Mix Design Basics

Mix Design Goals

adequate workability

adequate strength

adequate durability

minimum cost

Cost of Materials

crushed stone = $ 12/ton

concrete sand = $ 9/ton

Type I cement = $126/ton

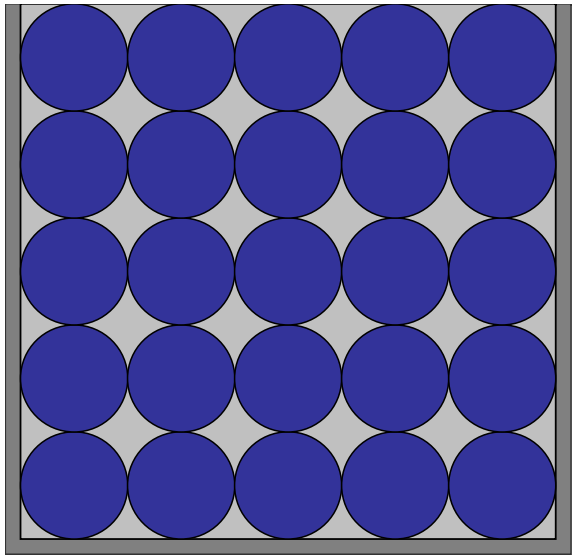
Minimum Cost = Minimum Cement

Minimizing ~~Cost~~ Cement

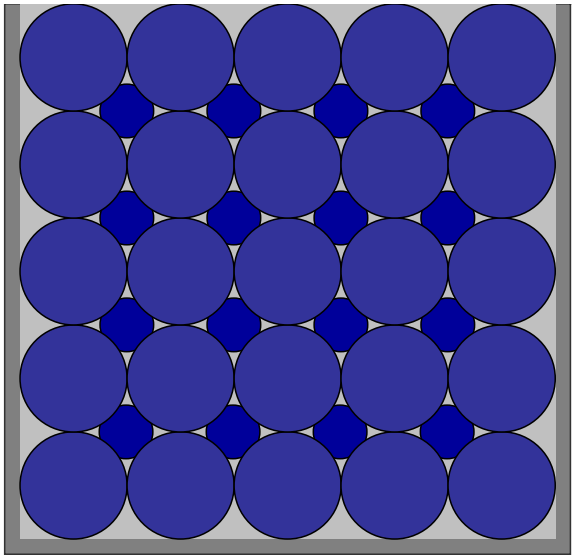
minimize the ***void space*** between aggregate particles that must be filled with cement paste

minimize the ***surface area*** of the aggregate particles that must be coated with cement paste

Minimizing Void Space



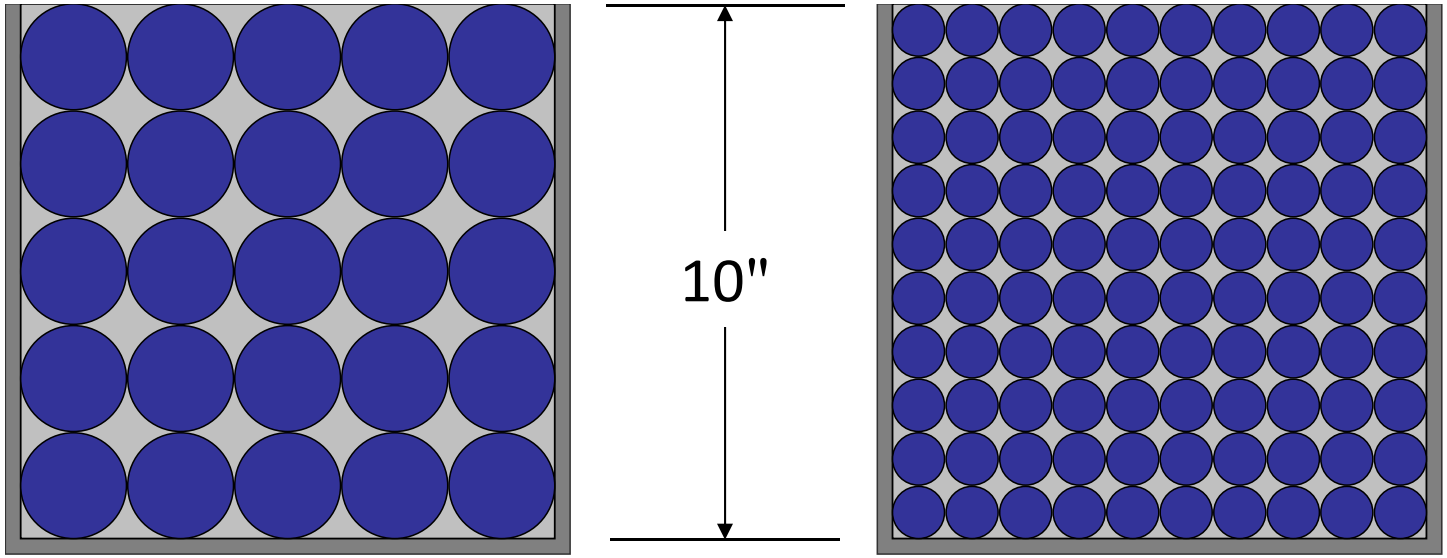
Void content = 48%



Void content = 41%

Use a gravel-sand blend with a dense gradation
to minimize the void content of the aggregate

Minimizing Surface Area

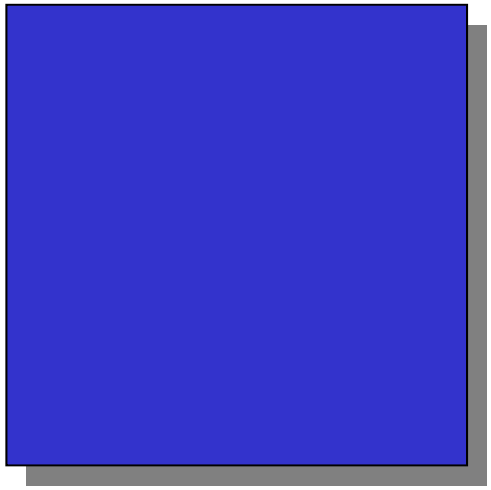


surface area = 11 ft^2

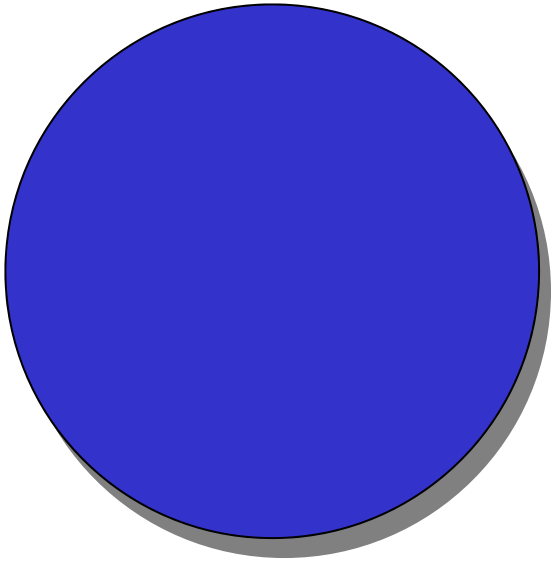
surface area = 22 ft^2

Use the largest NMAS you are allowed to in order to minimize the surface area per cubic yard of concrete

Minimizing Surface Area



surface area = 6.0 ft^2/ft^3



surface area = 4.8 ft^2/ft^3

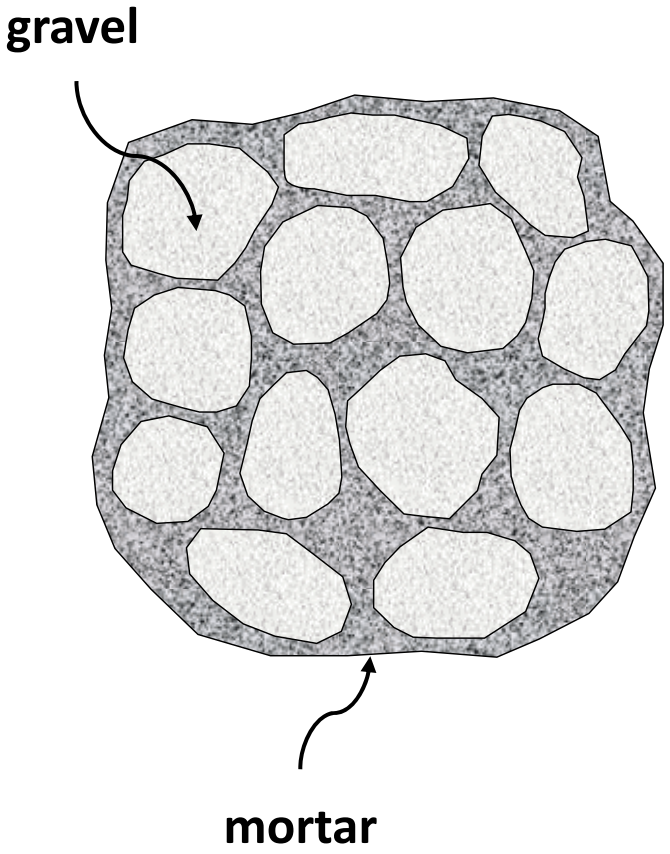
Use gravel instead of crushed stone if possible because it has a lower surface area per unit volume occupied

Obtaining Adequate Workability

To obtain good workability, you need enough mortar to fill the voids between the gravel particles, enough cement paste to fill the voids between sand particles, and enough water to both hydrate and lubricate the cement particles.

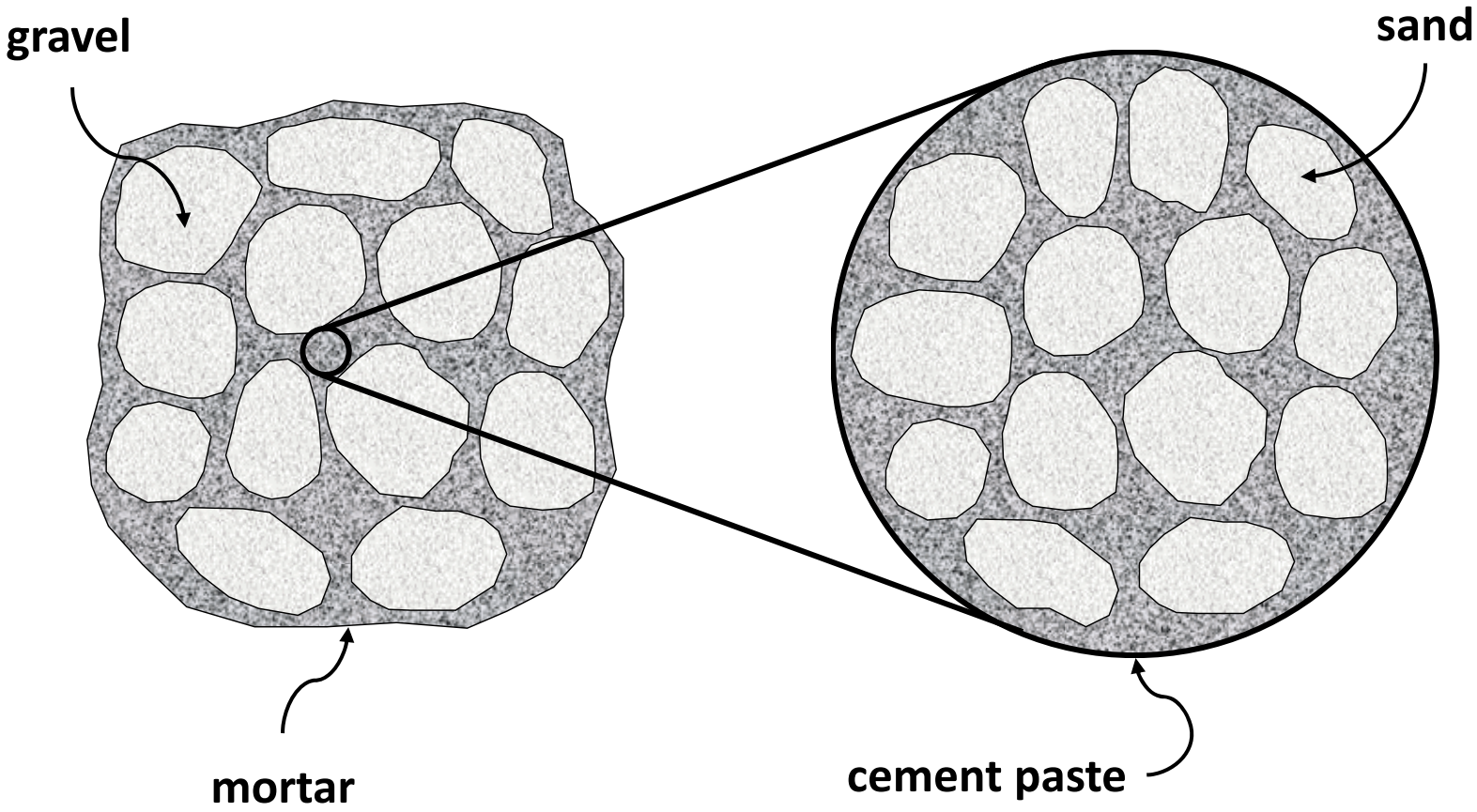
The main goal of the ACI mix design method is to get the relative volume proportions of the ingredients right in order to ensured good workability.

Obtaining Adequate Workability

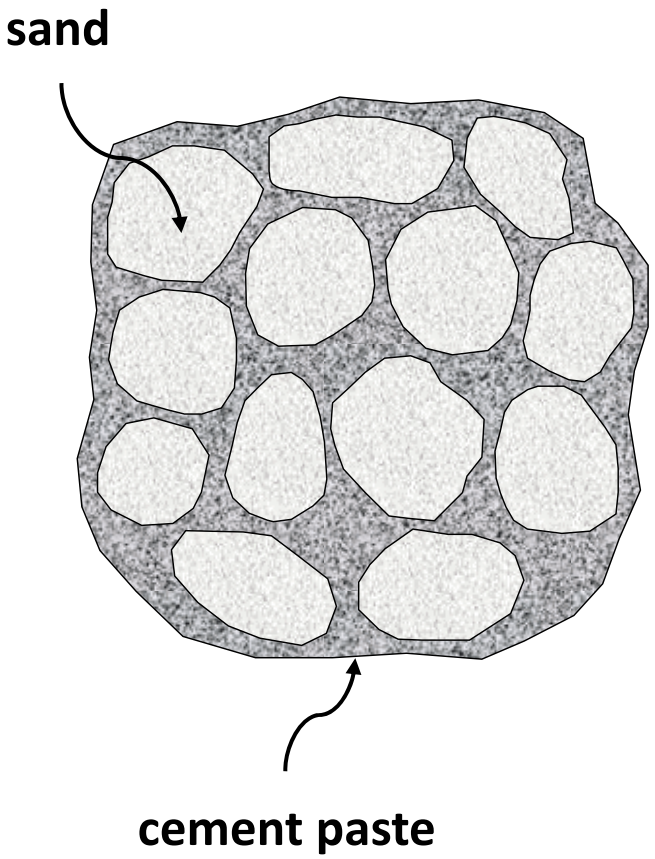


Need enough mortar to keep all the gravel particles apart.

Obtaining Adequate Workability

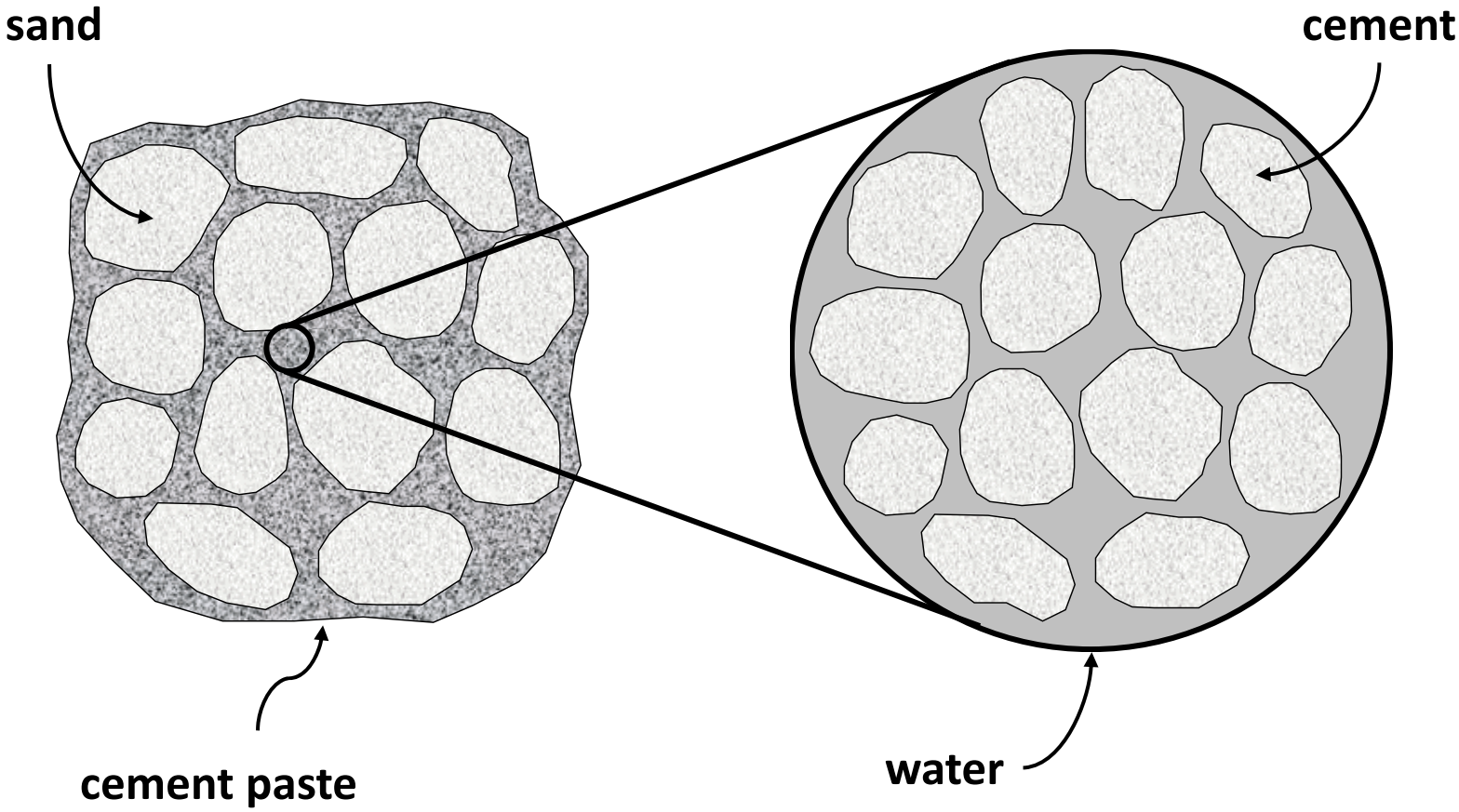


Obtaining Adequate Workability

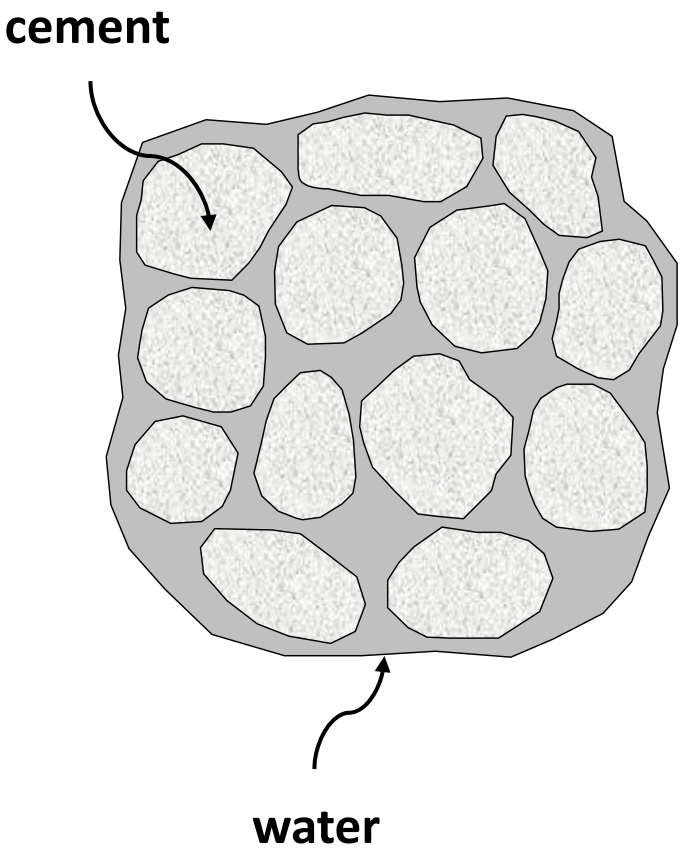


Need enough cement paste to keep all the sand grains apart

Obtaining Adequate Workability

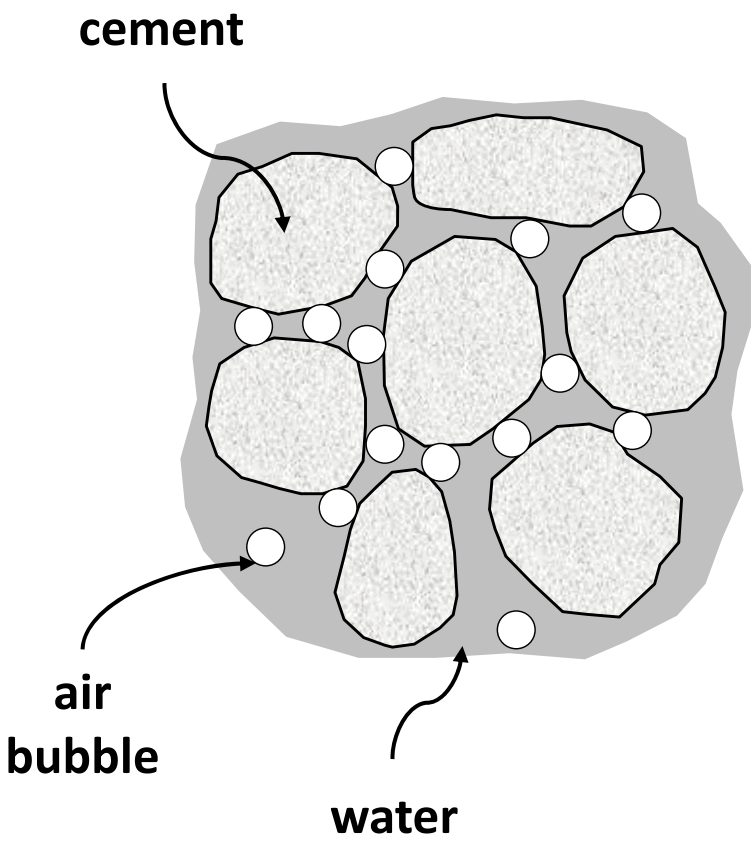


Obtaining Adequate Workability



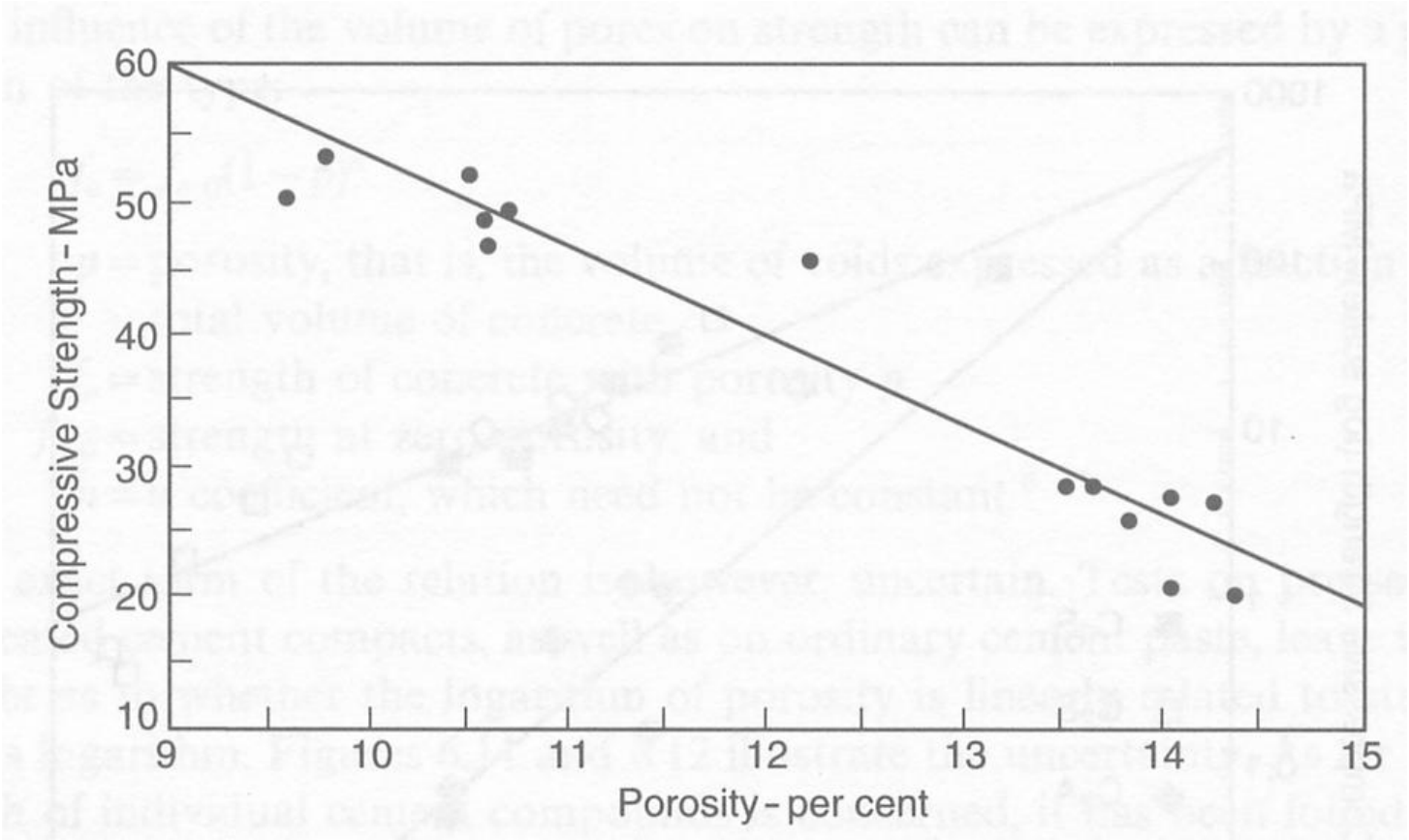
Need enough mixing water to lubricate all the cement grains

Obtaining Adequate Workability

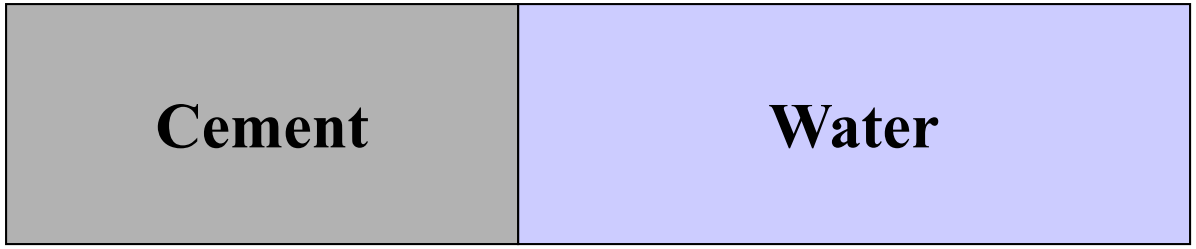


Air entrainment adds lubrication without adding additional water

Obtaining Adequate Strength

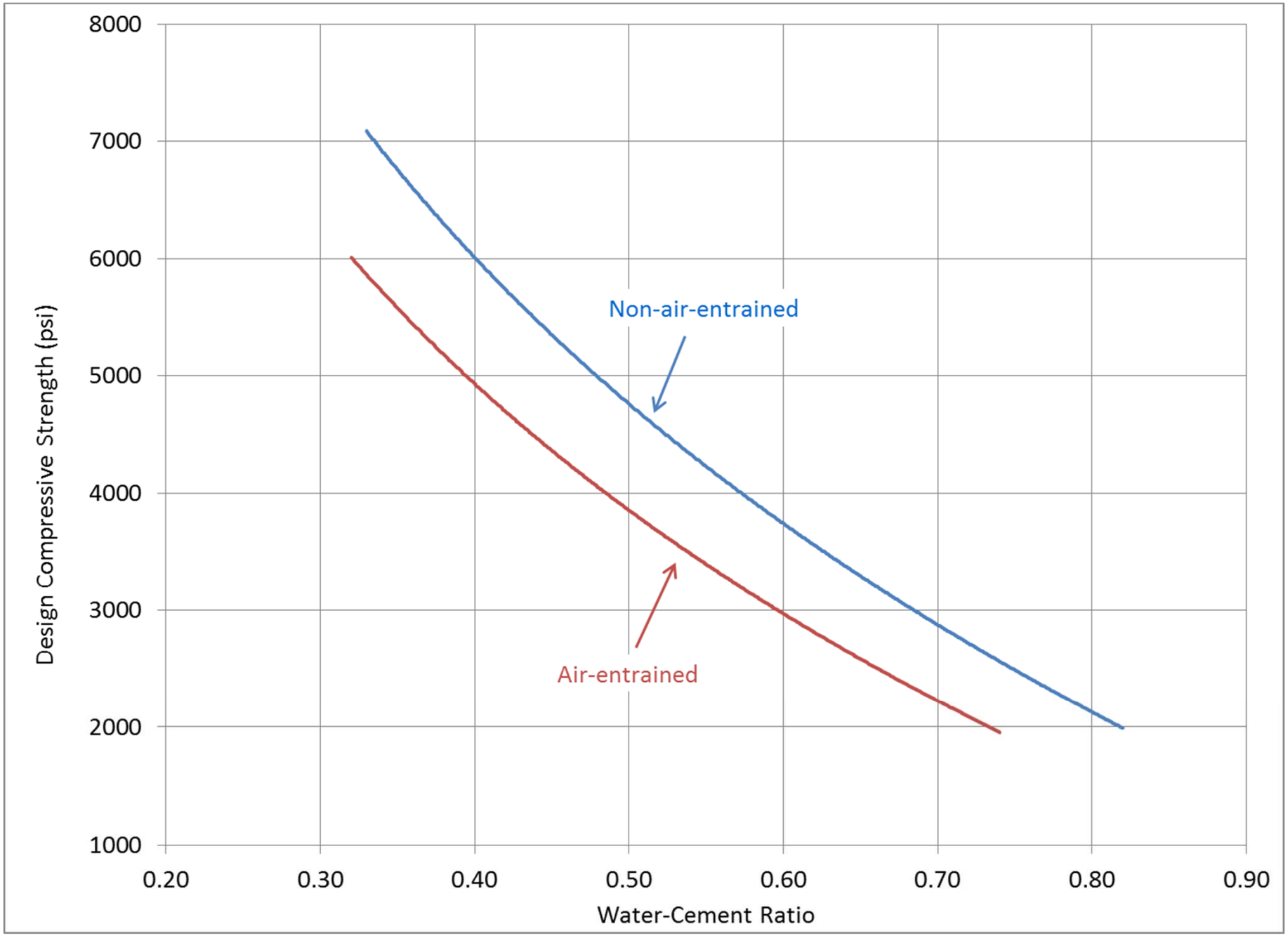


Water-Cement Ratio



0% Hydration

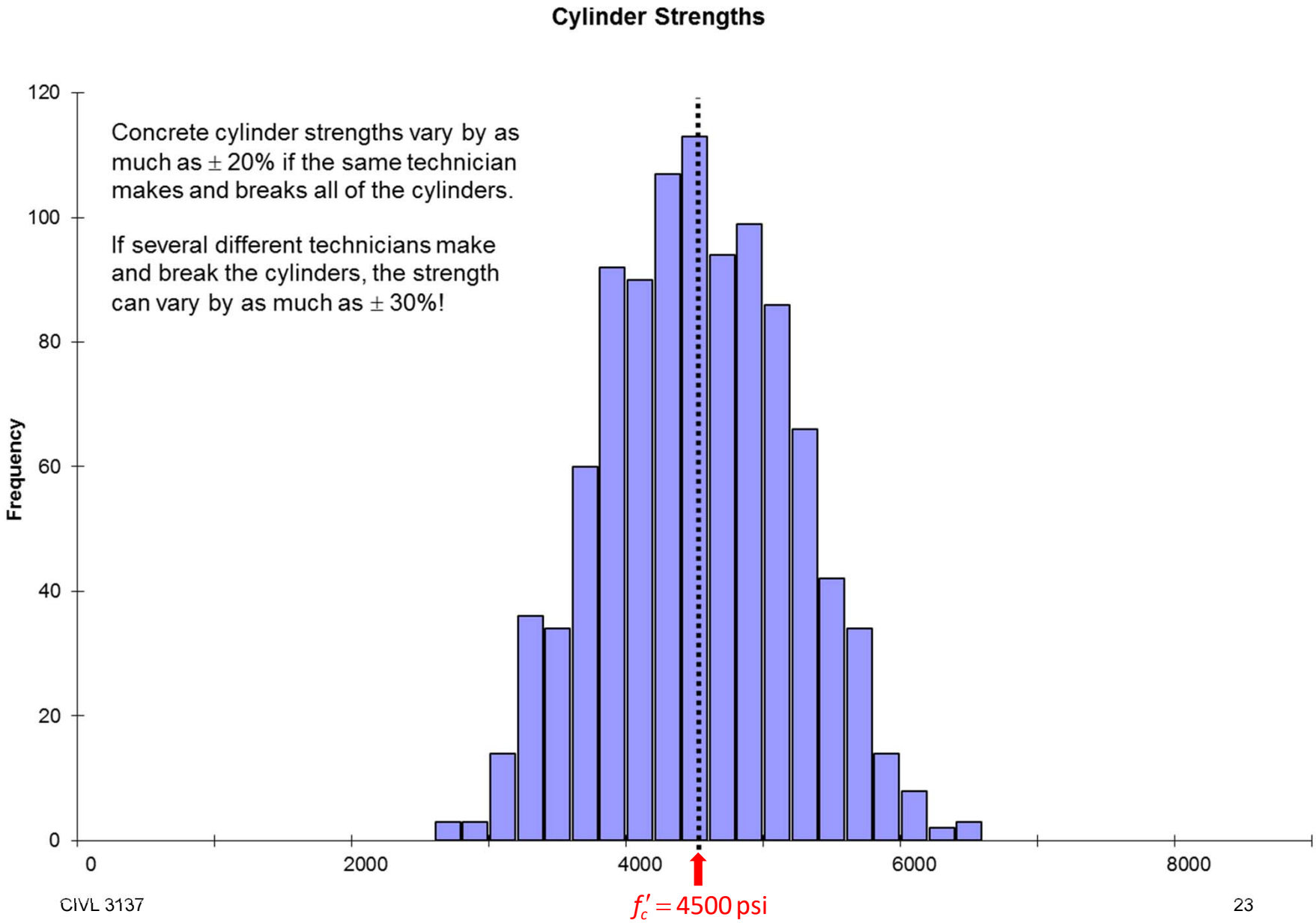
100% Hydration

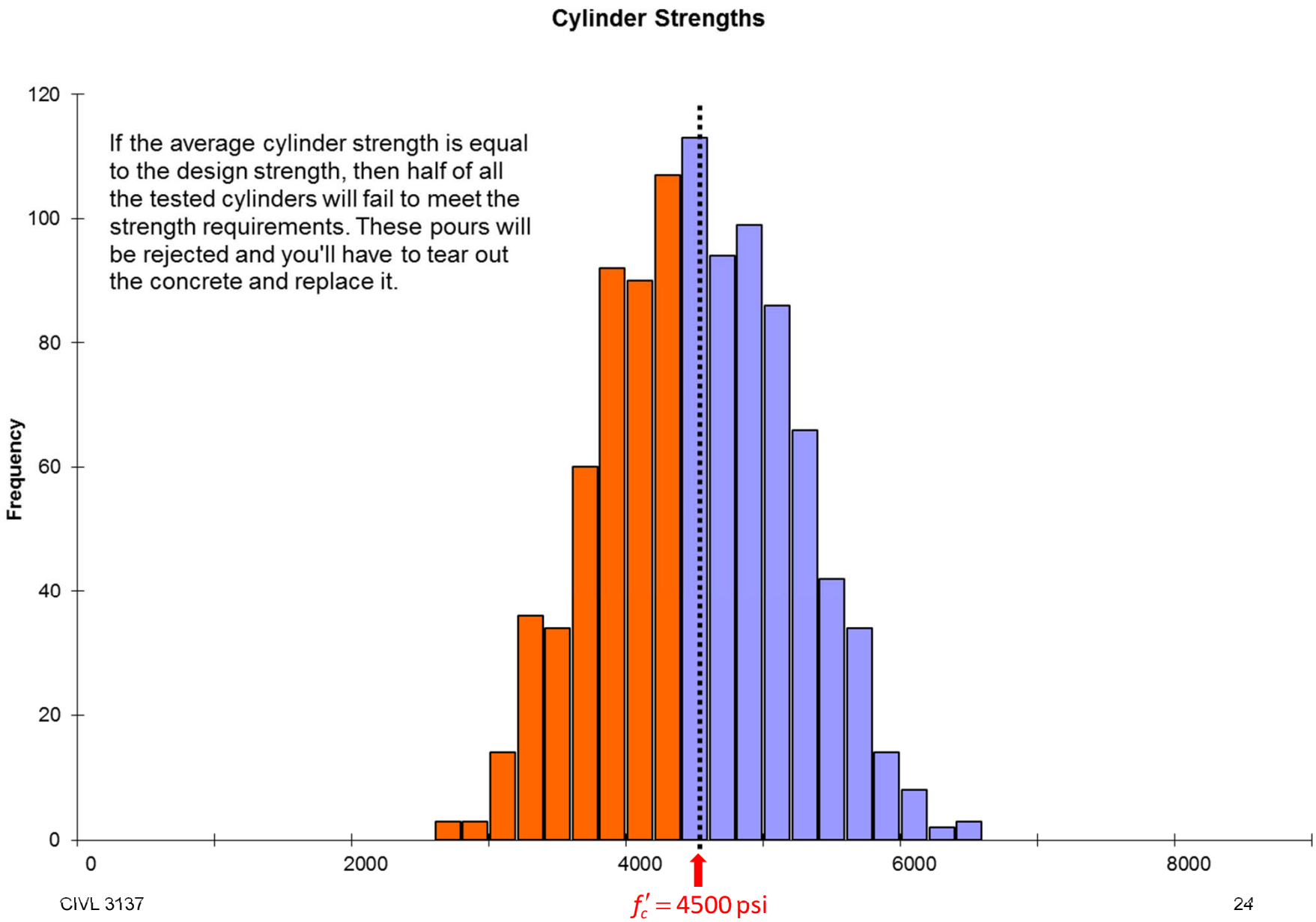

8000
7000
6000
5000
4000
3000
2000
1000
Design Compressive Strength (psi)
0.20
0.30
0.40
0.50
0.60
0.70
0.80
0.90
Water-Cement Ratio
Non-air-entrained
Air-entrained

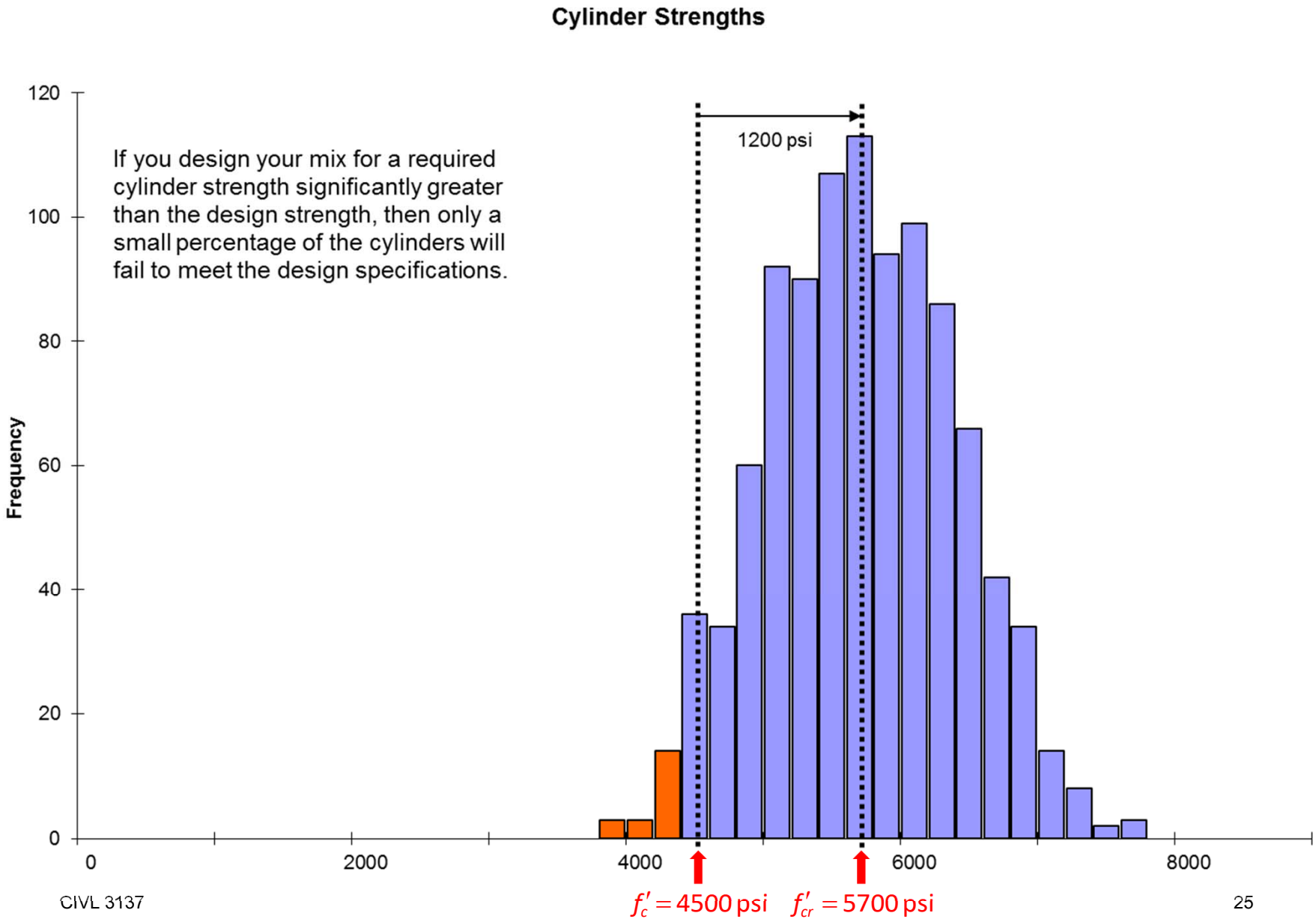
Obtaining Adequate Strength

If the structural engineer designs a beam based on a concrete strength of 4500 psi, you have to design your concrete mix to have a strength much higher than that.

WHY?


Cylinder Strengths
Concrete cylinder strengths vary by as much as ± 20% if the same technician makes and breaks all of the cylinders.
If several different technicians make and break the cylinders, the strength can vary by as much as ± 30%!
Frequency
120
100
80
60
40
20
0
0
2000
4000
6000
8000
$f_c' = 4500$ psi


Cylinder Strengths
If the average cylinder strength is equal to the design strength, then half of all the tested cylinders will fail to meet the strength requirements. These pours will be rejected and you'll have to tear out the concrete and replace it.
Frequency
120
100
80
60
40
20
0
0
2000
4000
6000
8000
$f_c' = 4500$ psi


Cylinder Strengths
If you design your mix for a required cylinder strength significantly greater than the design strength, then only a small percentage of the cylinders will fail to meet the design specifications.
1200 psi
Frequency
120
100
80
60
40
20
0
0
2000
4000
6000
8000
$f'_c = 4500$ psi
$f'_{cr} = 5700$ psi

Overdesign Factors

Required Average Compressive Strength When Data Are Not Available to Establish a Standard Deviation

Specified compressive strength, f'_c, psi	Required average compressive strength, f'_{cr}, psi
Less than 3000	$f'_c + 1000$
3000 to 5000	$f'_c + 1200$
Over 5000	$1.10 f'_c + 700$

Adapted from ASTM C94