Course: Concrete Technology

Lecture 10: ACI Mix Design Method

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Session Objectives

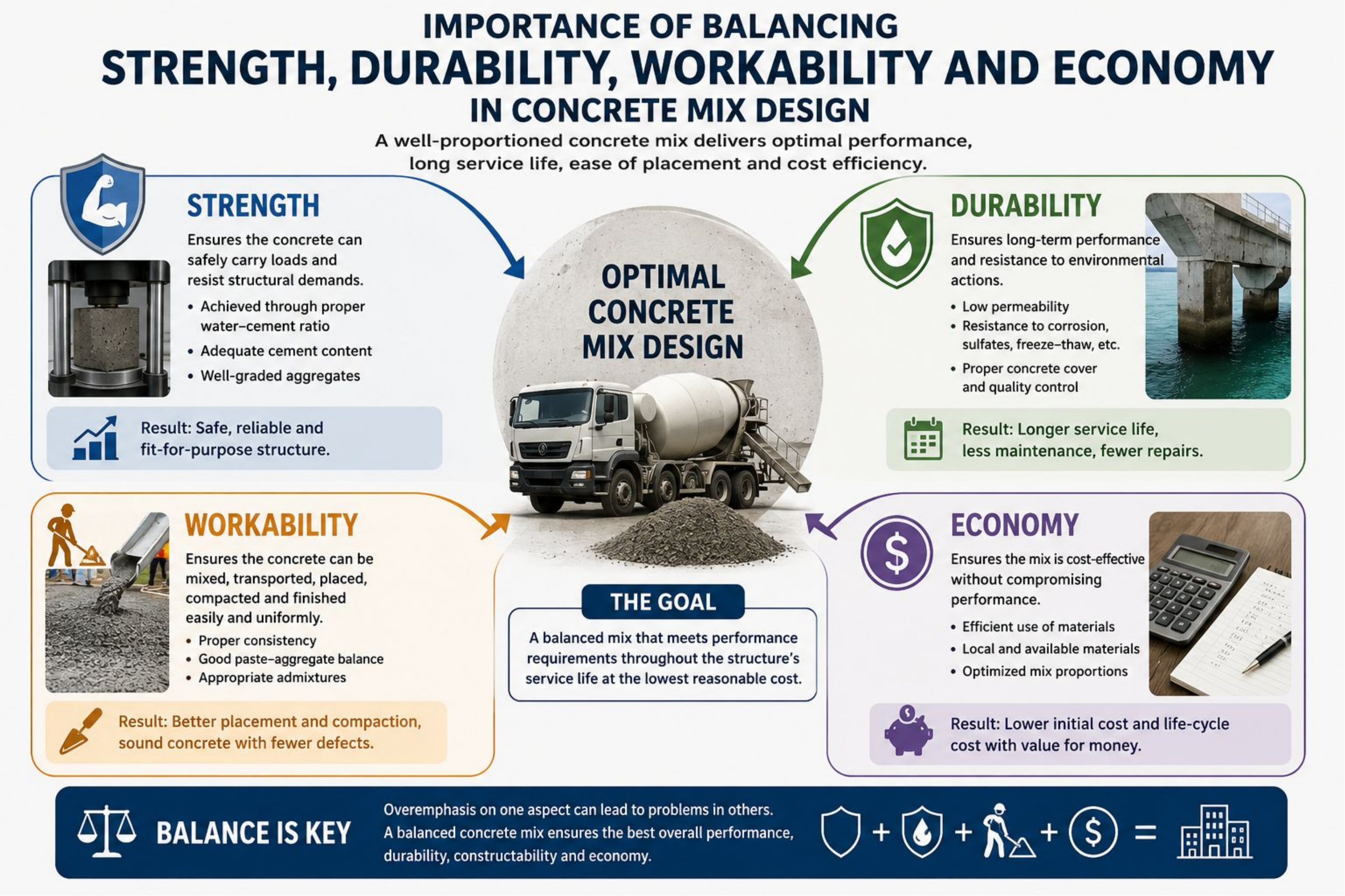
- Study hardened concrete properties: mechanical, physical, and durability aspects
- Analyze strength development: paste hydration, aggregates, and interface behavior
- Review key factors: w/cm ratio, materials, admixtures, curing, and age
- Examine testing methods and durability, including predictive tools and evaluation techniques

Content

- Fundamentals of the ACI Method and Design Criteria
- Concrete Proportioning Design
- Adjustment of the Design and Analysis of the ACI Method

Fundamentals of the ACI Method and Design Criteria

Objectives of the ACI Method



IMPORTANCE OF BALANCING STRENGTH, DURABILITY, WORKABILITY AND ECONOMY IN CONCRETE MIX DESIGN

A well-proportioned concrete mix delivers optimal performance, long service life, ease of placement and cost efficiency.

STRENGTH

Ensures the concrete can safely carry loads and resist structural demands.

- Achieved through proper water–cement ratio
- Adequate cement content
- Well-graded aggregates

Result: Safe, reliable and fit-for-purpose structure.

DURABILITY

Ensures long-term performance and resistance to environmental actions.

- Low permeability
- Resistance to corrosion, sulfates, freeze–thaw, etc.
- Proper concrete cover and quality control

Result: Longer service life, less maintenance, fewer repairs.

OPTIMAL CONCRETE MIX DESIGN

WORKABILITY

Ensures the concrete can be mixed, transported, placed, compacted and finished easily and uniformly.

- Proper consistency
- Good paste–aggregate balance
- Appropriate admixtures

Result: Better placement and compaction, sound concrete with fewer defects.

THE GOAL

A balanced mix that meets performance requirements throughout the structure's service life at the lowest reasonable cost.

ECONOMY

Ensures the mix is cost-effective without compromising performance.

- Efficient use of materials
- Local and available materials
- Optimized mix proportions

Result: Lower initial cost and life-cycle cost with value for money.

BALANCE IS KEY

Overemphasis on one aspect can lead to problems in others. A balanced concrete mix ensures the best overall performance, durability, constructability and economy.

Source: Open AI (2026)

Project Parameters in Mix Design

- Structural type affects placement and compaction
- Placement method influences workability requirements
- Compressive strength controls mechanical performance
- Durability depends on water-cement ratio control

Source: Open AI (2026)

Economic Factors in Mix Design

- Cement is the most expensive component
- Efficient cement use reduces concrete cost
- Aggregates influence transportation and production expenses
- Skilled labor improves concrete quality control

Source: Open AI (2026)

Preliminary Project Information

- Climate affects fresh and hardened concrete
- Structural drawings provide essential design requirements
- Slump and aggregate size must be defined
- Exposure conditions influence durability requirements

Source: Open AI (2026)

Material Characterization Requirements

- Cement density required for volume calculations
- Aggregate gradation improves concrete performance
- Specific gravity supports proportioning calculations
- Moisture correction controls effective water content

Source: Open AI (2026)

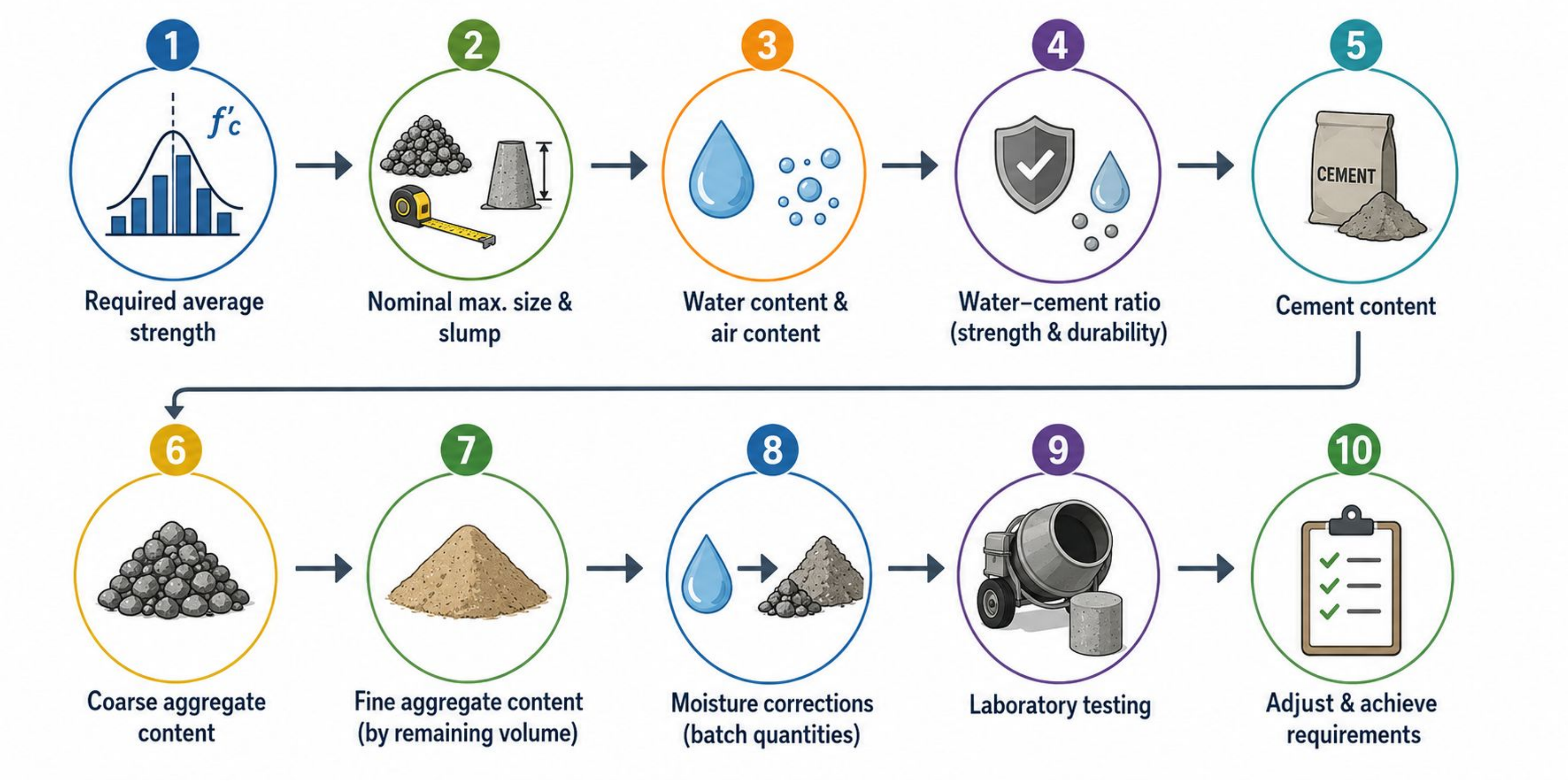
Sequential ACI Design Procedure

- ACI method follows sequential design steps
- Each calculation supports the following stage
- ACI tables guide material proportioning
- Procedure resembles an organized recipe process

Iterative Nature of Mix Design

- ACI method requires iterative trial adjustments
- Initial mixture must be laboratory tested
- Fresh concrete properties are experimentally evaluated
- Proportions adjusted for strength and workability

General Sequence of ACI Method



1. Required average strength
2. Nominal max. size & slump
3. Water content & air content
4. Water–cement ratio (strength & durability)
5. Cement content
6. Coarse aggregate content
7. Fine aggregate content (by remaining volume)
8. Moisture corrections (batch quantities)
9. Laboratory testing
10. Adjust & achieve requirements

Source: Open AI (2026)

Standard Deviation Calculation

- Requires minimum 30 consecutive tests
- Standard deviation measures production variability
- Lower deviation indicates better quality control
- Used to determine required average strength

$$f'cr = f'c + 1.34s$$

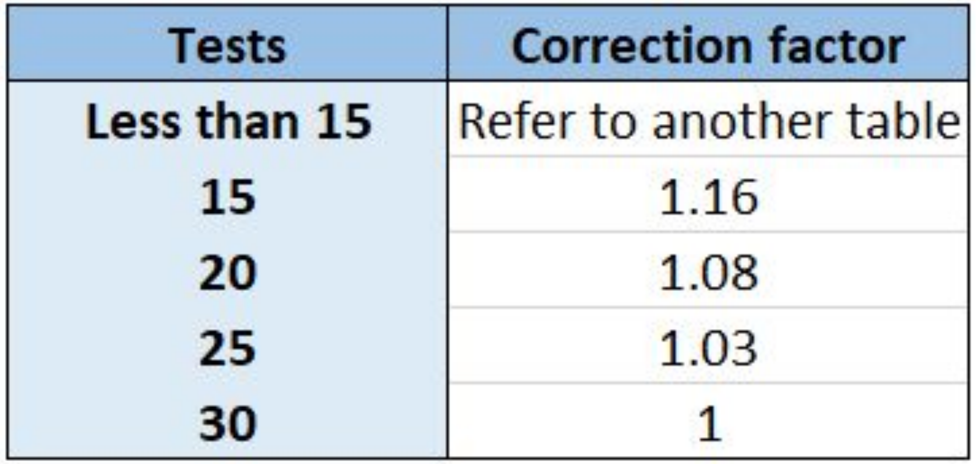
Combined Standard Deviation

- Uses two representative test result groups
- Minimum combined total: 30 tests
- Combines variability from both datasets
- Supports required average strength calculation

$$f'cr = f'c + 2.33s - 35$$

Required Average Strength

- Smaller datasets require correction factors
- Calculate required average concrete strength
- Evaluate two ACI strength equations
- Adopt higher calculated design value

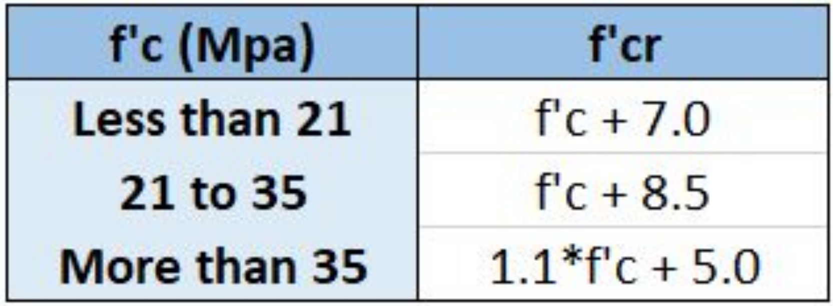


Tests	Correction factor
Less than 15	Refer to another table
15	1.16
20	1.08
25	1.03
30	1

Source: ACI 211 Comittee

Strength Without Historical Data

- Used without valid production records
- Apply additional safety strength margin
- Margin depends on specified strength range
- Ensures conservative and reliable mix design

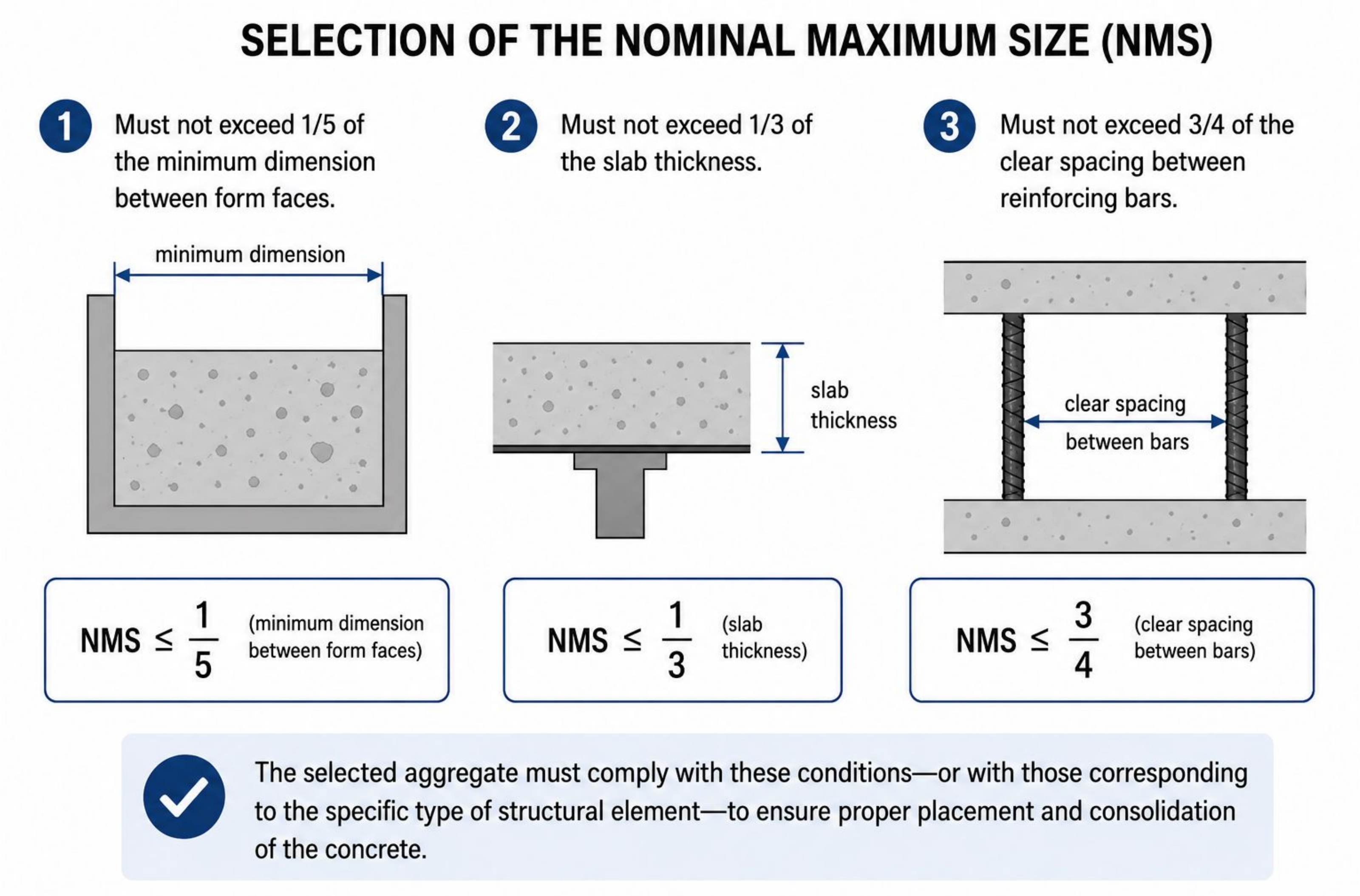


f'c (Mpa)	f'cr
Less than 21	f'c + 7.0
21 to 35	f'c + 8.5
More than 35	1.1*f'c + 5.0

Source: ACI 211 Comitteee

Concrete Proportioning Design

Nominal Maximum Aggregate Size



SELECTION OF THE NOMINAL MAXIMUM SIZE (NMS)

1. Must not exceed 1/5 of the minimum dimension between form faces.
2. Must not exceed 1/3 of the slab thickness.
3. Must not exceed 3/4 of the clear spacing between reinforcing bars.

$NMS \leq \frac{1}{5}$ (minimum dimension between form faces)

$NMS \leq \frac{1}{3}$ (slab thickness)

$NMS \leq \frac{3}{4}$ (clear spacing between bars)

✓ The selected aggregate must comply with these conditions—or with those corresponding to the specific type of structural element—to ensure proper placement and consolidation of the concrete.

Source: Open AI (2026)

Aggregate Size Selection Factors

Element's minimum dimension (cm)	Maximum aggregate size (inches)			
	Reinforced walls, beams and columns	Walls without reinforcement	Heavily reinforced slabs	Slabs without reinforcement or scarce reinforcement
6 - 15	1/2" - 3/4"	3/4"	3/4" - 1"	3/4" - 1 1/2"
19 - 29	3/4" - 1 1/2"	1 1/2"	1 1/2" - 3"	3/4" - 1 1/2"
30 - 74	1 1/2" - 3"	3"	1 1/2" - 3"	3"
75 or more	1 1/2" - 3"	6"	1 1/2" - 3"	3" - 6"

Source: ACI 211 Comittee

Pumped Concrete Aggregate Requirements

- Pumping requires compatible aggregate size
- Rounded aggregates improve pumping efficiency
- Angular aggregates require stricter size limits
- Smaller aggregates reduce blockage risks

Source: Kilsaran. (n.d.)

Slump Selection Criteria

Type of Construction	Maximum	Minimum
Reinforced footings and foundation walls	3"	1"
Plain foundations, caissons, and wall substructures	3"	1"
Reinforced beams and walls	4"	1"
Building columns	4"	1"
Slabs and pavements	3"	1"
Cyclopean concrete	2"	1"

Source: ACI 211 Comittee

Slump and Workability

- Slump indicates concrete consistency level
- Higher slump improves placement ease
- Workability depends on construction conditions
- SCC uses slump flow testing

Source: Backus, B. (n.d.)

Practical Slump Selection

Slump (inches)	Consistency	Workability Level	Type of Structure and Placement Conditions
0" to 1"	Very dry	Very low	High-strength beams or piles with formwork vibration
1" to 1 1/2"	Dry	Low	Pavements vibrated with mechanical equipment
1 1/2" to 2"	Semi-dry	Low	Mass concrete structures. Moderately reinforced slabs with vibration. Plain concrete foundations. Pavements with standard vibrators
2" to 4"	Medium	Moderate	Moderately reinforced slabs and manually compacted pavements. Columns, beams, foundations, and walls with vibration
4" to 6"	Wet	High	Heavily reinforced sections. Work where placement is difficult. Tunnel linings

Source: ACI 211 Comittee

Mixing Water Selection

Slump	Water (L/m³) for the indicated maximum nominal size (MNS) of coarse aggregate and consistency							
	3/8"	1/2"	3/4"	1"	1 1/2"	2"	3"	6"
Non-air-entrained								
1" to 2"	207	199	190	179	166	154	130	113
3" to 4"	228	216	205	193	181	169	145	124
6" to 7"	243	228	216	202	190	178	160	-
Air-entrained								
1" to 2"	181	175	168	160	150	142	122	107
3" to 4"	202	193	184	175	165	157	133	119
6" to 7"	216	205	197	184	174	166	154	-

Source: ACI 211 Comittee

Aggregate Shape and Water Demand

MNS of Coarse Aggregate	Unit Water Content (*) (L/m³) for the indicated slumps and types of coarse aggregate					
	1" to 2"		3" to 4"		6" to 7"	
	Rounded Aggregate	Angular Aggregate	Rounded Aggregate	Angular Aggregate	Rounded Aggregate	Angular Aggregate
3/8"	185	212	201	227	230	250
1/2"	182	201	197	216	219	238
3/4"	170	189	185	204	208	227
1"	163	182	178	197	197	216
1 1/2"	155	170	170	185	185	204
2"	148	163	163	178	178	197
3"	136	151	151	167	163	182

* Non-air-entrained concrete

Source: ACI 211 Comittee

Air Content in Concrete

MNS	Entrained air
3/8"	3,0%
1/2"	2,5%
3/4"	2,0%
1"	1,5%
1 1/2"	1,0%
2"	0,5%
3"	0,3%
6"	0,2%

MNS	Total Air Content (%) (*)		
	Mild Exposure	Moderate Exposure	Severe Exposure
3/8"	4,50%	6,00%	7,50%
1/2"	4,00%	5,50%	7,00%
3/4"	3,50%	5,00%	6,00%
1"	3,00%	4,50%	6,00%
1 1/2"	2,50%	4,50%	5,50%
2"	2,00%	4,00%	5,00%
3"	1,50%	3,50%	4,50%
6"	1,00%	3,00%	4,00%
*	A tolerance of 1.5% is permitted		

Source: ACI 211 Comittee

Water-Cement Ratio Selection

- Water-cement ratio controls concrete performance
- Lower ratios increase strength and durability
- Durability may govern ratio selection
- Adopt most restrictive design ratio

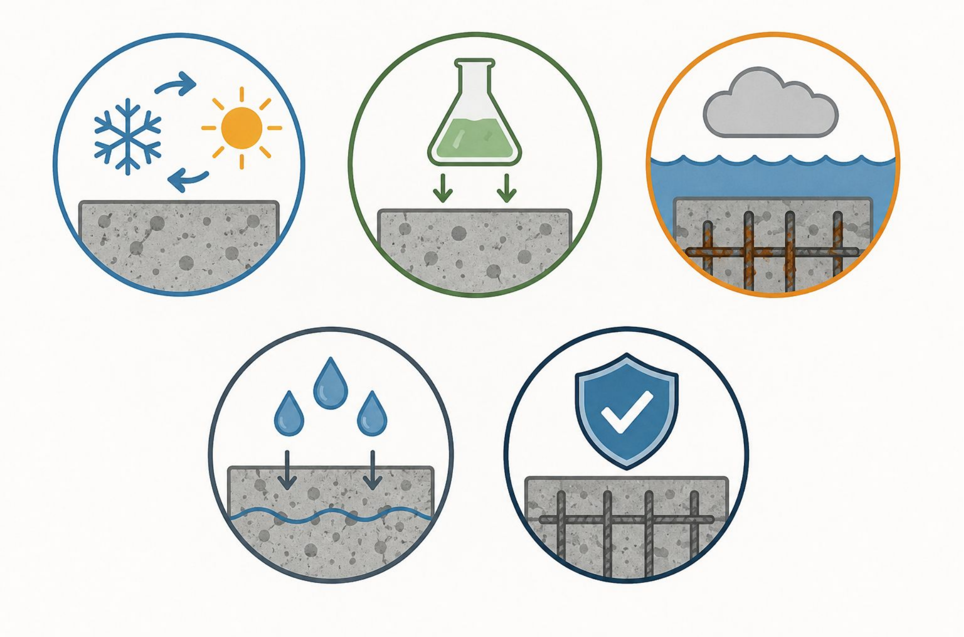
Water-Cement Ratio and SSD Condition

f'cr (28 days)	Design w/c ratio, by weight	
	Non-air-entrained concrete	Air-entrained concrete
150	0,8	0,71
200	0,7	0,61
250	0,62	0,53
300	0,55	0,46
350	0,48	0,4
400	0,43	-
450	0,38	-

Source: ACI 211 Comittee

Durability-Based Ratio Selection

- Durability may control water-cement ratio
- Freeze-thaw requires low permeability concrete
- Sulfates cause chemical concrete deterioration
- Corrosion protection limits chloride penetration



Source: Open AI (2026)

Freeze-Thaw Durability Requirements

Exposure Conditions	Maximum w/c Ratio, Conventional Aggregates	Minimum f'c, Lightweight Aggregates
Low-permeability concrete		260
a) Exposed to fresh water	0,5	
b) Exposed to seawater or brackish water	0,45	
c) Exposed to sewage	0,45	
Concrete exposed to freezing and thawing under wet conditions		300
a) Curbs, gutters, thin sections	0,45	
b) Other elements	0,5	
Corrosion protection for concrete exposed to seawater, brackish water, mist, or spray from these waters	0,4	325
If the minimum cover is increased by 15 mm	0,45	300

Source: ACI 211 Comittee

Sulfate Exposure Requirements

Sulfate Exposure	Water-Soluble Sulfate (SO_4) in Soil, % by Weight	Sulfate (SO_4) in Water (ppm)	Type of Cement	Normal-Weight Aggregate Concrete, Maximum w/c Ratio by Weight	Normal- and Lightweight Aggregate Concrete, Minimum f'c (kgf/cm²)
Negligible	$0.00 < SO_4 < 0.10$	$0 < SO_4 < 150$	–	–	–
Moderate	$0.10 < SO_4 < 0.20$	$150 < SO_4 < 1500$	II, IP (MS), IS (MS), P (MS), I (PM)(MS), I (SM)(MS)	0.50	280
Severe	$0.20 < SO_4 < 2.00$	$1500 < SO_4 < 10,000$	V	0.45	310
Very Severe	$SO_4 > 2.00$	$SO_4 > 10,000$	V + pozzolan	0.45	310

Source: ACI 211 Comittee

Chloride-Induced Steel Corrosion

Element	Maximum Water-Soluble Chloride Ion in Concrete (% by Weight of Cement)
Prestressed concrete	0.06
Reinforced concrete exposed to chlorides	0.15
Reinforced concrete that will remain dry or protected from moisture during its service life	1.00
Other reinforced concrete structures	3.00

Source: ACI 211 Comittee

Cement Content Calculation

- Cement calculated using water-cement ratio
- Water content determines required cement quantity
- Verify minimum durability cement requirements
- Cement expressed kilograms or bags

Aggregate Selection Criteria

- ASTM standards define aggregate gradation requirements
- Proper gradation improves concrete density
- Angular aggregates increase void content
- Rounded aggregates improve workability significantly

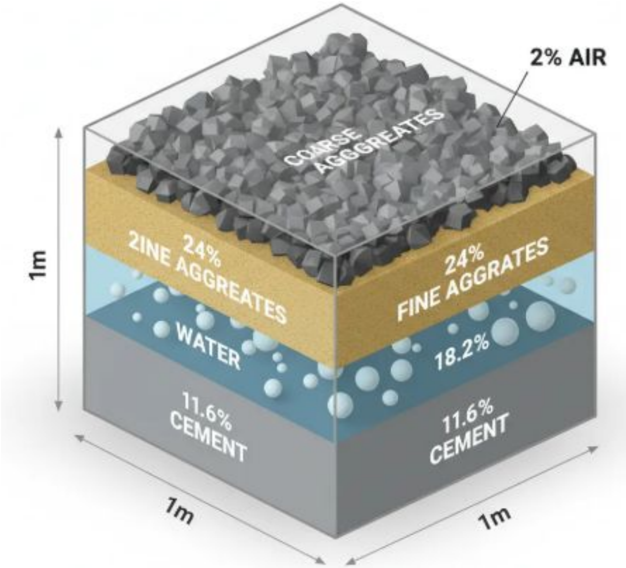
Coarse Aggregate Determination

MNS of Coarse Aggregate	Volume of coarse aggregate, dry-rodded, per unit volume of concrete, for various fineness moduli			
	2,4	**2,6**	**2,8**	**3**
3/8"	0,50	0,48	0,46	0,44
1/2"	0,59	0,57	0,55	0,53
3/4"	0,66	0,64	0,62	0,60
1"	0,71	0,69	0,67	0,65
1 1/2"	0,76	0,74	0,72	0,70
2"	0,78	0,76	0,74	0,72
3"	0,81	0,79	0,77	0,75
6"	0,87	0,85	0,83	0,81

Source: ACI 211 Comittee

Absolute Volume Principle

- Concrete components volumes equal one cubic meter
- Fine aggregate determined by volume difference
- Specific gravity converts volume into weight
- Absolute volumes consolidate final mix proportions



Source: Solvebility. (2025)

Aggregate Moisture Correction

- Design initially assumes SSD aggregate condition
- Surface moisture affects effective mixing water
- Positive moisture reduces mixing water
- Negative moisture increases mixing water

Moist aggregate
Source: Suryakanta. (2015)

Adjustment of the Design and Analysis of the ACI Method

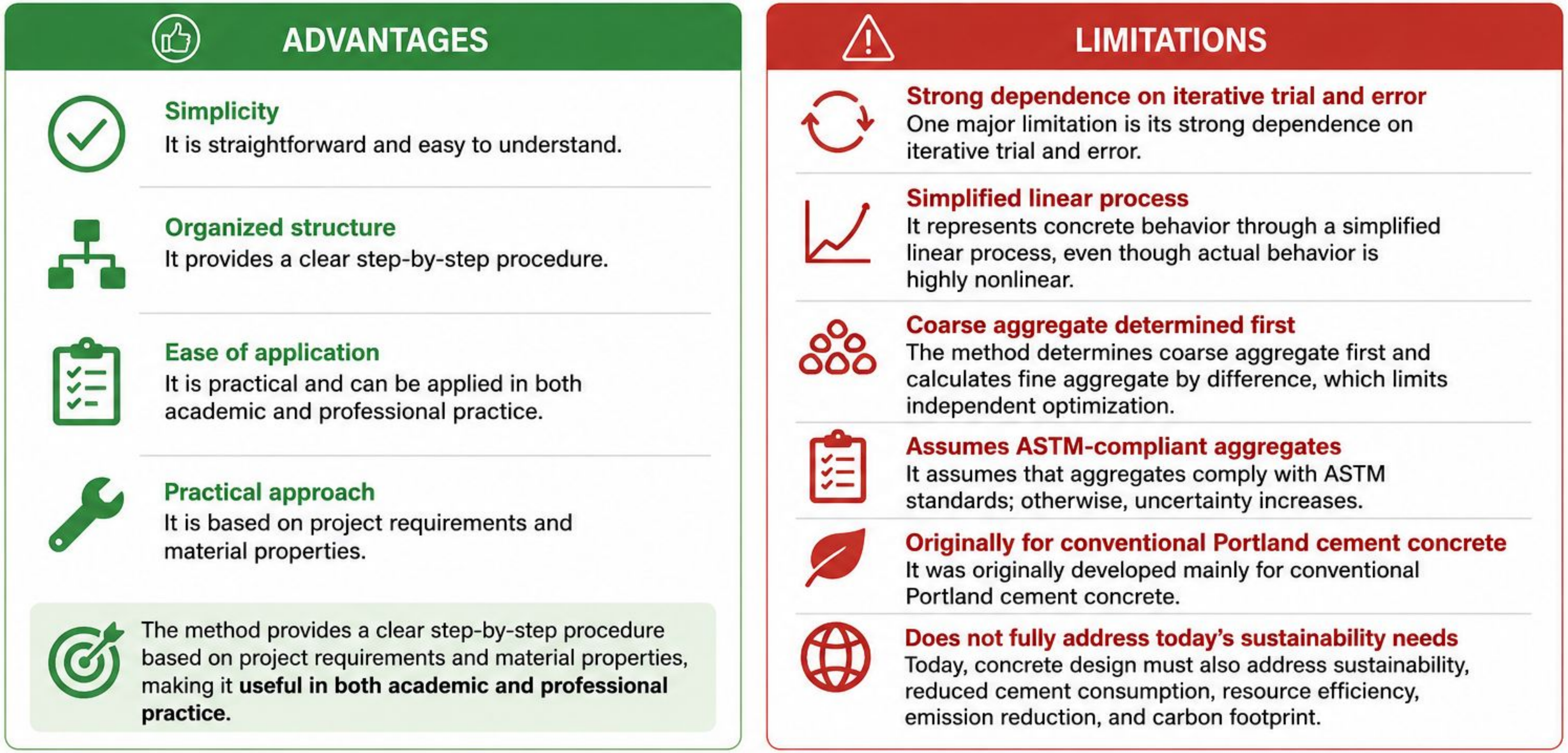
Theoretical Mix Validation

- Theoretical mix requires experimental validation
- Design considers strength and durability requirements
- Fresh concrete properties require verification
- Testing enables adjustment and readjustment process

Iterative Mix Optimization

- Mix design is empirical and requires continuous testing and adjustment.
- Concrete behavior is nonlinear due to multiple interacting variables.
- Theoretical proportions are only the starting point for optimization.
- Fresh and hardened concrete properties must both be verified.
- Successful adjustments depend on repetition, experience, and technical control.

ACI Method Advantages and Limitations



ADVANTAGES

Simplicity
It is straightforward and easy to understand.

Organized structure
It provides a clear step-by-step procedure.

Ease of application
It is practical and can be applied in both academic and professional practice.

Practical approach
It is based on project requirements and material properties.

The method provides a clear step-by-step procedure based on project requirements and material properties, making it **useful in both academic and professional practice.**

LIMITATIONS

Strong dependence on iterative trial and error
One major limitation is its strong dependence on iterative trial and error.

Simplified linear process
It represents concrete behavior through a simplified linear process, even though actual behavior is highly nonlinear.

Coarse aggregate determined first
The method determines coarse aggregate first and calculates fine aggregate by difference, which limits independent optimization.

Assumes ASTM-compliant aggregates
It assumes that aggregates comply with ASTM standards; otherwise, uncertainty increases.

Originally for conventional Portland cement concrete
It was originally developed mainly for conventional Portland cement concrete.

Does not fully address today's sustainability needs
Today, concrete design must also address sustainability, reduced cement consumption, resource efficiency, emission reduction, and carbon footprint.

Source: Open AI (2026)

Conclusions

- The ACI Committee 211 method is a practical and sequential procedure used to determine appropriate concrete proportions according to project requirements. The water-cement ratio is the most important parameter because it controls strength, durability, and concrete behavior. Proper material characterization, especially aggregate properties and moisture conditions, is essential for accurate design.
- Mix design must consider not only strength, but also workability, durability, placement conditions, and environmental exposure. Since the process is empirical and iterative, continuous testing and adjustments are necessary. Although the ACI method has limitations regarding sustainability and optimization, it remains a fundamental basis for modern concrete proportioning methods and concrete technology education.

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