Lecture 5:

Concrete Mix Design: ACI Method of Mix Design

In USA, the minimum strength is called f'_c, the specified design strength or specified compressive strength.

- The first step in designing a concrete mix is to decide on a strength higher than the minimum required strength. This higher strength is called
  - Reqd. avg. strength or reqd. avg. comp. strength, f'_{cr} in USA

** i.e. the higher strength
= minimum strength + some additional strength

Additional strength is the result of the statistical behaviour of hardened concrete which is the reflection of the quality control of concrete manufacturing.

Salient Features of ACI method:

- From ACI manual of Concrete Practice, Part 1 - 2008
- Standard Practice for Selecting Proportions for Normal, Heavyweight, and Mass concrete (ACI 211.1 – 91) Reapproved 2002.
- Contains chapter 1-8 as scope, introduction, relationship, admixtures, background data, procedure, sample calculation and references. Appendix 1-5 includes SI units, calculations in SI, laboratory tests, heavy weight mix and mass concrete mix proportioning.
- Mix design method provides a first approximation of proportions intended to be checked by trial batches in the laboratory or field and adjusted, as necessary to produce the desired characteristics of concrete.
- Selection of proportions involves a balance between economy and requirements for
  - Placeability o strength o durability o density and o appearance
- Concrete strength is determined by the net quantity of water per unit quantity of cement or total cementitious materials. For a given w/c or w/(c+p) ratio, differences in strength result from changes in
  - Maximum size of aggregate
  - Grading, surface texture, shape, strength and stiffness of aggregate particles
  - Differences in cement type and sources
  - Air content, and
  - Chemical admixtures that affect cement hydration process
- Concrete must be durable i.e. must be able to endure those exposures that may deprive it of its serviceability

Background Data:

- Sieve analysis of fine and coarse aggregate
- Unit weight of coarse aggregate
- Bulk sp.gr. and absorption of fine and coarse aggregate
- Mixing water requirements from experience of aggregates
- Relationship between strength and w/c or w/(c+p) ratio
- Sp. Gr. Of Portland cement and other cementitious materials if used
- Optimum combination coarse aggregates to meet the maximum density gradings

In absence of the above information, estimates given in ACI 211.1-91 may be employed

Job Specification Requirements:

- Maximum w/c or w/(c+p) ratio
- Minimum cement content
- Air content: maximum or minimum
- Slump (range)
- Maximum size of aggregate
- Strength (avg. design strength, specific strength, margin)
- Admixtures, special types of cement or aggregates

ACI 211.1-91: Steps for the Design of Normal Concrete Mixes

Step 1: Choice of slump

- Determine slump from Table 6.3.1 for vibratory compaction
- For other compaction, increase by 1 inch
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Table 6.3.1 — Recommended slumps for various types of construction*

Types of construction	Slump, in.	
	Maximum+	Minimum
Reinforced foundation walls and footings	3	1
Plain footings, caissons, and substructure walls	3	1
Beams and reinforced walls	4	1
Building columns	4	1
Pavements and slabs	3	1
Mass concrete	2	1

*Slump may be increased when chemical admixtures are used, provided that the admixture-treated concrete has the same or lower water-cement or water-cementitious material ratio and does not exhibit segregation potential or excessive bleeding.

†May be increased 1 in. for methods of consolidation other than vibration.

Step 2: Choice of maximum size of aggregate

- Largest size economically available and consistent with dimension of structure
- For higher strength, lower maximum sizes are used
- Structural limits for maximum size:
    - Max. size 1/5th of narrowest dimension between sides of forms
      1/3rd of the depth of the slab
      3/4th of the minimum clear spacing between bars

Step 3: Estimating mixing water and air content

- For a given slump, max. size of agg., Approx. mixing water and air content is obtained from Table 6.3.3 which are for
  - Use at 68 -77°F,
  - Angular and well graded aggregate

- Round aggs. Need 30 lb less water for non-air entrained and 25 lb less water for air entrained concrete

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Table 6.3.3 — Approximate mixing water and air content requirements for different slumps and nominal maximum sizes of aggregates

	Water, lb/yd³ of concrete for indicated nominal maximum sizes of aggregate							
Slump, in.	⅜ in.*	½ in.*	¾ in.*	1 in.*	1-½ in.*	2 in.*,†	3 in.†,‡	6 in.†,‡
Non-air-entrained concrete								
1 to 2	350	335	315	300	275	260	220	190
3 to 4	385	365	340	325	300	285	245	210
6 to 7	410	385	360	340	315	300	270	—
More than 7*	—	—	—	—	—	—	—	—
Approximate amount of entrapped air in non-air-entrained concrete, percent	3	2.5	2	1.5	1	0.5	0.3	0.2
Air-entrained concrete								
1 to 2	305	295	280	270	250	240	205	180
3 to 4	340	325	305	295	275	265	225	200
6 to 7	365	345	325	310	290	280	260	—
More than 7*	—	—	—	—	—	—	—	—
Recommended averages§ total air content, percent for level of exposure:								
Mild exposure	4.5	4.0	3.5	3.0	2.5	2.0	1.5**,††	1.0**,††
Moderate exposure	6.0	5.5	5.0	4.5	4.5	4.0	3.5**,††	3.0**,††
Severe exposure‡‡	7.5	7.0	6.0	6.0	5.5	5.0	4.5**,††	4.0**,††

Step 4: Selection of w/c or w/ (c+p) ratio

- For OPC, relatively conservative w/c ratio can be taken from Table 6.3.4(a)
- Strength values in 6.3.4(a) are based on 6”x12”cylinders moist cured for 28 days and tested as per ASTM C31, for OPC, AND ¾” -1” max. size
- Values are for 2% air for non-airentrained and 6% air for airentrained concrete
- Avg. strength values exceed specific strength by a margin (ACI 214 and ACI 318)

Increase in strengths when records of test data are not available are, (ACI 318)

1000 psi for less than 3000 psi concrete
1200 psi for 3000 – 5000 psi concrete, and
1400 psi for more than 5000 psi concrete

- For severe exposure Table 6.3.4(b) may be used

Table 6.3.4(a) — Relationship between water-cement or water-cementitious materials ratio and compressive strength of concrete

Compressive strength at 28 days, psi*	Water-cement ratio, by weight	
	Non-air-entrained concrete	Air-entrained concrete
6000	0.41	—
5000	0.48	0.40
4000	0.57	0.48
3000	0.68	0.59
2000	0.82	0.74

Step 5: Calculation of cement content

Required cement content = estimated mixing water (Table 6.3.3) / w/c ratio (Table 6.3.4(a)

Step 6: Estimation of coarse aggregate content

- For max. agg. size and F.M. of fine agg., coarse aggregate (O-D basis, rodded) is determined from Table 6.3.6 per unit volume of concrete
- Volume from Table 6.3.6 is converted to weight by O-D, rodded unit weight of C.A.
- For workable pumping concrete, values in Table 6.3.6 may be increased by 10%
- For less workable concrete (pavement) the values of Table 6.3.6 may be decreased by 10%

Table 6.3.6 — Volume of coarse aggregate per unit of volume of concrete

Nominal maximum size of aggregate, in.	Volume of oven-dry-rodded coarse aggregate* per unit volume of concrete for different fineness moduli of fine aggregate+			
	2.40	2.60	2.80	3.00
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	0.75	0.73	0.71	0.69
2	0.78	0.76	0.74	0.72
3	0.82	0.80	0.78	0.76
6	0.87	0.85	0.83	0.81

*Volumes are based on aggregates in oven-dry-rodded condition as described in ASTM C 29.

Step 7: Estimation of fine aggregate content

- Fine aggregate weight = Wt. of fresh concrete – Wt. of (CA + Cement + Water)
- Wt. of fresh concrete is taken from experience or (as a first estimate) from Table 6.3.7.1
- Exact unit wt. of fresh concrete, U = 16.85Ga(100-A) + C(1-Ga/Gc) – W(Ga-1) -- sheet
- Values in Table 6.3.7.1 are adjusted in trial batches

Step 8: Adjustment for aggregate moisture

- Moisture in aggregate
- Mixing water should be reduced for surface water of saturated aggregate
- For dry aggregate, moisture required for absorption should be added with required mixing water or preconditioning (SSD) is required

Step 9: Trial batch adjustments

- Trial batches are to be prepared as per ASTM C192
- Only sufficient water is to be added for required slump
- Calculate new batch weights starting with step , modifying the volume of coarse aggregate from Table 6.3.6, if necessary, to provide proper workability

Example: Page 14 – sheet supplied
