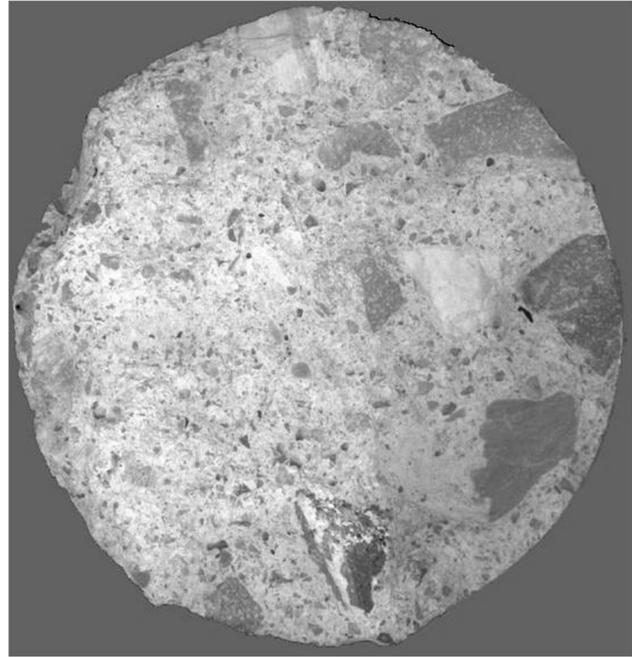


## Reinforced Concrete

- Material Properties
  - Aggregate
  - Cement
  - Water
  - Reinforcement
- Strength
  - Compression,  $f_c$
  - Tension,  $f_t$
- PCA – Concrete Fundamentals



## Constituents of Concrete

- **Aggregate**
- Cement
- Water

Fine aggregate  
(Sand)  
 $\leq 1/4"$



coarse aggregate  
 $\sim 3/8"$  (small)



coarse aggregate  
 $\sim 1/2"$  to  $1"$  (medium)

coarse aggregate  
 $\sim 1.5"$  (large)

# Constituents of Concrete

- **Aggregate**
- Cement
- Water

## Characteristics:

- Abrasion resistance
- Freezing resistance
- Sulfate resistance
- Alkali resistance
- Shape and texture
- Grading
- Void content
- Density
- Moisture absorption
- Flexural strength



crushed stone



smooth "river rock"

# Constituents of Concrete

- Aggregate
- **Cement**
- Water

## Ingredients:

- Limestone
- Cement rock
- Clay
- Iron ore
- + (after firing and grinding)
- gypsum



# Cement Types

- **Type 1**  
normal portland cement. Type 1 is a **general use** cement.
- **Type 2**  
is used for structures in water or soil containing **moderate amounts of sulfate**, or when heat build-up is a concern.
- **Type 3**  
**high early strength**. Used when high strength are desired at very early periods.
- **Type 4**  
**low heat** portland cement. Used where the amount and rate of heat generation must be kept to a minimum.
- **Type 5**  
**Sulfate resistant** portland cement. Used where water or soil is high in alkali.
- Types IA, IIA and IIIA are cements used to make **air-entrained** concrete.

# Constituents of Concrete

- Aggregate
- Cement
- **Water**
  - “potable”
  - No sulfates or organic impurities



## Add mixtures:

- Air-entraining
- Water-reducing
- Plasticizers
- Accelerating
- Retarding
- Hydration control
- Shrinkage reducer
- Alkali-silicate inhibitor
- Coloration
- Bonding
- Foaming
- And others...

# Constituents of Concrete

## batch guidelines

### Common Concrete Mix Ratios:

$\frac{1}{5} \quad \frac{1}{2} \quad \frac{3}{3}$   
1:2:3 (Cement:Sand:Gravel):

This is a widely used ratio for general construction, offering a good balance of strength and workability.

1:1.5:3 (Cement:Sand:Gravel):

Another popular option, especially for foundations and beams, offering a good balance of strength and durability.

1:4:8 (Cement:Sand:Gravel):

This ratio is preferred for foundations and mass concrete work.

$\frac{1}{3}$   
1:1:2 (Cement:Sand:Gravel):

This ratio is used for construction work that requires high-strength concrete.

# Constituents of Concrete

## PCA batch tables

Table 9-16 (Inch-Pound). Proportions by Mass to Make One Cubic Foot of Concrete for Small Jobs

Nominal maximum size coarse aggregate, in.	Air-entrained concrete				Non-air-entrained concrete			
	Cement, lb	Wet fine aggregate, lb	Wet coarse aggregate, lb*	Water, lb	Cement, lb	Wet fine aggregate, lb	Wet coarse aggregate, lb	Water, lb
¾	29	53	46	10	29	59	46	11
½	27	46	55	10	27	53	55	11
¾	25	42	65	10	25	47	65	10
1	24	39	70	9	24	45	70	10
1½	23	38	75	9	23	43	75	9

\*If crushed stone is used, decrease coarse aggregate by 3 lb and increase fine aggregate by 3 lb.

Table 9-17. Proportions by Bulk Volume\* of Concrete for Small Jobs

Nominal maximum size coarse aggregate, mm (in.)	Air-entrained concrete				Non-air-entrained concrete			
	Cement	Wet fine aggregate	Wet coarse aggregate	Water	Cement	Wet fine aggregate	Wet coarse aggregate	Water
9.5 (¾)	1	2¼	1½	½	1	2½	1½	½
12.5 (½)	1	2¼	2	½	1	2½	2	½
19.0 (¾)	1	2¼	2½	½	1	2½	2½	½
25.0 (1)	1	2¼	2¾	½	1	2½	2¾	½
37.5 (1½)	1	2¼	3	½	1	2½	3	½

\*The combined volume is approximately ¾ of the sum of the original bulk volumes.

# Constituents of Concrete

## W/C ratios

### Understanding the w/c Ratio:

- **Definition:** The w/c ratio is the ratio of the weight of water to the weight of cement used in a concrete mix.
- **Importance:** It's a critical factor in concrete mix design, influencing strength, durability, and workability.
- **How it affects strength:**
  - Lower w/c ratio: Leads to higher strength and durability, reduced shrinkage, and lower permeability.
  - Higher w/c ratio: Results in lower strength and increased permeability, potentially leading to cracking and reduced durability.
- **Typical Range:** The typical w/c ratio for different grades of concrete mix falls between 0.40 and 0.60.
- **Minimum w/c ratio:** The minimum w/c ratio is 0.30 - 0.35.
- **Workability:** A lower w/c ratio can make the concrete mix stiffer and more difficult to work with, requiring the use of plasticizers or superplasticizers to improve workability.

# Constituents of Concrete

## W/C ratios - Strength

### Concrete Strength and w/c Ratio:

Water-Cement Ratio (w/c)	Approximate Compressive Strength (psi)	Notes
0.8	<u>2000</u>	<u>Fairly weak</u> concrete, more water
<u>0.50</u>	—	Maximum for <u>normal strength</u> concrete
<u>0.45</u>	—	Maximum for <u>high strength</u> concrete
<u>0.30 - 0.35</u>	—	Minimum w/c ratio
0.3	Too stiff to handle	Requires superplasticizers

## Workability

### Measured in inches of “slump” of a molded cone of fresh mix.

- range 1” to 4” with vibration
- 2” to 6” without vibration



### Water/Cement Ratio

- range 0.4 to 0.7
- for strength: higher is weaker
- for workability: higher is more workable



### Cement Content

- LBS per cubic yard
- range 400-800 lbs/yd<sup>3</sup>
- dependent on aggregate
- increases cost



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# Constituents of Concrete

## Slump and Workability

### Slump and Workability:

#### Slump Test:

The slump test measures the consistency of fresh concrete by observing how much it settles after being poured into a cone.

#### Slump Range:

- 0-1 inch (0-25 mm): Very low workability, suitable for dry mixes like pavements.
- 1-2 inches (25-50 mm): Low workability, suitable for foundations with light reinforcement.
- 2-4 inches (50-100 mm): Medium workability, suitable for manually compacted flat slabs.
- 4-7 inches (100-175 mm): High workability, suitable for sections with tight reinforcement or where concrete needs to flow a great distance.

## Reinforcing

### Grade = Yield strength

- gr. 40 is 40 ksi
- gr. 60 is 60 ksi
- gr. 75 is 75 ksi

### Size in 1/8 inch increments

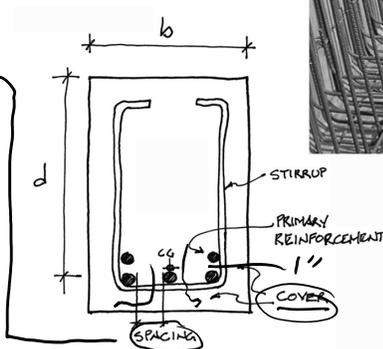
- #4 is 1/2 inch dia.
- #6 is 3/4 inch dia.

### Deformation Patterns

- add to bond with concrete

### Minimum Spacing

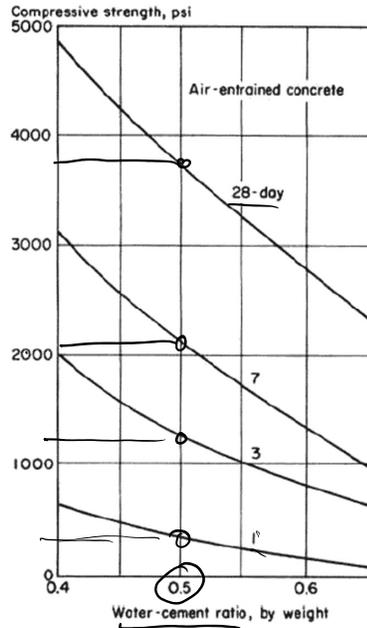
- between bars (horizontal)  
the greatest of the 3  
is the minimum
  - Bar diameter
  - 1"
  - 5/4 x max aggregate size
- between layers (vertical)  
1"
- cover
  - 3" against soil
  - 1.5"-2" exterior
  - 3/4" interior



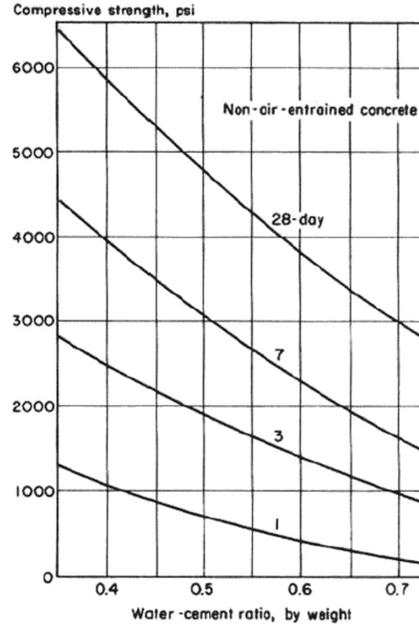
Reinforcement of Weidatalbrücke photo by Störfix

# Curing

Strength increases with age. The “design” strength is 28 days.



Portland Cement Association



## Strength Measurement

### Compressive strength

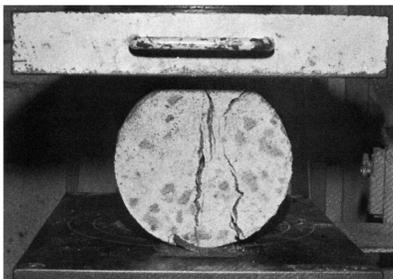
- 12"x6" cylinder
- 28 day moist cure
- Ultimate (crushing) strength

$$f'_c$$

### Tensile strength

- 12"x6" cylinder
- 28 day moist cure
- Ultimate (failure) strength
- Split cylinder test
- ca. 10% of  $f'_c$

$$f'_t$$



# Young's Modulus

Depends on density and strength

$$E_c = w_c^{1.5} 33 \sqrt{f'_c}$$

$w_c$  = concrete density

$f'_c$  = concrete compressive strength

For normal weight concrete (144 PCF)

$$E_c = 57000 \sqrt{f'_c}$$

Examples:

$f'_c$	$E_c$
10000 psi	5,700,000 psi
8000 psi	5,098,000 psi
6000 psi	4,415,000 psi
4000 psi	3,605,000 psi
3000 psi	3,122,000 psi

