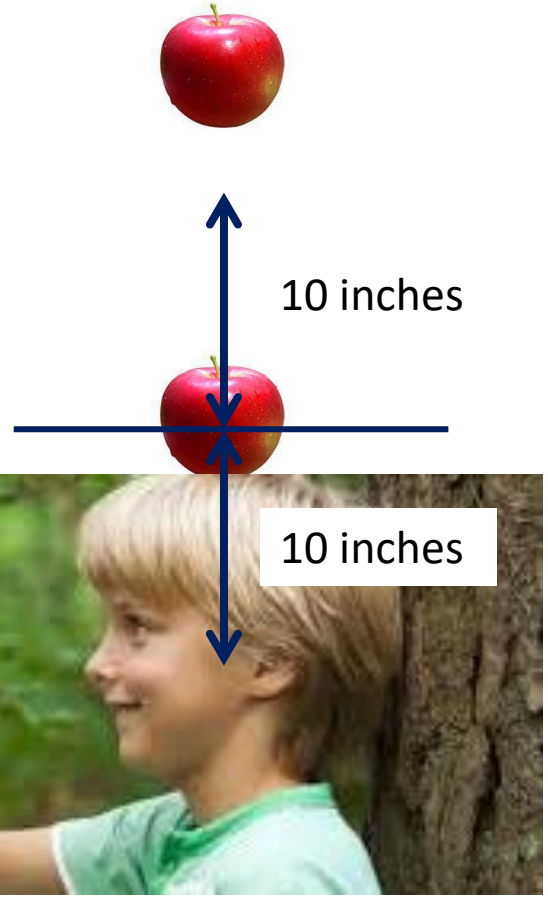
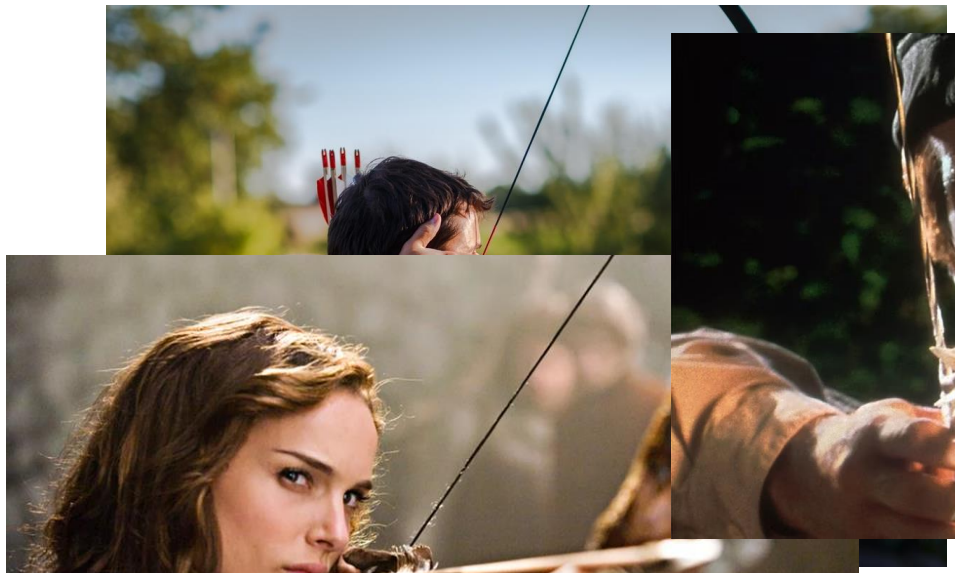


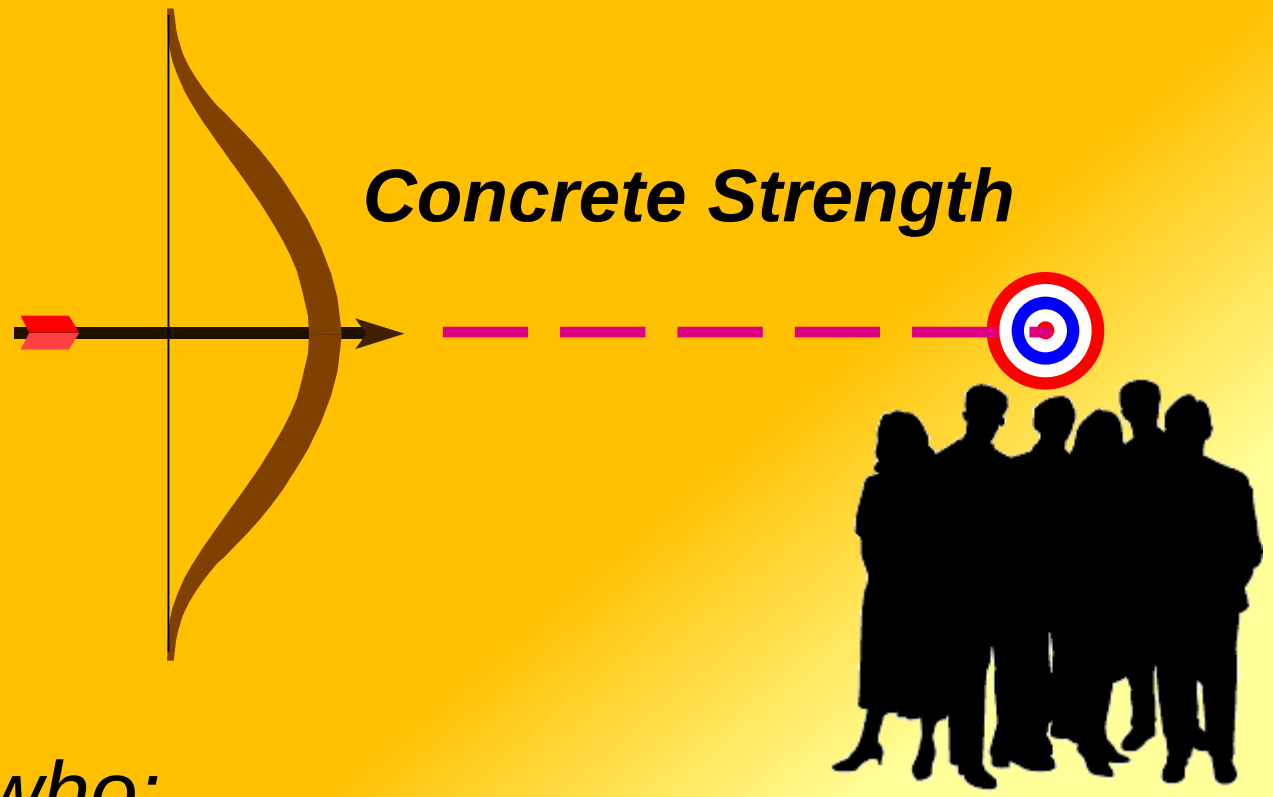
About 2/3 of shots are within 10 inches of center of shot pattern!


10 inches
10 inches

How far we raise the apple…

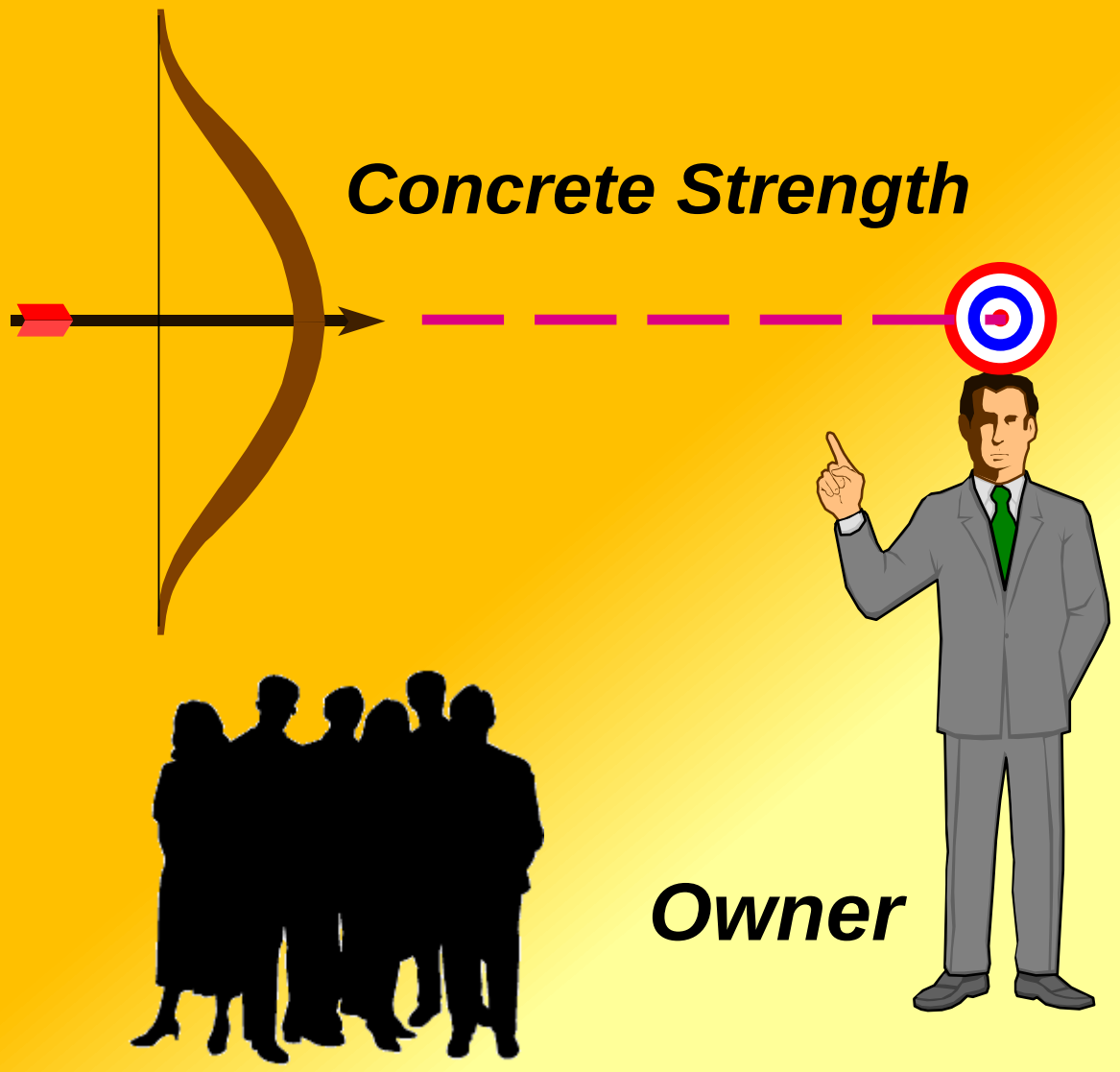
Depends on the archer



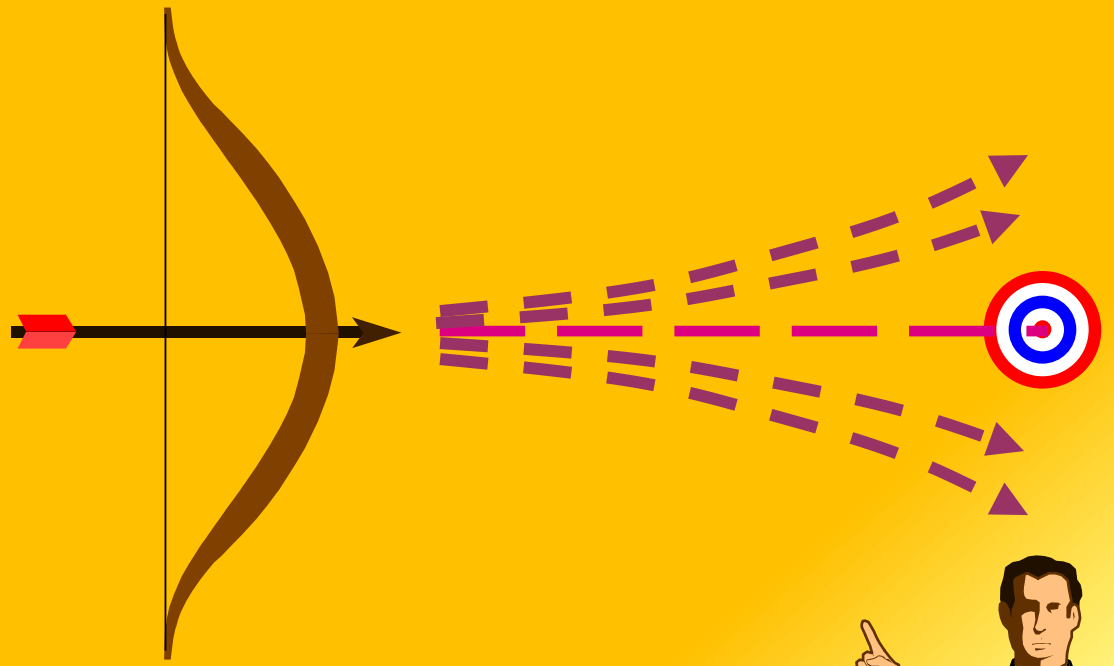


How High we set the target depends on how good He shooter is!

People who:
Live, work, eat, drink, relax, play in,
Walk, ride, or drive near,
or otherwise depend on your structure

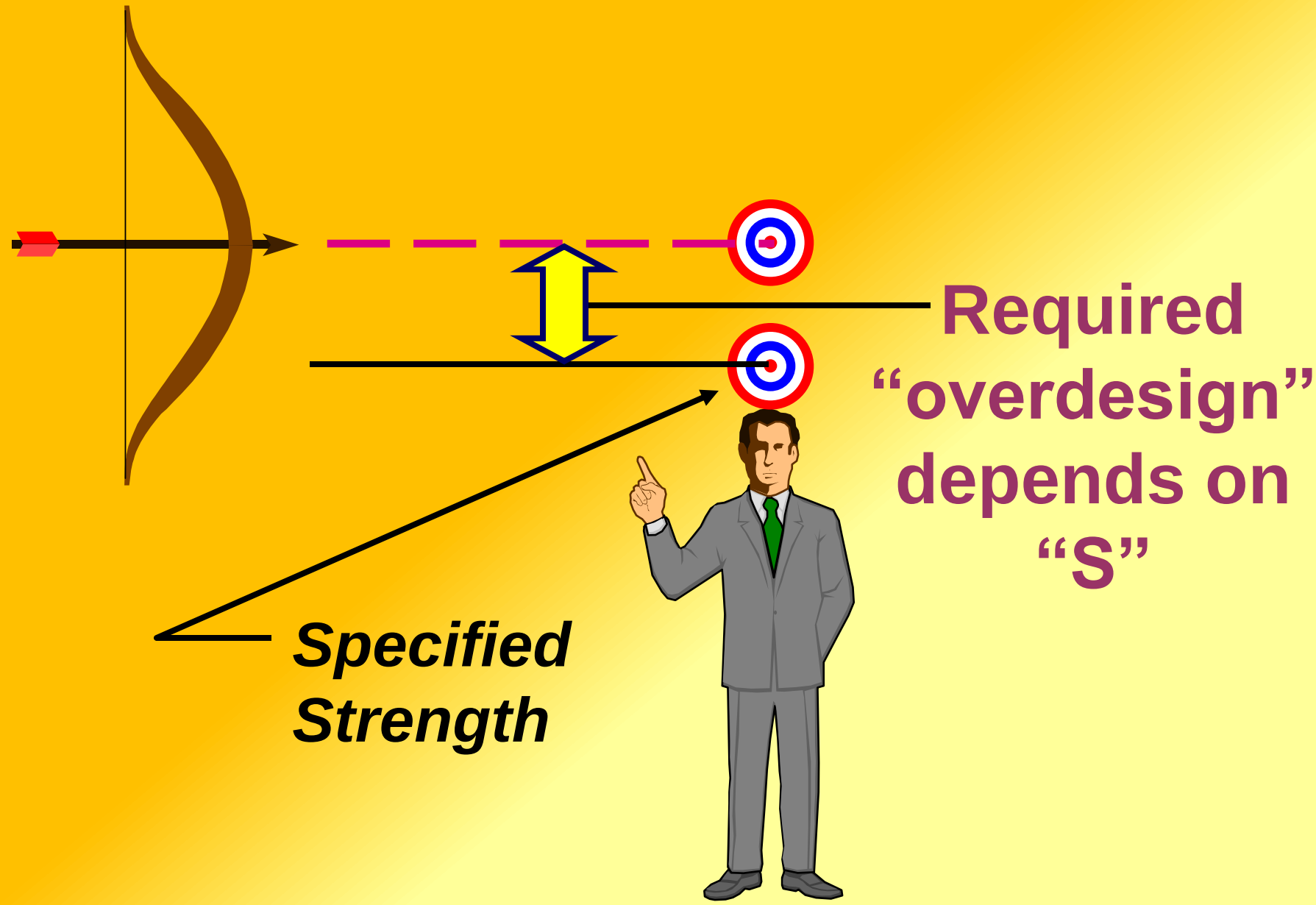


How High you set the target depends on how good You are!

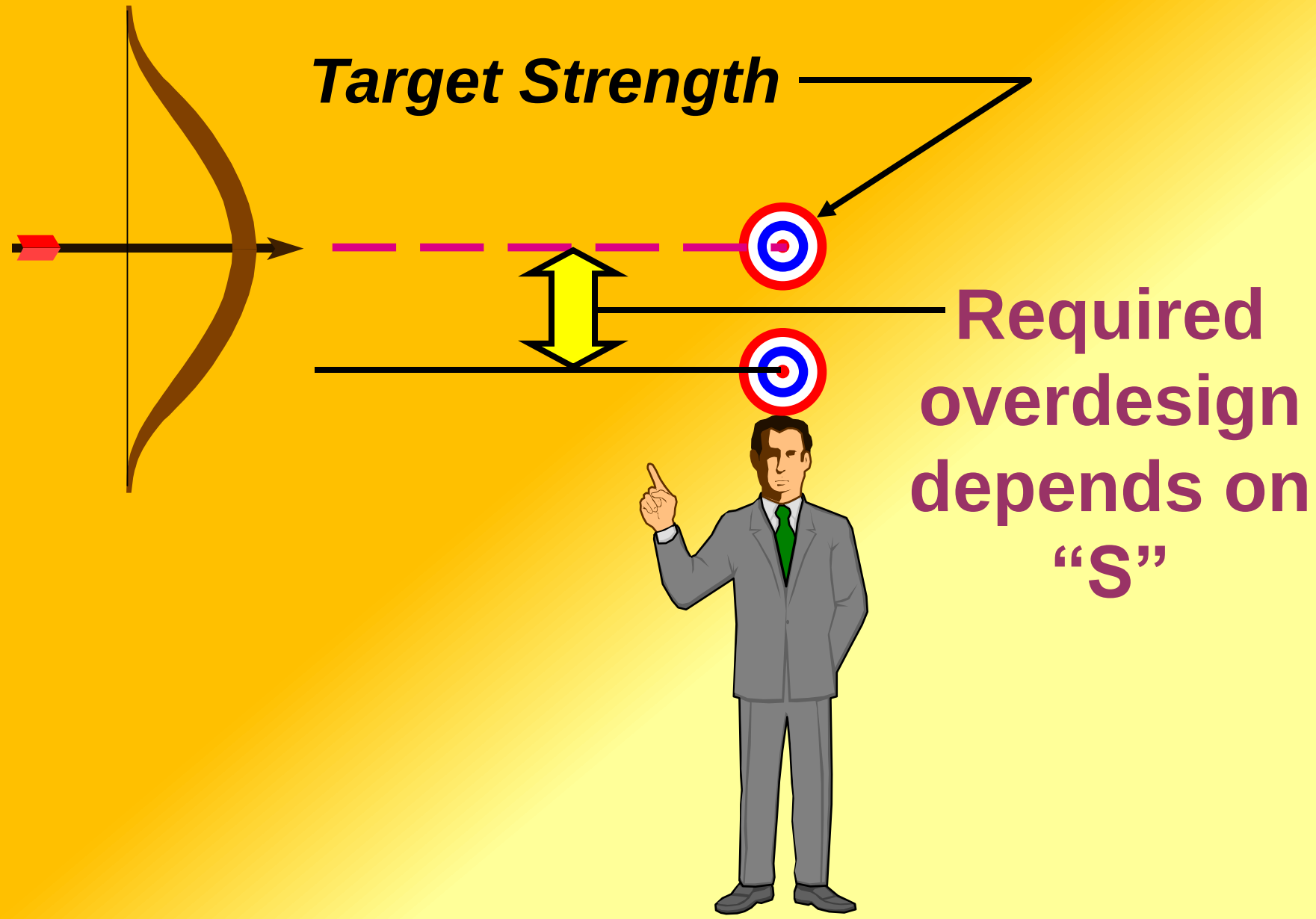


How High you set the target depends on How Good You Are!

Owner

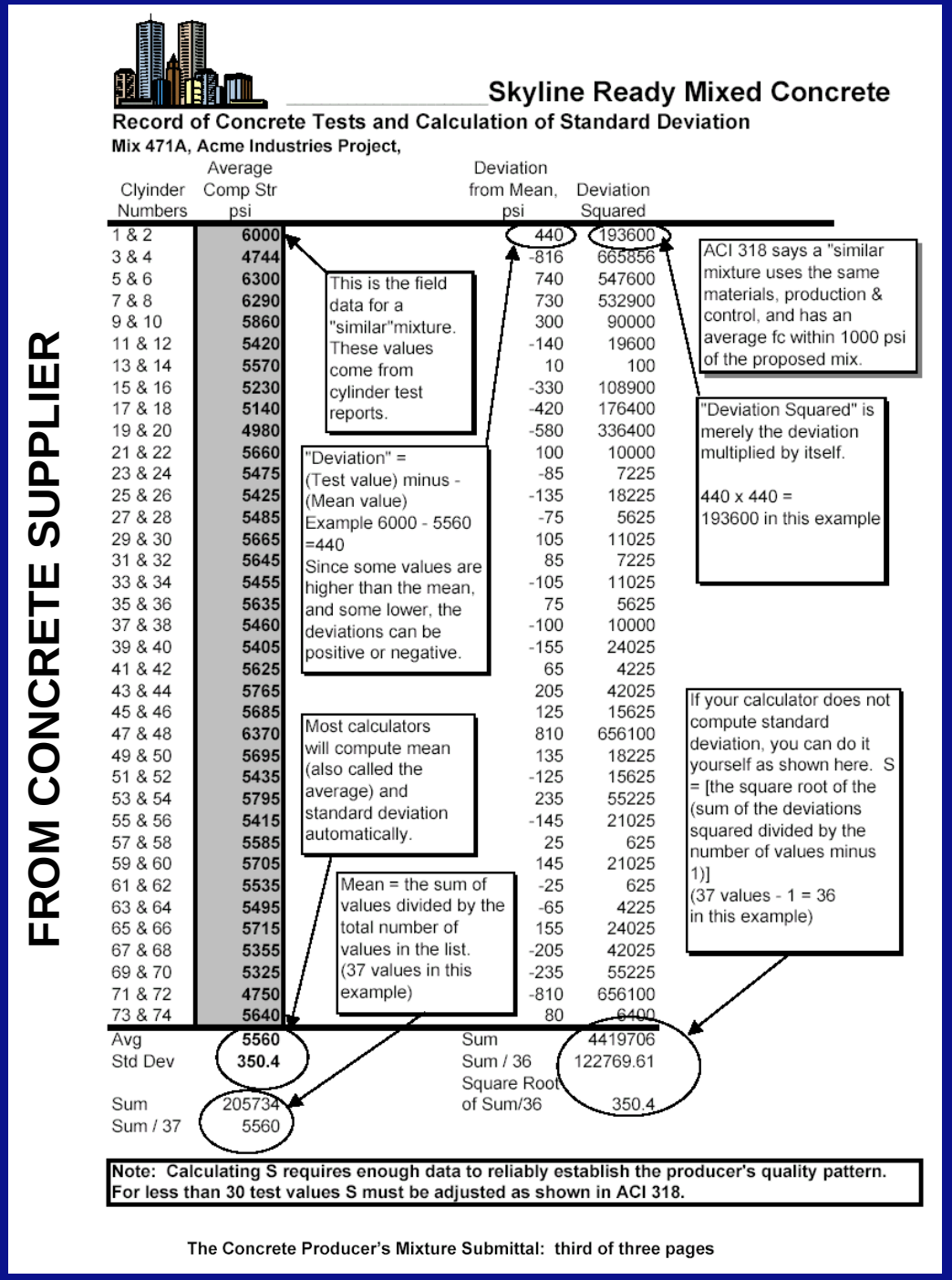


(See Appendix A to calculate S value from cylinder records)



(See Appendix A to calculate S value from cylinder records)

Cylinder Test Records for Similar Mix



Skyline Ready Mixed Concrete

Record of Concrete Tests and Calculation of Standard Deviation

Mix 471A, Acme Industries Project,

FROM CONCRETE SUPPLIER

Clyinder Numbers	Average Comp Str psi	Deviation from Mean, psi	Deviation Squared
1 & 2	6000	440	193600
3 & 4	4744	-816	665856
5 & 6	6300	740	547600
7 & 8	6290	730	532900
9 & 10	5860	300	90000
11 & 12	5420	-140	19600
13 & 14	5570	10	100
15 & 16	5230	-330	108900
17 & 18	5140	-420	176400
19 & 20	4980	-580	336400
21 & 22	5660	100	10000
23 & 24	5475	-85	7225
25 & 26	5425	-135	18225
27 & 28	5485	-75	5625
29 & 30	5665	105	11025
31 & 32	5645	85	7225
33 & 34	5455	-105	11025
35 & 36	5635	75	5625
37 & 38	5460	-100	10000
39 & 40	5405	-155	24025
41 & 42	5625	65	4225
43 & 44	5765	205	42025
45 & 46	5685	125	15625
47 & 48	6370	810	656100
49 & 50	5695	135	18225
51 & 52	5435	-125	15625
53 & 54	5795	235	55225
55 & 56	5415	-145	21025
57 & 58	5585	25	625
59 & 60	5705	145	21025
61 & 62	5535	-25	625
63 & 64	5495	-65	4225
65 & 66	5715	155	24025
67 & 68	5355	-205	42025
69 & 70	5325	-235	55225
71 & 72	4750	-810	656100
73 & 74	5640	80	6400
Avg	5560	Sum	4419706
Std Dev	350.4	Sum / 36	122769.61
		Square Root of Sum/36	350.4
Sum	205734		
Sum / 37	5560		

This is the field data for a "similar"mixture. These values come from cylinder test reports.

"Deviation" = (Test value) minus - (Mean value) Example 6000 - 5560 =440 Since some values are higher than the mean, and some lower, the deviations can be positive or negative.

Most calculators will compute mean (also called the average) and standard deviation automatically.

Mean = the sum of values divided by the total number of values in the list. (37 values in this example)

ACI 318 says a "similar mixture uses the same materials, production & control, and has an average fc within 1000 psi of the proposed mix.

"Deviation Squared" is merely the deviation multiplied by itself.

440 x 440 = 193600 in this example

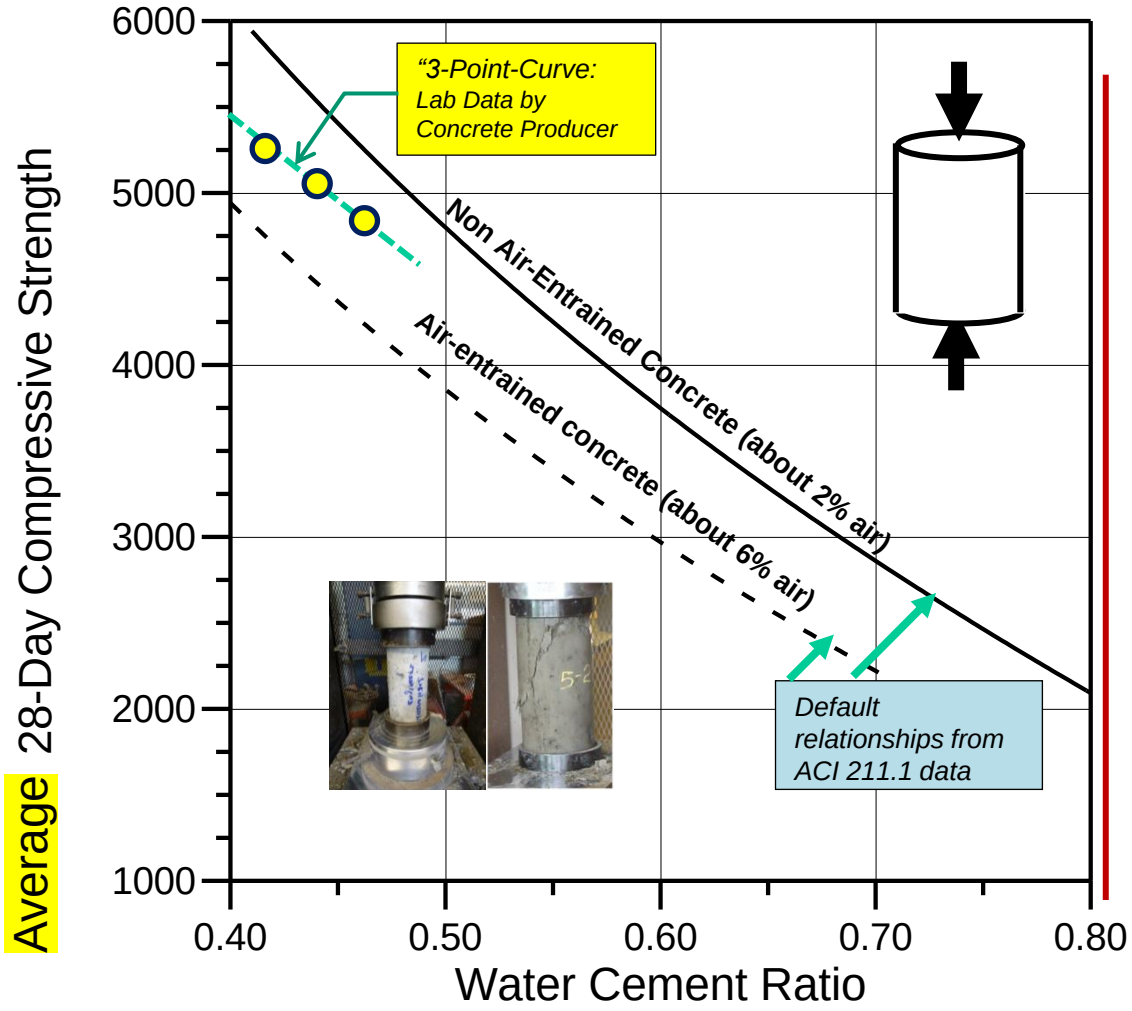
If your calculator does not compute standard deviation, you can do it yourself as shown here. S = [the square root of the (sum of the deviations squared divided by the number of values minus 1)] (37 values - 1 = 36 in this example)

Note: Calculating S requires enough data to reliably establish the producer's quality pattern. For less than 30 test values S must be adjusted as shown in ACI 318.

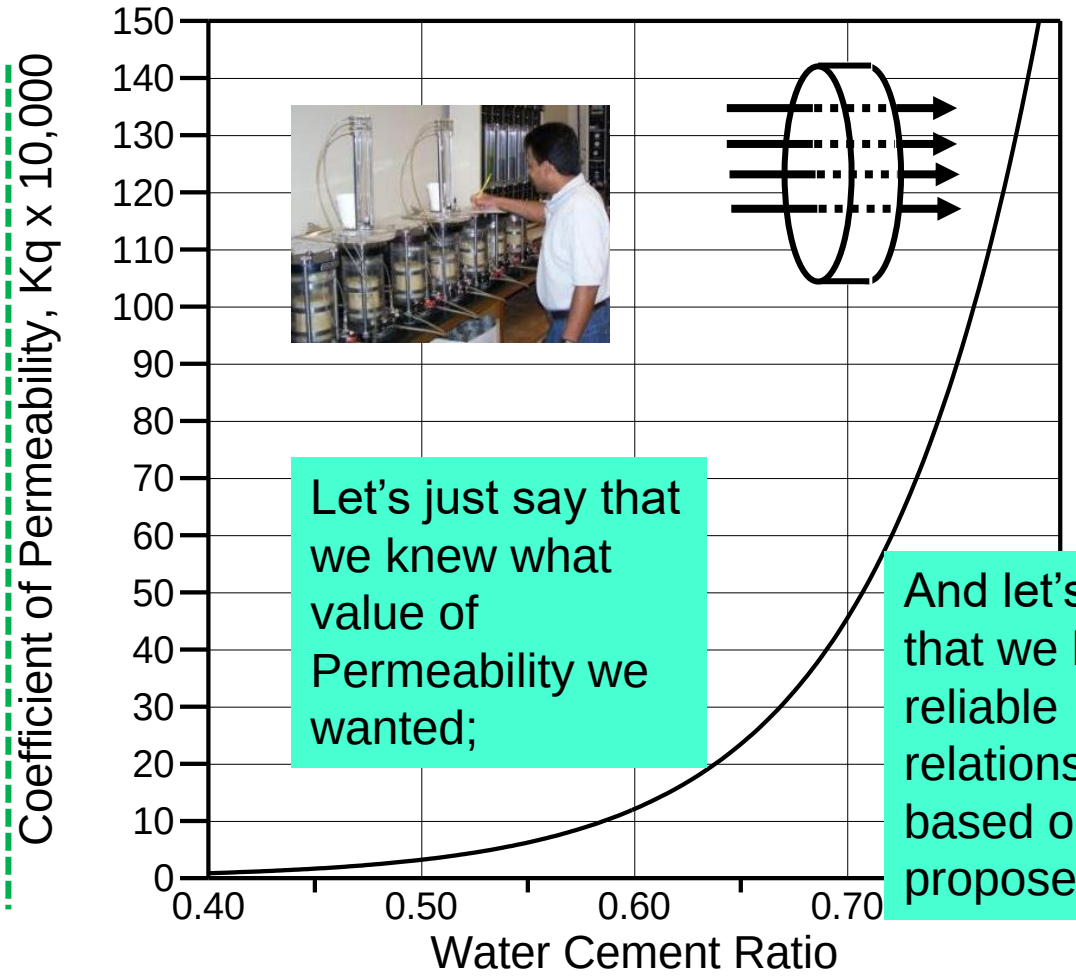
The Concrete Producer's Mixture Submittal: third of three pages

4. Selecting water/cementitious materials ratio (w/c or w/cm)

Influence of W/C on Strength and Permeability



Approximate 28-Day Compressive Strength as a function of Water/Cement Ratio. Adapted from ACI 211.1-91, Table 6.3.4(a)

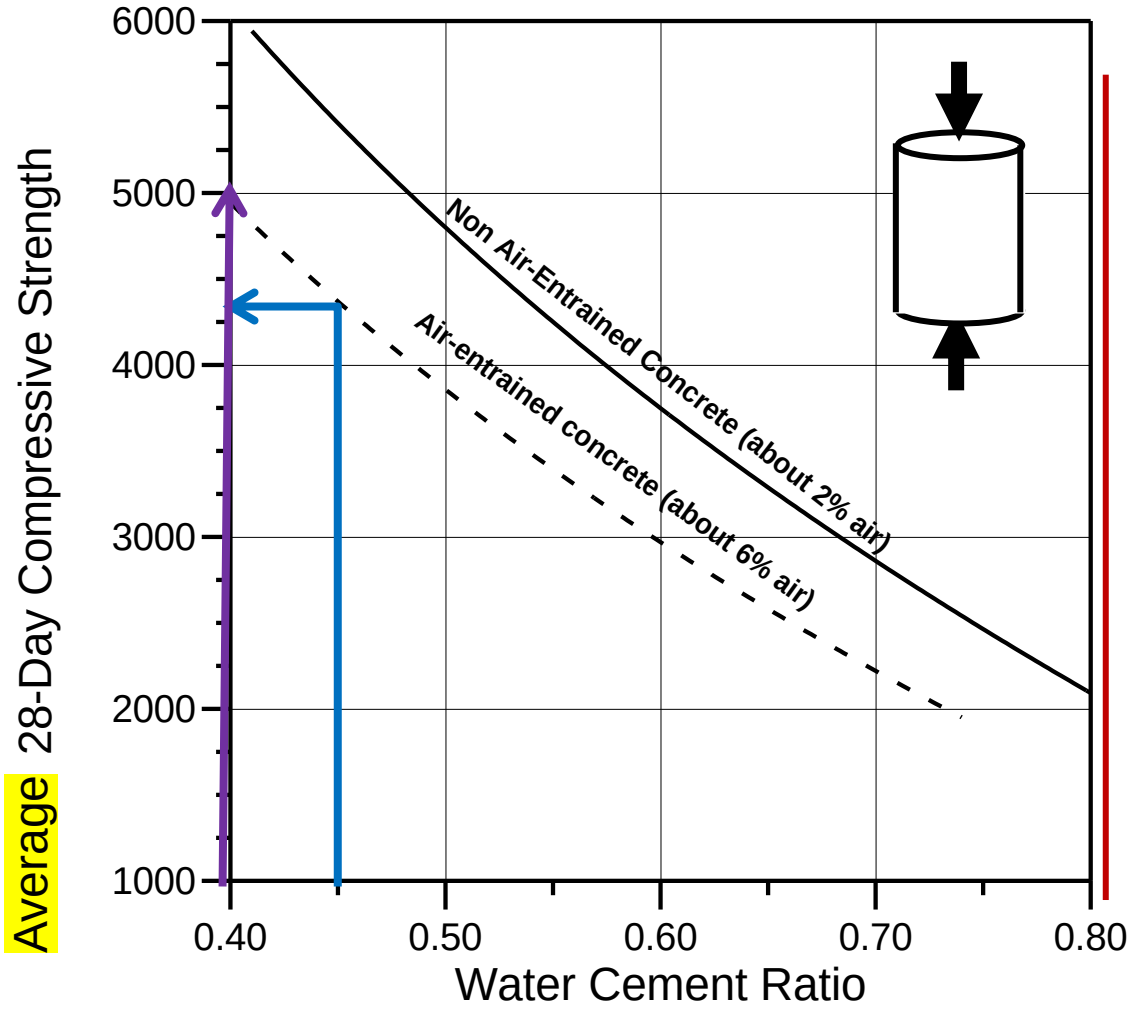


Permeability as a function of Water/Cement Ratio. Data from Bureau of Reclamation Concrete Manual, 8th Edition, 1975, Figure 17, page 27.

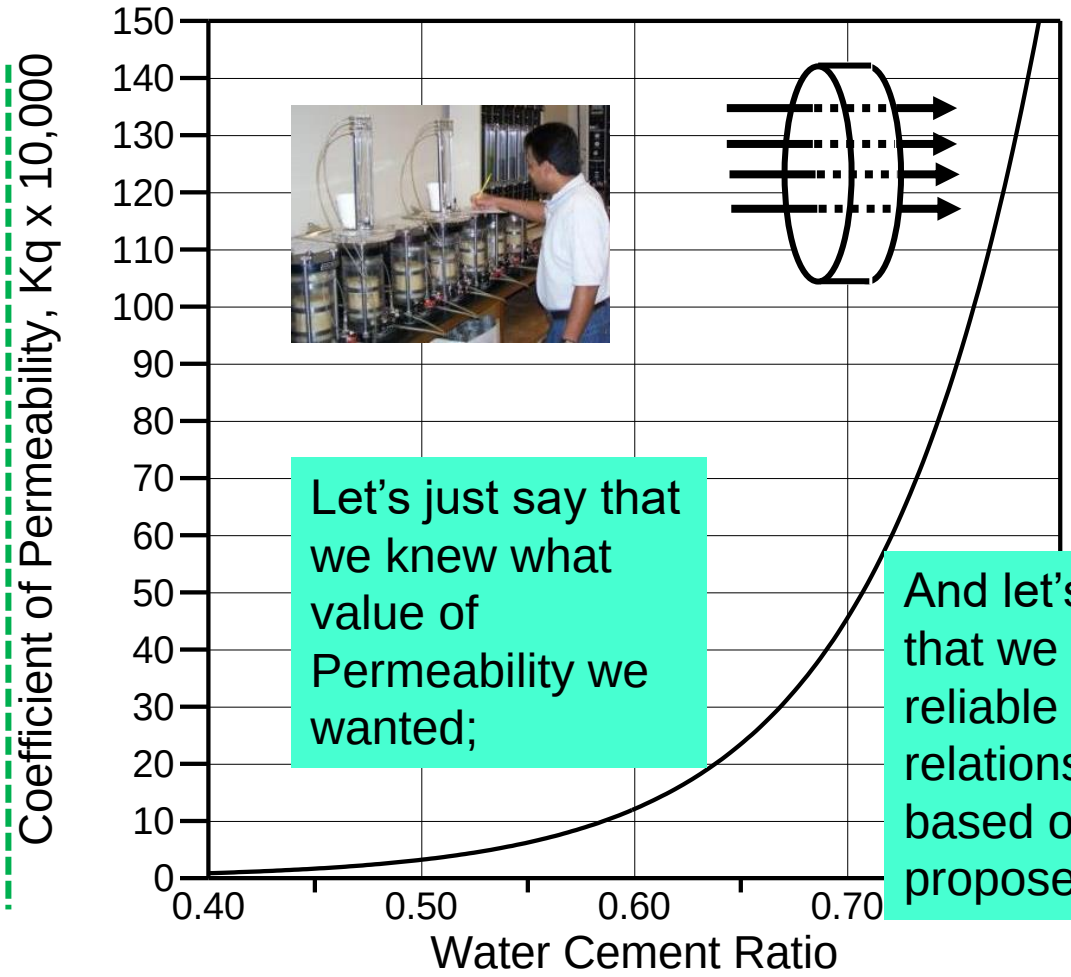
No "standard" relationship for all mixtures & materials

4. Selecting water/cementitious materials ratio (w/c or w/cm)

Influence of W/C on Strength and Permeability



Approximate 28-Day Compressive Strength as a function of Water/Cement Ratio. Adapted from ACI 211.1-91, Table 6.3.4(a)

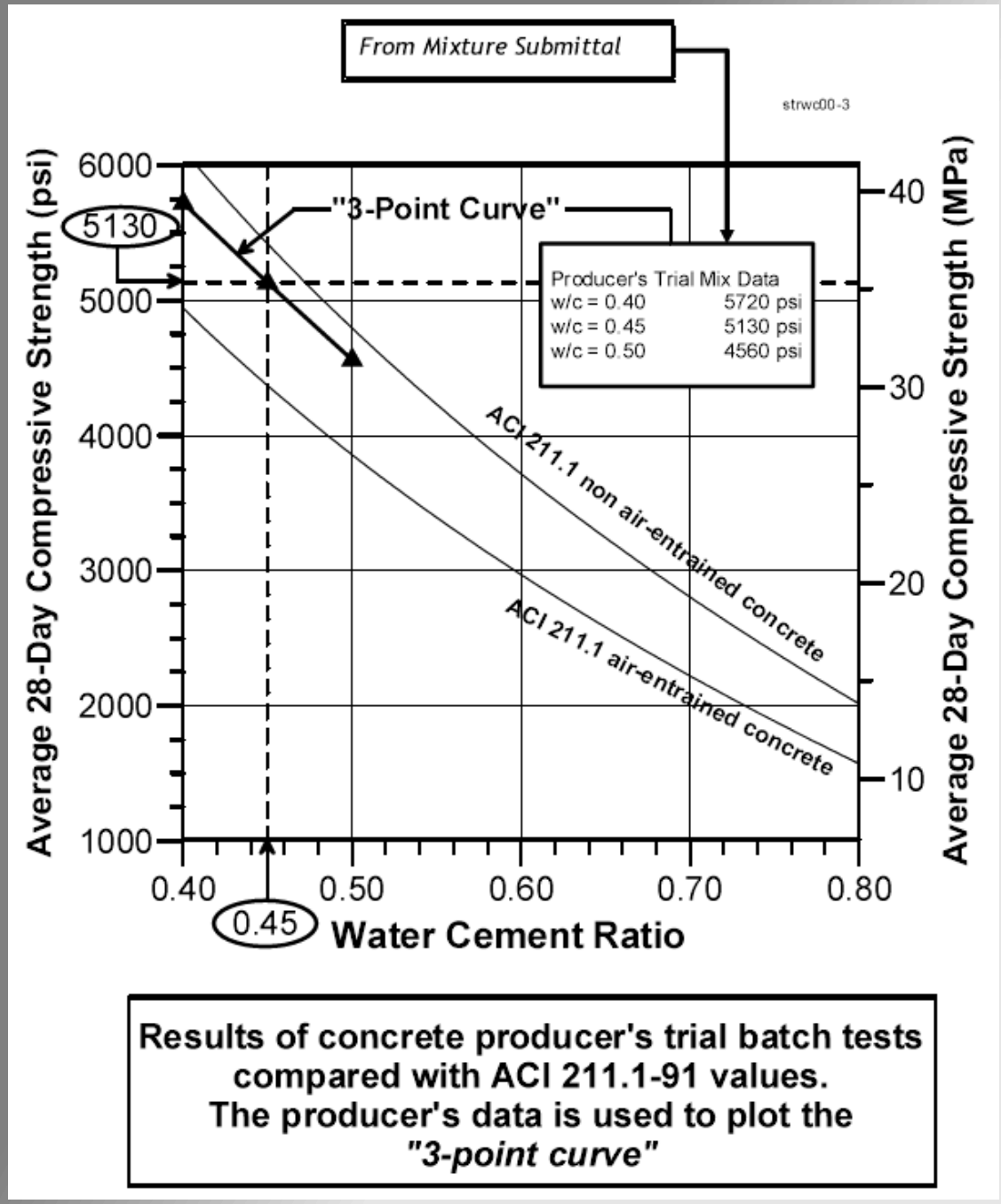


Let's just say that we knew what value of Permeability we wanted;

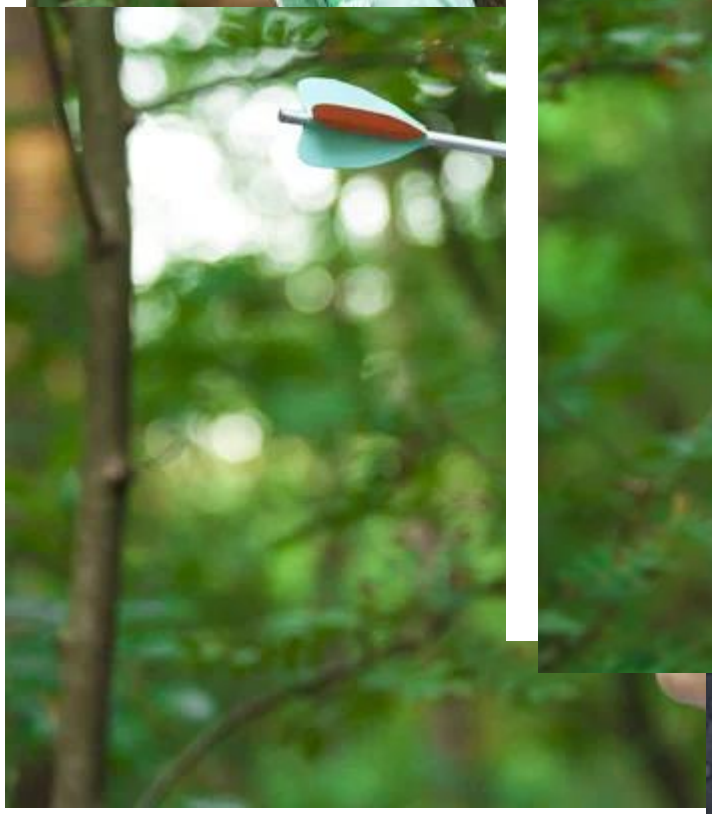
And let's just say that we had a reliable relationship based on the proposed mix.

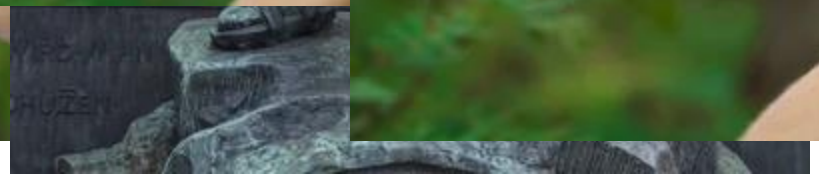
Permeability as a function of Water/Cement Ratio. Data from Bureau of Reclamation Concrete Manual, 8th Edition, 1975, Figure 17, page 27.

No "standard" relationship for all mixtures & materials

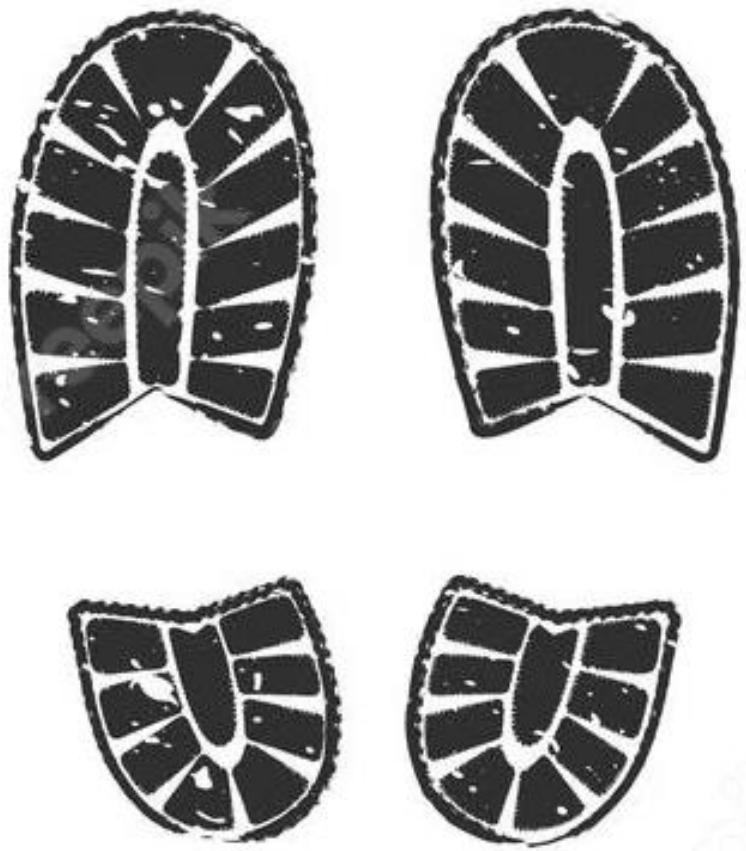


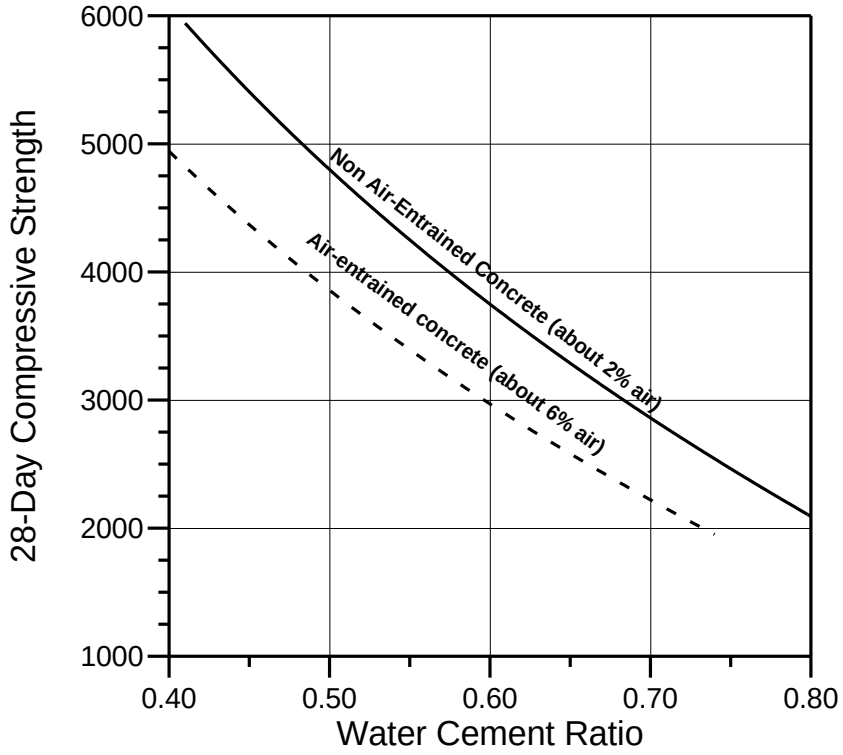
Results of concrete producer's trial batch tests compared with ACI 211.1-91 values. The producer's data is used to plot the *"3-point curve"*



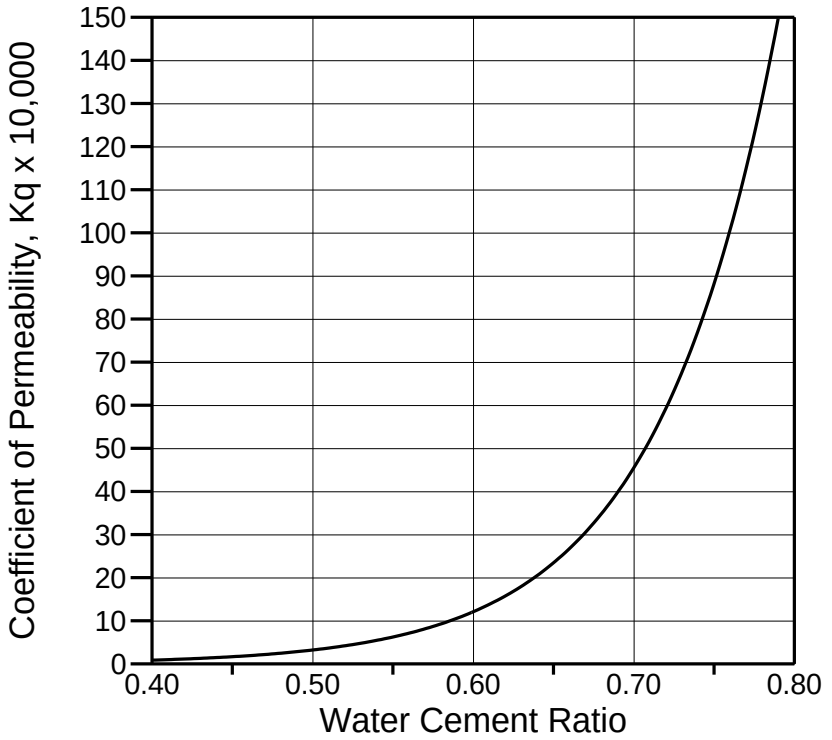



VECTOR



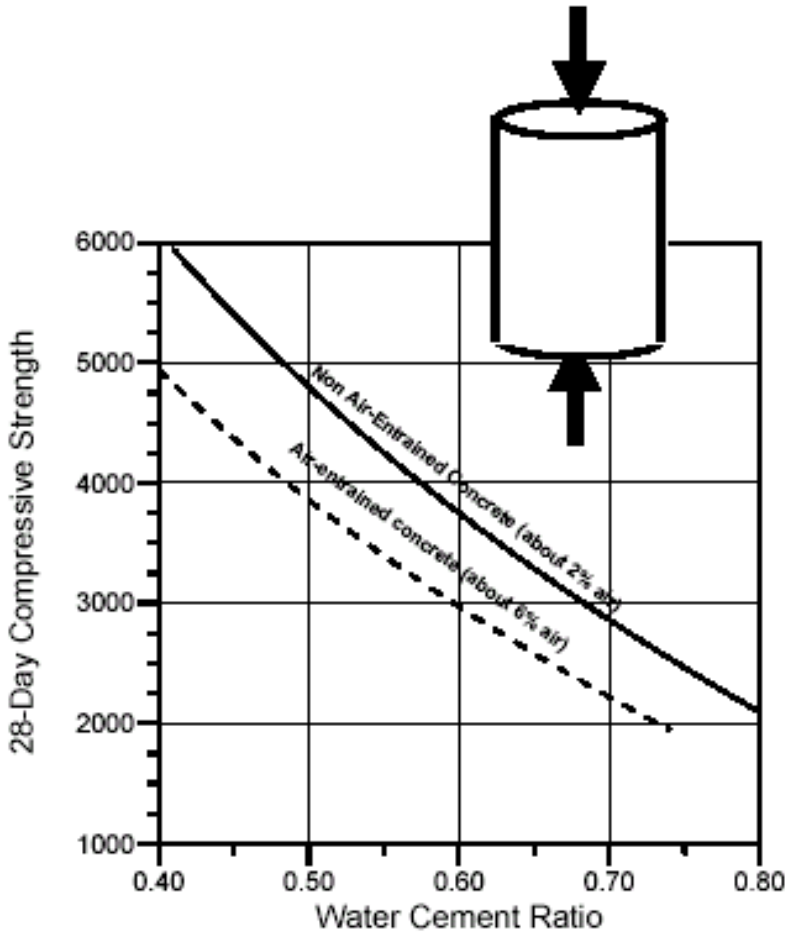


Approximate 28-Day Compressive Strength
as a function of Water/Cement Ratio.
Adapted from ACI 211.1-91, Table 6.3.4(a)

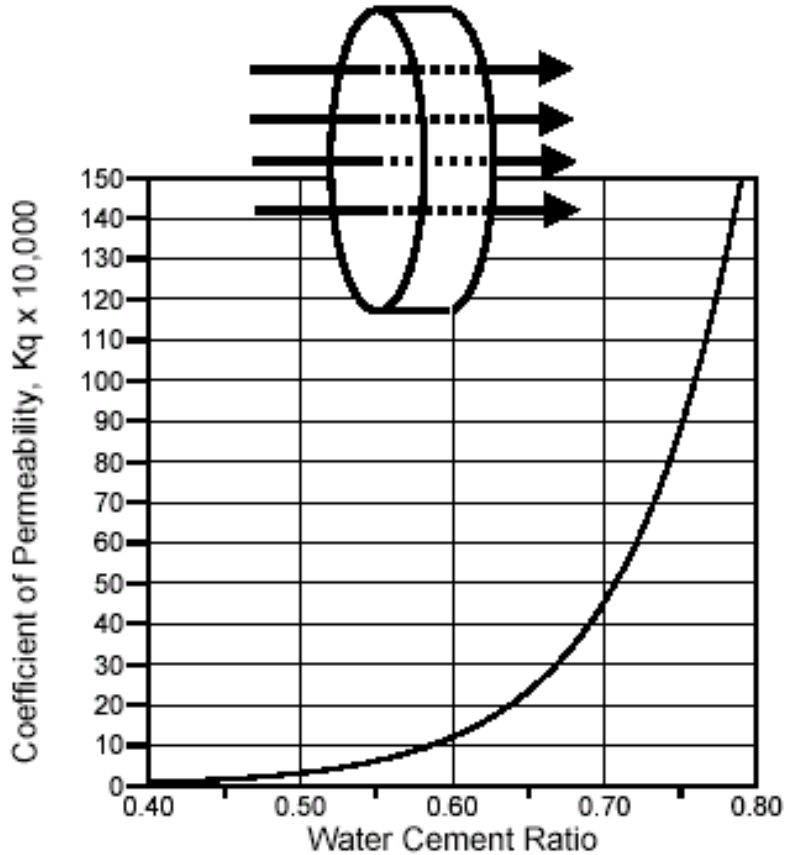


Permeability as a function of Water/Cement Ratio.
Data from Bureau of Reclamation Concrete Manual,
8th Edition, 1975, Figure 17, page 37.

Influence of W/C on Strength and Permeability



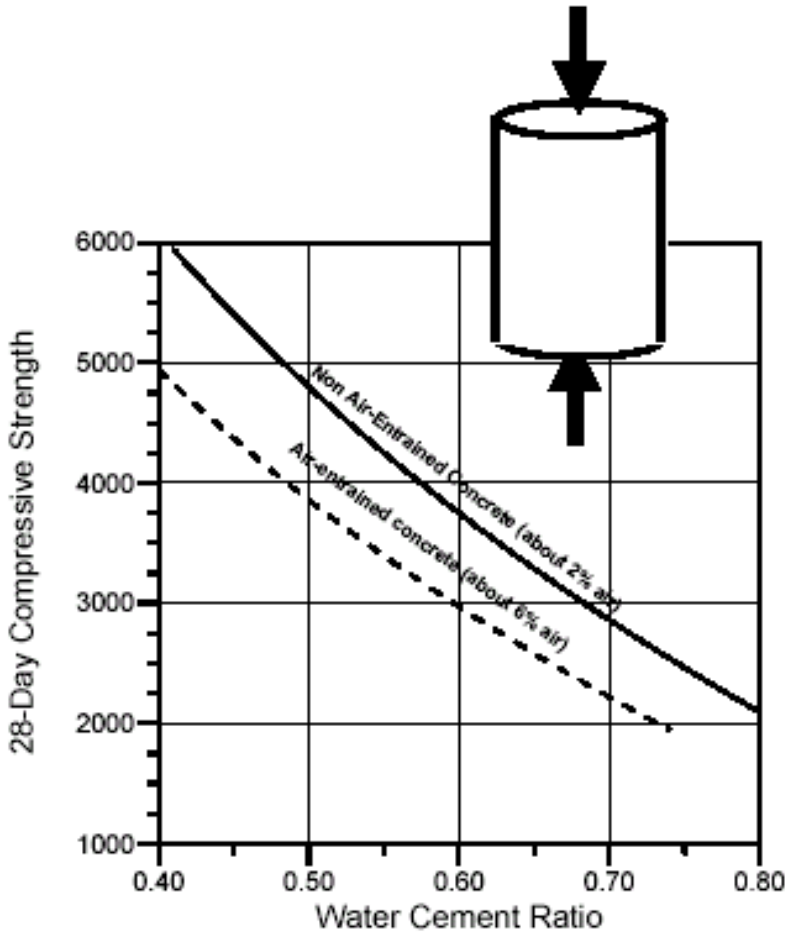
Approximate 28-Day Compressive Strength as a function of Water/Cement Ratio. Adapted from ACI 211.1-91, Table 6.3.4(a)



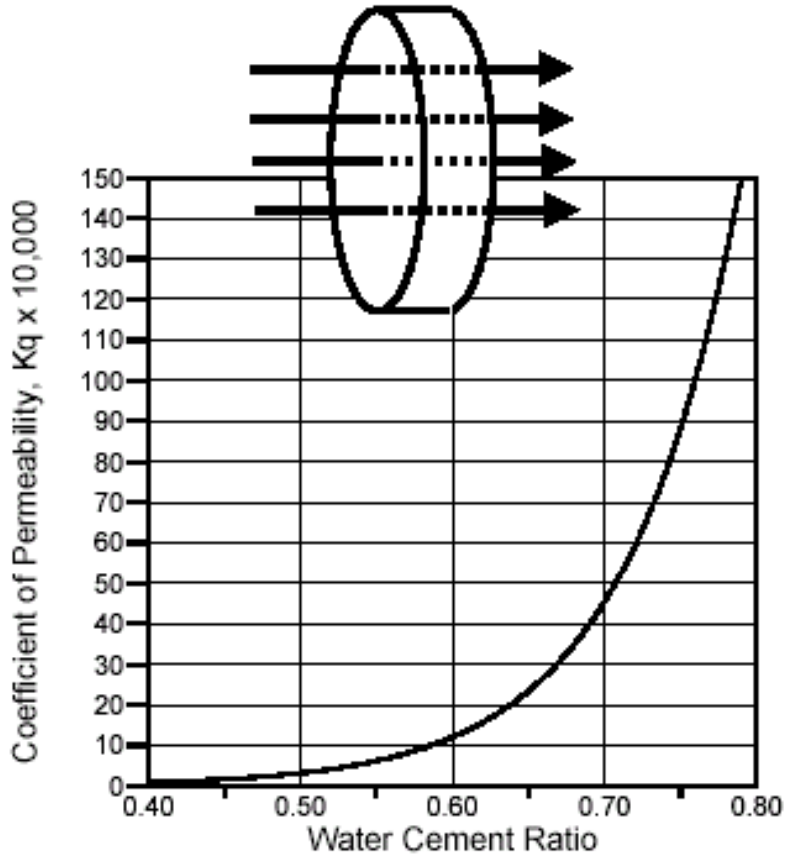
Permeability as a function of Water/Cement Ratio. Data from Bureau of Reclamation Concrete Manual, 8th Edition, 1975, Figure 17, page 37.

Influence of w/c on compressive strength and on permeability

Influence of W/C on Strength and Permeability



Approximate 28-Day Compressive Strength as a function of Water/Cement Ratio. Adapted from ACI 211.1-91, Table 6.3.4(a)



Permeability as a function of Water/Cement Ratio. Data from Bureau of Reclamation Concrete Manual, 8th Edition, 1975, Figure 17, page 37.

Influence of w/c on compressive strength and on permeability

High Card

Highest single card

50.1%

Odds
0.995 : 1

One Pair

Two cards of the same rank

42.3%

Odds
1.37 : 1

Two Pairs

Two separate pairs

4.75%

Odds
20.0 : 1

Three of a Kind

Three cards of the same rank

2.11%

Odds
46.3 : 1

Straight

Five cards in sequence

0.39%

Odds
254 : 1

Flush

Five cards of the same suit

0.20%

Probability
0.1965%
Odds
508 : 1

Full House

Three of a kind and a pair

0.14%

Probability
0.1441%
Odds
693 : 1

Four of a Kind

Four cards of the same rank

0.02%

Probability
0.0240%
Odds
4.164 : 1

Straight Flush

Five suited cards in sequence

0.0011%

Probability
0.00139%
Odds
72.192 : 1

Royal Flush

A, K, Q, J, 10 of the same suit

0.00015%

Probability
0.000154%
Odds
649.739 : 1

50.1%

High Card

High Card

42.3%

One Pair

One Pair

4.75%

Two Pairs

Two Pairs

2.11%

Three of a Kind

Three of a Kind

0.39%

Straight

Straight

0.20%

Flush

Five cards of the same suit

Flush

0.14%

Full House

Three of a kind and a pair

Full House

0.02%

Four of a Kind

Four cards of the same rank

Four of a Kind

0.0011%

Straight Flush

Five suited cards in sequence

Straight Flush

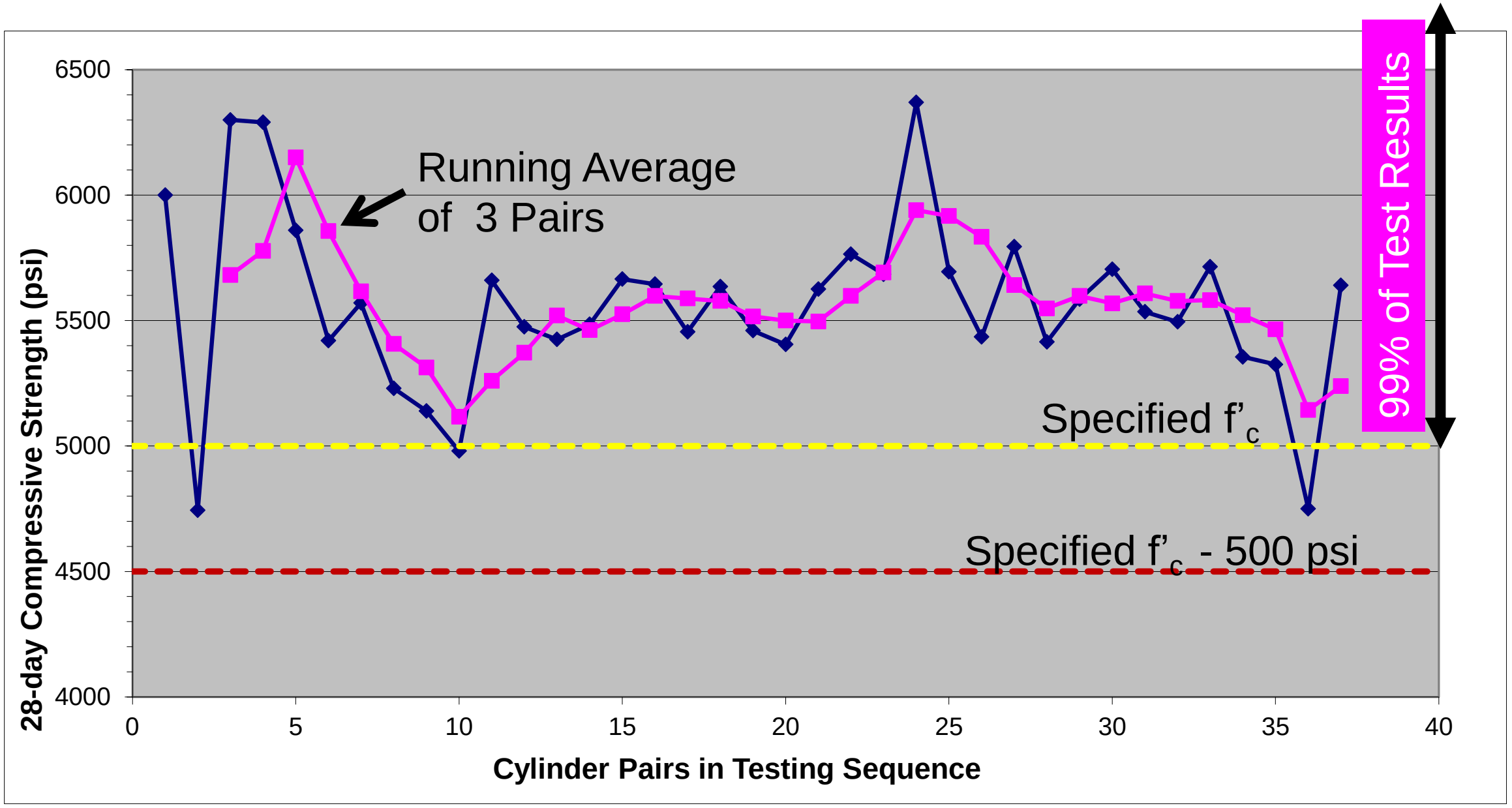
0.00015%

Royal Flush

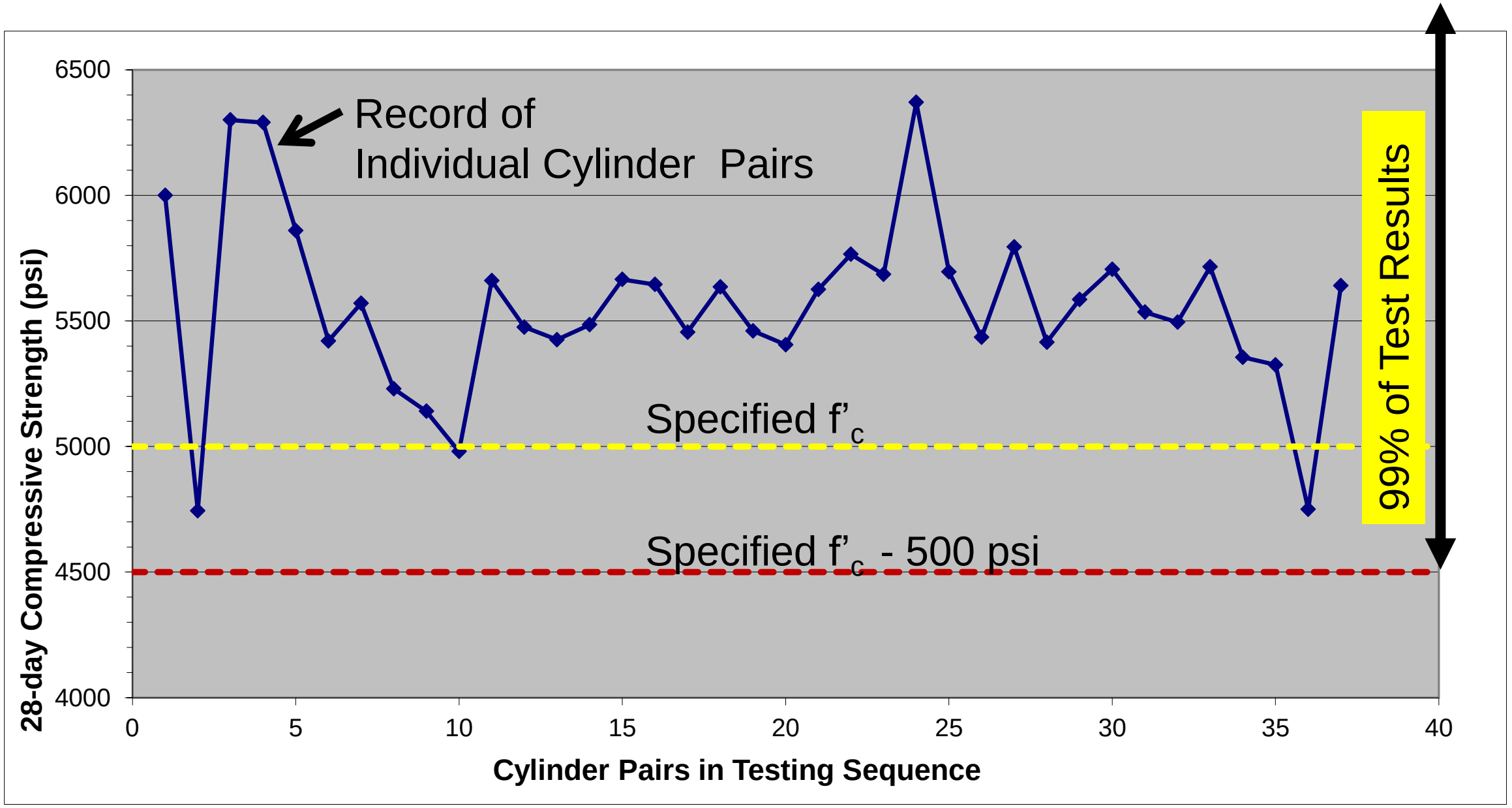
A, K, Q, J, 10 of the same suit

Royal Flush

Raise the Apple!


6500
6000
5500
5000
4500
4000
0
5
10
15
20
25
30
35
40
28-day Compressive Strength (psi)
Cylinder Pairs in Testing Sequence
Running Average
of 3 Pairs
Specified f'c
Specified f'c - 500 psi
99% of Test Results

Target Analogy


6500
6000
5500
5000
4500
4000
0
5
10
15
20
25
30
35
40
28-day Compressive Strength (psi)
Cylinder Pairs in Testing Sequence
Record of
Individual Cylinder Pairs
Specified f'c
Specified f'c - 500 psi
99% of Test Results

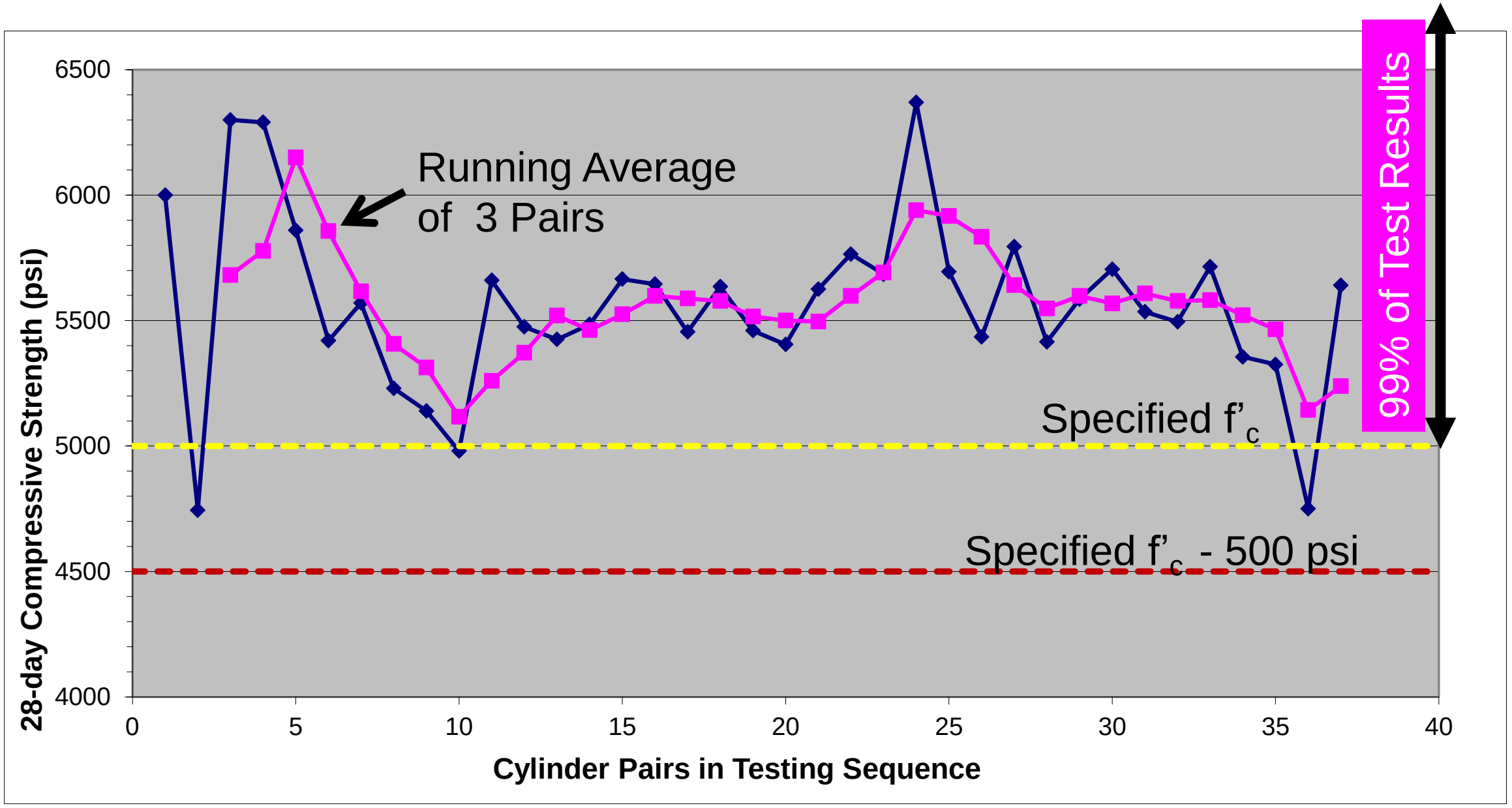

6500
6000
5500
5000
4500
4000
0
5
10
15
20
25
30
35
40
28-day Compressive Strength (psi)
Cylinder Pairs in Testing Sequence
Running Average
of 3 Pairs
Specified f'c
Specified f'c - 500 psi
99% of Test Results

Table 3.2—Standards of concrete control*

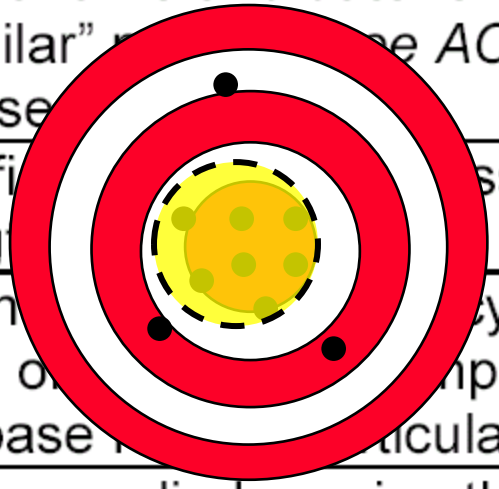
Overall variation					
Class of operation	Standard deviation for different control standards, MPa (psi)				
	Excellent	Very good	Good	Fair	Poor
General construction testing	Below 2.8 (below 400)	2.8 to 3.4 (400 to 500)	3.4 to 4.1 (500 to 600)	4.1 to 4.8 (600 to 700)	Above 4.8 (above 700)
Laboratory trial batches	Below 1.4 (below 200)	1.4 to 1.7 (200 to 250)	1.7 to 2.1 (250 to 300)	2.1 to 2.4 (300 to 350)	Above 2.4 (above 350)
Within-test variation					
Class of operation	Coefficient of variation for different control standards, %				
	Excellent	Very good	Good	Fair	Poor
Field control testing	Below 3.0	3.0 to 4.0	4.0 to 5.0	5.0 to 6.0	Above 6.0
Laboratory trial batches	Below 2.0	2.0 to 3.0	3.0 to 4.0	4.0 to 5.0	Above 5.0

*$f'_c \leq 34.5$ MPa (5000 psi).

Supplemental Information on the accuracy and precision of test results for similar concrete produced by supplier	
Project name and date for which a "similar" mixture (*see ACI 318*) was used.	*Data collected from Acme Industries Project,*
Specified 28-day compressive strength was:	**5000** psi
Total number of pairs of cylinders tested on project for compiling a data base for this particular mix:	**37** (minimum of 30 pairs required)
For these cylinder pairs, the average cylinder strength was:	**5560** psi
The standard deviation of the test results = S = *(This value is an indicator or index to the concrete producer's level of precision--see Appendix A for further commentary)*	**350** psi

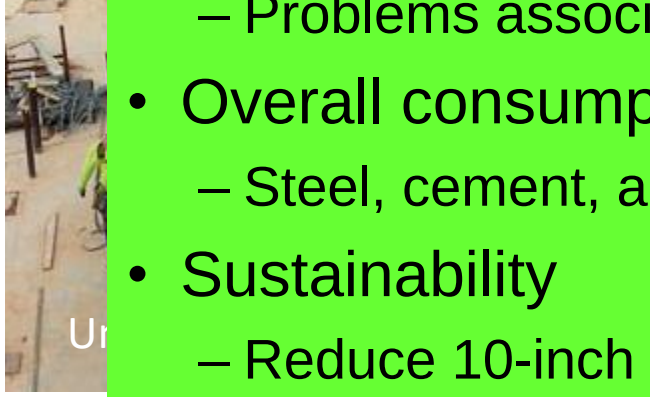
Supplemental Information on the accuracy and precision of test results for similar concrete produced by supplier	
Project name and date for which a "similar" r… *e ACI 318*) was use…	*Data collected from Acme Industries Project,*
Specifi… …ssive streng…	**5000** psi
Total n… …ylinders tested o… …mpiling a data base f… …ticular mix:	**37** (minimum of 30 pairs required)
For these cylinder pairs, the average cylinder strength was:	**5560** psi
The standard deviation of the test results = S = *(This value is an indicator or index to the concrete producer's level of precision--see Appendix A for further commentary)*	**350** psi

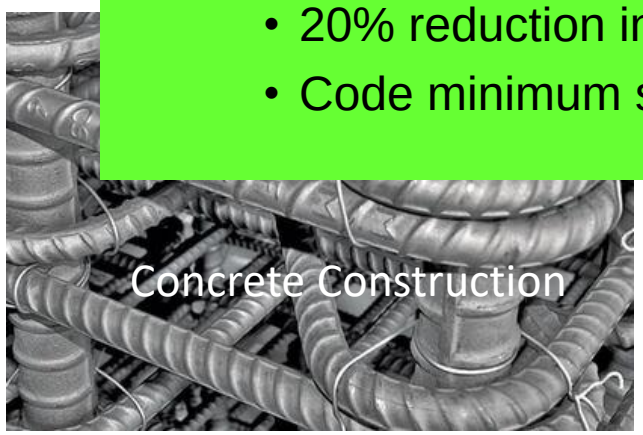
Supplemental Information on the accuracy and precision of test results for similar concrete produced by supplier	
Project name and date for which a "similar" [illegible] *ACI 318*) was use[illegible]	*Data collected from Acme Industries Project,*
Specifi[illegible] ssive streng[illegible]	**5000** psi
Total n[illegible] cylin[illegible] tested o[illegible] npilin[illegible] data base [illegible] ticular m[illegible]	pairs required)
For these cylinder pairs, the average cylinder strength was:	psi
The standard deviation of the test results = S = *(This value is an indicator or index to the concrete producer's level of precision--see Appendix A for further commentary)*	**350** psi

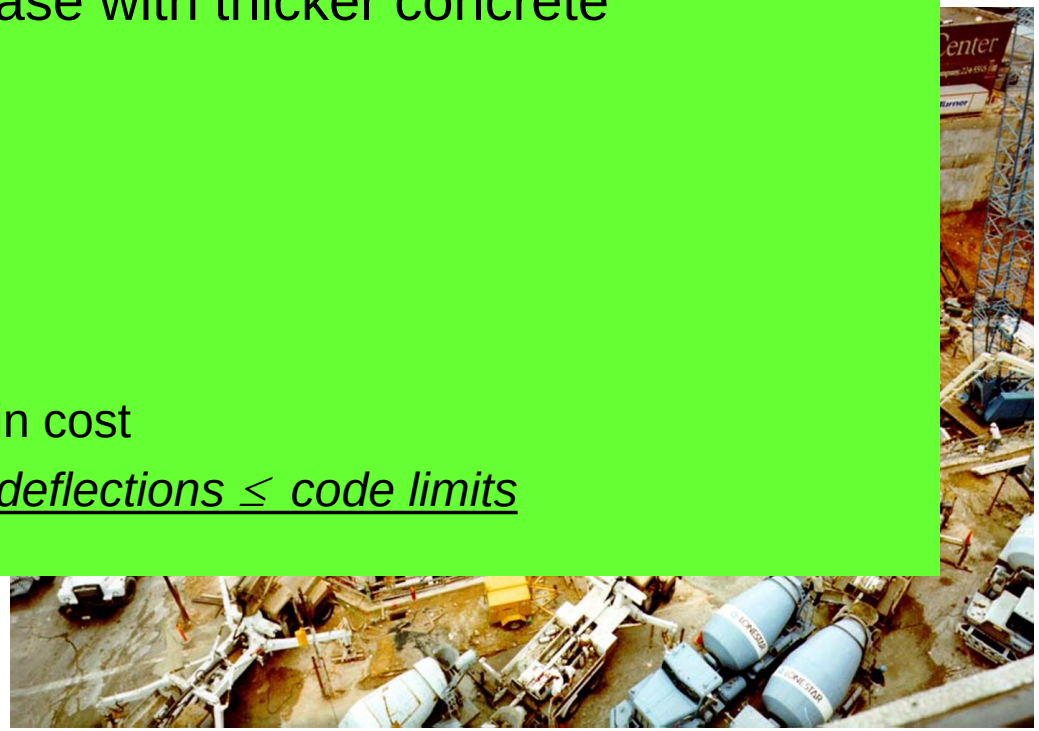


About 2/3 of shots are within 350 psi of center of shot pattern!

- Sometimes concern for Mechanical “Overdesign” is justified:
  - Constructability (congested rebar)
  - Problems associated with Heat of Hydration increase with thicker concrete
- Overall consumption and cost of resources
  - Steel, cement, aggregates
- Sustainability
  - Reduce 10-inch slab to 8-inch slab→
    - 20% reduction in carbon footprint with some reduction in cost
    - Code minimum slab thickness apply *<u>unless calculated deflections ≤ code limits</u>*







“Mechanical” Overdesign?

Myth and Misinterpretation of "Overdesign"

- Conventional reference to “Overdesign” → *“^*&%%^&*_ Overdesign”*
- Common interpretation → Arbitrary choice by designer or mandated by code
- Implications of “Overdesign”
  - More than owner wanted / needed / or is knowingly willing to pay for
  - More load capacity than required for owner’s intended use
  - Longer service life (more durability) than required for service exposure
  - Greater reliability (Smaller probability of failure) than normally expected
- Consequences of “Overdesign” [When truly in excess of owner expectations]
  - Increased cost of concrete component of structure
  - Increased consumption of resources
  - Increased carbon footprint [in absence of carbon-neutral technology]


aci
CONCRETE
CONVENTION

Working Outline-March 26, 2023

Nobody complains about overdesign if the concrete walls, slabs, or columns are too thick or wide, unless the project is overbudget or the carbon footprint is too deep.

But its not just high strength that differentiates the competition based on their ability to produce hi-perf. Concrete reliability, truck after truck, day after day, cylinder after cylinder.

But if we wanted to curb that overdesign, we could take a shot at it-

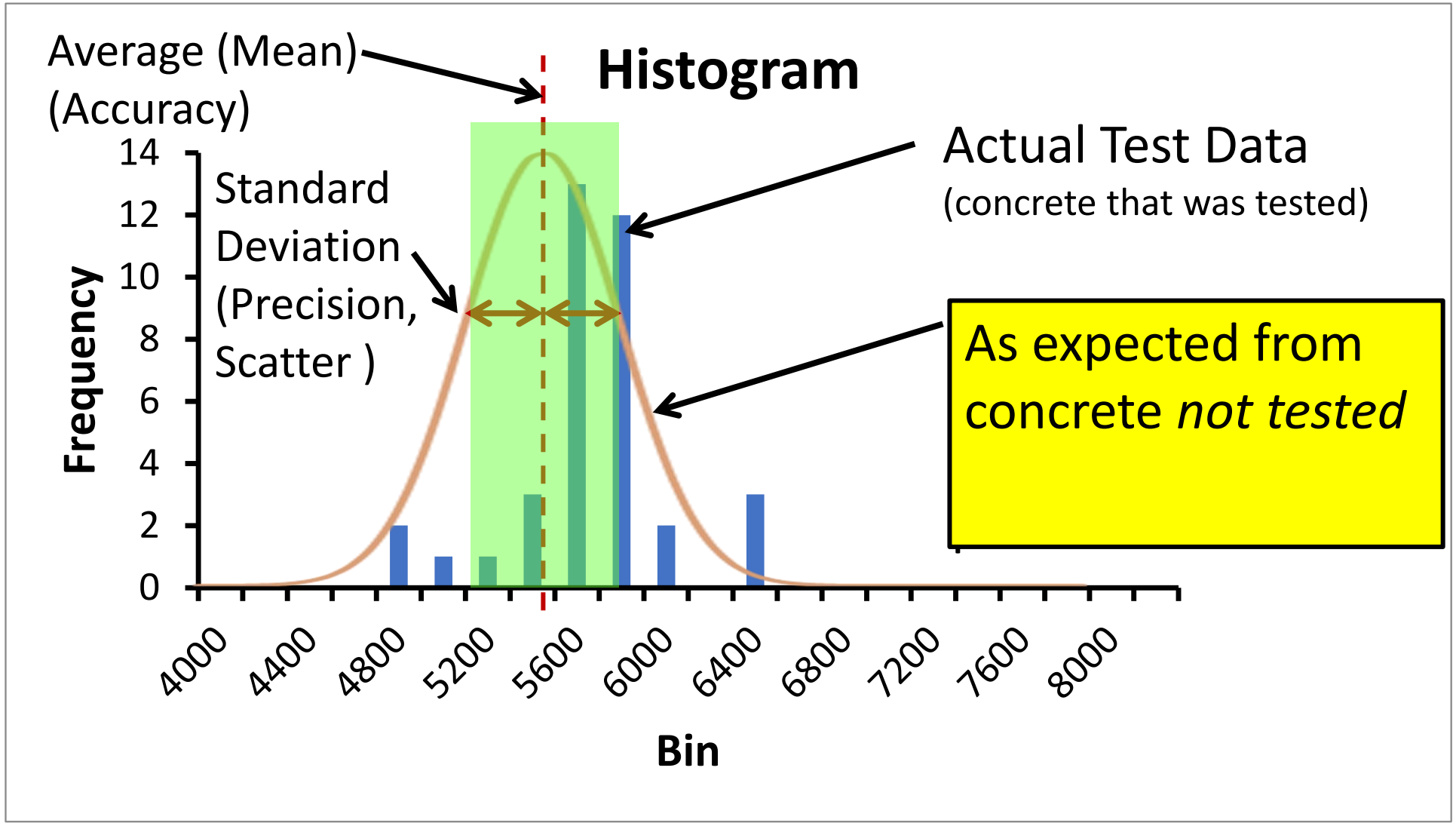
Thinner slabs if we check deflection
Thinner slabs if we use PT

Producers like high strength concrete. Just not so happy when the strength does not come up.

Hi-Performance concrete producers like to produce Hi-performance concrete and don't complain about specified hi-Strengths—it sorts out the competition. It differentiates the competition.

Boosting capacity for one member only could be ineffective.

– Increased carbon footprint [in absence of carbon-neutral technology]


Average (Mean)
(Accuracy)
Histogram
Actual Test Data
(concrete that was tested)
Standard
Deviation
(Precision,
Scatter)
As expected from
concrete *not tested*
Frequency
14
12
10
8
6
4
2
0
4000
4400
4800
5200
5600
6000
6400
6800
7200
7600
8000
Bin

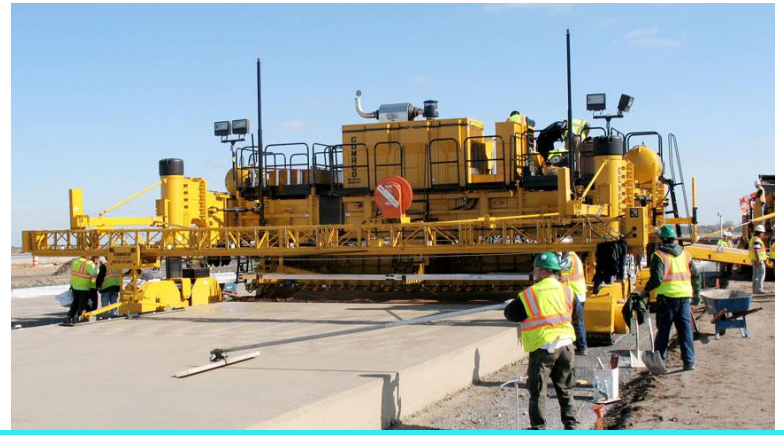
Conventional reference to “Overdesign”:

“^*&%%^& Overdesign”*

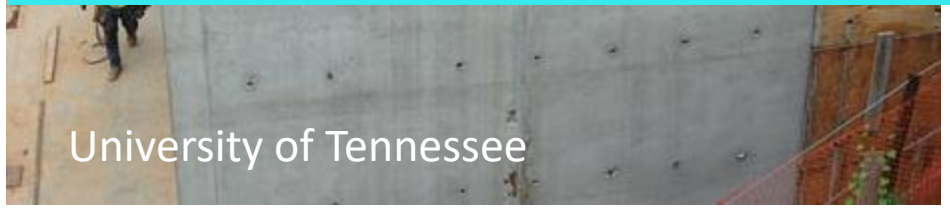
“Arbitrary, Conservative, Building Code Imposition.”

“Costs Money and Resources.”

“Mechanical” Overdesign?



So Called “Overdesign”…



“Mechanical” Overdesign?