#2

CE 201: ENGINEERING MATERIALS

Lecture 1:

1. Introduction
2. Rationale -- why is important for CE students? Other importances of CE 201
3. Materials for Civil Engg. Constructions
4. Bldg. Materials for Developing Countries

1
Introduction

What is civil engineering?

What are the works of civil engineers?

Where do the civil engineers work?

2
What is the rationale of this course?

- Why do we need this course for civil engineers?
- What is the necessity of this course material for highway/civil engineers?
- What is the importance of study of materials for civil engineers?
- Materials course is of utmost importance for civil/highway engineers – justify

Materials for Civil Engineering Constructions

See attached sheet

5. Standard:

Definition
Development
Users

6. Specification:

Definition
Agencies

7. Test Method:

Definition
Development
Result and Units

See attached sheet

Building Materials for Developing Countries

#3

CE201 · Sept · 2015 : Lecture 1

Lecture-1: CE 201

Engineering Materials, Materials of Construction
Civil Engg. Materials, Materials for Civil & Hwy Engrs.
নির্মাণ সামগ্রী, নির্মাণের উপাদান ॥

Introduction

Rationale : Why is needed?

Importance : Public Domain / Human-life, Job, Interview

3 Materials for Civil Engineering Construction :

- Materials occupying main volume
  - stability, strength
- Materials for binding
  - stability, strength, allowable deformation
- Materials for reinforcement
  - added strength, size reduction
- Materials for protection
  - prevention of deterioration
- Materials for decoration
  - aesthetic quality,

Building Materials for Developing Countries :

- Developing country
- Low-cost construction
- Local Materials

CIVIL ENGG.
CONSTRUCTION
CONTRACTORS
CONSULTANT

Standards, Specifications, Tests
— Developments and Techniques

5. Development of Research

- human civilization
- utility and comfort for betterment
- economy
- competition / war → impetus on science & tech.

Development of Standards:

Standard: a document that has been developed and established within the concensus principles of a 'society' and that meets the approval requirements of the society's procedures and regulations.

- are developed through years of research
- become legally binding only by govt. regulations
- are used by: individuals, companies, scientists, engineers, architects, designers, govt. agencies.

6. Specification:

- a precise statement of a set of requirements to be satisfied by a material, product, system or service that indicates the procedures for determining whether each of the requirements is satisfactory.

Specification requirements:

- numerical
- appropriate units
- limits
- tolerances

6 Specification Agencies:
- National e.g. BSTI
- International e.g. ASTM, BS etc.

7 Test method:
- a definite procedure for the identification, measurement and evaluation, of one or more qualities, characteristics or properties of a material, product, system or service that produces a test result.

Test methods:
- ASTM standard test methods
- British / Euro standard test methods
- BDS test methods

Test methods in Bangladesh Building Code:
- BDS
- ASTM / BS
- IS (Indian Standards)

? Preparation of Tender Document:
- Specification for elements of construction
- Specification requires test methods
- Test methods need standards

Quality Control:

Frequency of Tests:

Tolerances in Specifications:

25.09.15

Lecture 2-3: Stones & Aggregates #4

Stones

Q. **Formation of a Rock:**

- Formation of solid earth crust
- Changes due to volcanic eruption and weathering agents
- Formation of rocks
- Derivation of stones from rocks [illegible] খনি থেকে পাথর কেটে নিয়ে আসা।

Q. **Classification of Stones:**

- Geological
- Engineering
- Structural
- Based on Hardness
- Practical

(Question 1: How do you get building stones? What are the classifications of stones?)

1. Geological classification

   - Igneous: granite, trap, basalt
   - Sedimentary: sandstone, limestone, shale
   - Metamorphic: marble, quartzite, slate

2. Engineering/Chemical classification (constituent particle এর ভিত্তিতে)

   - Silicious: granite, sandstone, quartzite (at least ৩টা উদাহরণ দিতে হবে)
   - Argillaceous: laterite, porphyry, slate
   - Calcareous: limestone, dolomite, marble

3. Structural classification

   - Stratified: sandstone, slate (layer এ থাকে)
   - Unstratified: igneous rock, granite, basalt

4. Classification based on Hardness

   - Soft: talk, gypsum, sandstone
   - Medium: limestone, dolomite
   - Hard: basalt, quartzite, gravel
   - Very hard: granite, trap, taconite

5. Practical classification based on physical characteristics

   - Granite and other igneous rocks
   - Slate and schist
   - Sandstone
   - Limestone

(Question #2: What is the classification of stones? Give examples for each classification.)

Q. Uses of stones

- Blocks of stones are used in foundations, walls, bridge pier, abutments, light houses, aqueducts, retaining walls
- Flags or thin slabs are used for paving, roofing etc.
- Broken or crushed stones are used as aggregates in concrete, in road constructions and as railway ballast
- Stone screenings are used as natural substitute for sand
- Some stones e.g. limestone is the basic material for the manufacture of lime and cement
- As blocks along the river and canal banks for preventing erosion, called riprap
- For ornamental works in and outside the buildings, as blocks, slabs and chips

Q. Characteristics of good stones

Essential requirements are,

- Strength: resistance to crushing, depends on,
  (i) Origin (ii) Formation, and (iii) Type of stone
- Durability: ability to sustain strength characteristics for longer duration, depends on,
  - Chemical composition
  - Physical structure
  - Position and type of use

এর engg. material এর এই দুটো fundamental requirement থাকতেই হয়।

Apart from these two fundamental requirements, other subsidiary considerations are,

- Structure of stone: mode of formation of stone, types are stratified and unstratified, unstratified stones are hard and demanded

- Texture: arrangement, size, shape of its constituents mineral grains,
  - Crystalline or homogeneous texture are close grained and compact
  - Action of weathering agents makes open textured
  - Most sedimentary rocks are granular and crystalline
  - Amorphous rocks are of glassy and fused texture

  Texture is generally indicated by fractured surface, and fracture may be Even; Uneven – required for good crushing characteristics; & Concoidal (curved)

  Bright, clean and sharp fractures with well cemented grains are always desirable

- Appearance and color: required for decoration and face works, stones containing iron should not be used, should also have the ability to receive good polish, marble, limestone, sandstone and granite are well known for their appearance

- Hardness and toughness: required to resist wear and tear, factors affecting strength, hardness and toughness are,
  - Hardness and softness of component minerals
  - Proportion of hard and soft mineral in the same stone
  - The size and shape of minerals
  - The manner in which the minerals are interlocked
  - The cohesion between the component minerals
  - The quality of cementing material binding the grains and minerals

Considering the above factors, igneous and metamorphic rocks are naturally hard and strong than the sedimentary rocks.

- Weight (sp.gr.): stones with higher sp.gr. are required in the construction of dams, bridge piers, retaining walls and foundations etc., so as to impart greater stability, stones with lower sp.gr. are required for upper parts of high rise building. Specific gravities of some important rock types are,

  - Granite --- 2.65
  - Basalt --- 2.77
  - Sandstone -- 2.06
  - Limestone --- 2.60
  - Gneiss --- 2.97
  - Quartzite -- 2.64
  - Marble ---- 2.73
  - Slate ---- 2.77

- Porosity and water absorption: porosity is the void space between the component minerals whereas absorption is the characteristic property of the mineral constituents

  - Permeability is a measure of the size of the voids
  - Less porous and less permeable stones are desirable

- Abrasion resistance: required for stones to be used in surface courses of roads. Los Angeles abrasion test is a renowned abrasion test

- Fire resistance: fire damages a stone structure quickly because of,

  - Unequal coefficient of expansion
  - Bad conductivity of stones, in general
  - Rapid rise in temperature
  - Sudden cooling of surfaces

Crystalline varieties(granite, gneiss) disintegrate quickly, trap stones are better fire resistant, limestone gets covered with quicklime

- Electrical conductivity:
  - bad conductors offer high resistance
  - wet stones have low resistance
  - marbles are suitable for switchboard panels

- Seasoning quality: fresh stones have mineral water in solution and are termed as quarry sap or quarry water, when it dries mineral constituents is deposited in the pores and makes the stone more compact. Therefore stones should be seasoned before use.

- Facility of work: it is also called dressability – the art of shaping a stone, stones as blocks and thin slabs need dressing before use.

- Cost: is an important consideration in the selection of building stones,

Q. Deterioration or Decay of Stones

The stones used in construction works may suffer weathering, disintegration or decomposition which depend on the environment to which the stone is exposed. Various agencies which cause deterioration or decay of stones are,

- Chemical movement
- Atmospheric impurities
- Winds
- Rain
- Frost
- Alternate wetting and drying
- Vegetation growth
- Worms, bacteria and boring sea animals
- Nature of binding material

Q. **Preservation of Stones:**

Preservation of stones means making the stone strong enough to face the atmospheric agencies which are the root cause of its deterioration and can be effected in the following ways:

- Filling up the stone pores
- Coating the stone with a preservative
- Use of stones containing carbonate is discouraged to use in industrial town
- Stones like limestone and sandstone should not be laid close to each other
- Should be bound by material having no adverse effect
- Growth of plants on the stones should be checked

Some of the preservatives are as follows,

- Coal tar
- Paraffin
- Solution of soda or potash
- Calcium hydroxide
- Linseed oil (raw and boiled)
- Wax and benzene
- Wax and silicon
- Barium hydroxide

Q. **Testing of stones**

To determine the suitability of stones for its intended use in engineering works, there are many tests to be done of which strength and durability are the important ones. Durability tests are,

① Durability Test

- Smith's test: broken stone sample is immersed in water in a tube and vigorously shaken. Stone is not durable if the water becomes dirty
- Brard's test: to determine the soundness of stone, 4cm cube sample is put in Na_2SO_4 solution at 68°F for two hrs, dried in hot air for few days and weighed after 12 cycles. Loss in weight is recorded and sound stones will have almost no loss.
- Acid test: required to ascertain the suitability of the stone in industrial town where the atmosphere contains acidic vapours. Stone fragments with sharp edges are kept immersed in 1% sulphuric and 1% hydrochloric acid for seven days, taken out and examined, rounding of edges and deposits on the surface will indicate the presence of Ca or Mg carbonate or both and not suitable for use in industrial use.

② **Strength tests:** on prepared rock sample, strength tests are as,

- Compressive strength or crushing test
- Transverse strength test
- Shear strength test
- Impact strength test

③ **Other important tests** are,

- Water absorption test
- Hardness test
- Permeability test
- Attrition test
- Microscopic test

AGGREGATES

Definition
Types
Classification
Sources
Uses
Tests and specifications

Im **Defn. of Aggregate:** Aggregate is an aggregation of non-metallic minerals obtained in particulate form and can be processed and used for civil and highway engineering constructions

Classification of Aggregates:

- Based on source
    - Natural: crushed stones, crushed boulders, gravels, shingles, sands, etc
    - Artificial: crushed brick, clay +pfa, synthetic etc.

- V.Imp Based on size
    - Coarse aggregate, CA – passing max size and retained on 4.75 mm sieve
    - Fine aggregate, FA – passing 4.75 mm sieve and retained on 0.15/.075 mm sieve
    - Silt and clay or dust or fines or filler – passing .075 mm sieve

- Based on weight (sp.gr.)
    - Normal weight: bulk unit weight, 1520-1680 kg/m^3 (95-105 pcf), so that normal wt. concrete (NWC) has a unit wt. 150 lb/cft (2400 kg/m^3)
    - Light weight: bulk unit wt. less than 1120 kg/m^3
    - Heavy weight: bulk unit wt. more than 130pcf (2080 kg/m^3)

Aggregates work in a mass, so their size distribution, shape and texture are important characteristics along with their strength (individual or in mass).

The density, voids, compactibility, shear strength etc. largely depends on the above characteristics

Question: Why is grading important for any aggregate construction?

Grading; Fineness Modulus

Grading: The distribution of particle sizes (d) within any batch of aggregate is called grading or

- Expressed as a cumulative% of particles that are smaller than each of a series of sieve openings

- The percentages are customarily presented in graphical form known as grading curve or sieve curve

Strength tests of aggregates:

- ASTM tests (sheet given for concrete aggs.) - L. A. Abrasion test
- BS tests for strength and crushing characteristics

□ AIV test □ ACV test □ 10% Fines Value test □ AAV test

V.V.Imp **Los Angeles Abrasion Test: -- universal strength test for aggregates**

- ASTM C 131-06 {for <37.5mm} and ASTM C535 {for >37.5mm aggs.}
- Strength and crushing characteristics, relative quality of aggs.
- 5 kg aggregate in grading A,B, C or D placed in a steel drum of 28"Dx20" L
- 500 rev. @ 32 rev. per min with steel charges and aggs. in closed drum
- Crushed aggs. sieved through 1.70mm (#12 sieve) and passing portion is expressed as % loss in L.A. abrasion test

Absorption test: absorption capacity, effective absorption, surface moisture, air dry, oven dry, SSD (saturated surface dry), as per ASTM C 127,

- Apparent specific gravity
- Bulk specific gravity (ssd basis)
- Bulk specific gravity (o-d basis)

Durability tests অনেকদিন টিকবে কিনা। Long term ability to retain the strength characteristic

- Soundness by sodium sulphate
- Soundness by magnesium sulfate
- Wet and dry test
- Freeze and thaw test

crack করলে → durable না

Other tests of aggregates

As per sheets given [BRTC test sheet, JMBP aggs. test]

Specification of aggregates

As per sheets given (৭)

- Theoretically, y = f (d)
- Grading types
  - Continuous
  - Well graded [$p = (d/D)^{0.5} \times 100$]
  - Skip or gap graded
  - Uniform
  - Single graded

Fineness Modulus (F.M)

F.M. is a numerical characteristics of aggregates, especially for fine aggregates. The original definition by Abrams is

> *The F.M. is obtained by adding the total percentages of an aggregate sample retained on each of a specified Tyler sieve series(?) and dividing the sum by 100,*

Fineness Modulus,

- Represents an average particle size representing coarseness or fineness
- Proportional to the logarithmic avg. particle size of grading
- Fundamental parameter of the particle size distribution

Q. Find the FM of the sand with the following sieve analysis results. Draw grading curve

Sieve No.	Sieve size, mm	Material retained (gm)			
#4	4.75	1.0			
#8	2.36	5.9			
#16	1.18	11.9			
#30	0.60	24.0			
#50	0.30	25.1			
#100	0.15	28.0			
#200	0.075	2.9			
PAN	-	1.2			

Question: What is the difference between grading and fineness modulus?

Blending of Aggregates

1. What is it?
2. Why is needed?
3. **How is done? (mix design methods)**

1. Mixing of agregates of different size for attaining aggregate of required gradation is called blending.
2. It is needed for aequarcing aggregate of required gradation.

Testing of aggregates:

- Grading, Fineness Modulus
- Strength tests
- Durability tests
- Other tests

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Table 3.12.1: Tests for Concrete Aggregates (For JMBP - ≻ BB)

Jamuna Bridge এর concrete এ যে aggregate use করা হয়েছে তার ওই সব Test করা হয়েছে

		Test	Limits
1.	Description and Classification of materials	BS 812: Part 1:1975 Section 6	as specified
2.	Particle size distribution by sieve analysis	BS 812: Part 1:1975 Test method 7.1	as specified
3.	Clay, fine silt and fine dust 5% in fine or coarse 7.2.4	BS 812: Part 1:1975 Test method sands, 1% mix. for natural or crushed gravel coarse aggregates. 3% max. for crushed rock coarse aggregates.	3% max. for natural or crushed gravel sands, max. for crushed stone
4.	Clay lumps	ASTM C-142: 1978	3% max. for fine aggregate, 2% max. for coarse aggregate
5.	Flakiness Index	BS 812: Part 1:1975 Test 7.3	25% max. for all coarse aggregate test fractions
6.	Elongation Index	BS 812: Part 1:1975 Test 7.4	25% max. for all coarse aggregate test fractions
7.	Angularity Number	BS 812: Part 1:1975 Test 7.5	9 or 10. To be confirmed by the Engineer
8.	Determination of Relative Densities and Water Absorption	BS 812: Part 2:1975 Tests 5	Water absorption - 2.5% ; max. for all aggregates
9.	Determination of Bulk Density and Voids and Bulk-Aggregates	BS 812: Part 2:1975 Test 6.3	To be determined by the Engineer from test ·ing of results
10.	Field Settling Test	BS 812: Part 1:1975 Test 7.2.5	To be determined by the Engineer from test results
11.	10% Fines Value	BS 812: Part 3:1975	For concrete Class 40 and above not less than 100kN. For other con-crete not less than 50kN

#7

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17 Sept.15

Table 3.12.1: Tests for Concrete Aggregates (for JMBP -> BB)

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CEMENT:

- History
- Manufacture
- Chemistry
- Types
- Uses
- Properties
- Tests and Specifications

Q. **History:**
- Egyptians, Romans, Indians
- Pyramid mortar 81.5% $CaSO_4$ and 9.5% carbonate
- Indians used powdered brick named as surki in mortar
- Romans used blood, milk and lard to achieve workability
- John Smeaton in 1756 concluded that limestone with clayey matter yields hydraulic cement
- L.J. Vicat and James Frost (1911) also led the knowledge of cement
- Joseph Aspdin Leeds builder patented PC in Oct, 1824
- Germans specified PC in 1877, British in 1904, ASTM in 1904
- PC was first manufactured in India in 1913

Q. **Manufacture:**

- Collection of raw materials
- Crushing, grinding and mixing of raw materials
- Burning
- Grinding of clinker
- Addition of gypsum

Q. **Cement Chemistry:**

Raw materials of cement – lime, silica, alumina and iron oxide interact with one another in the kiln and a chemical equilibrium is reached by making complex four major compounds. The relative proportions of these compounds are responsible for influencing various properties of cement in addition to rate of cooling and fineness of grinding. Following are the compounds.

	Compound	Oxide Comp.	Abb.	%	Function
1.	Tricalcium Silicate	$3CaOSiO_2$	C_3S	54.1	Strength
2.	Dicalcium Silicate	$2CaOSiO_2$	C_2S	16.6	Strength
3.	Tricalcium Aluminate	$3CaOAl_2O_3$	C_3A	10.8	helps reaction
4.	Tetracalcium Aluminoferrite	$4CaOAl_2O_3Fe2O_3$	C_4AF	9.1	Acc. Hydr Accelerates Hydration

Q. **Functions of various ingredients/oxides of cement:**

1 Lime Oxide ...ngth and soundness, its deficiency reduces strength and setting time

2.. Silica – SiO_2-- it forms about 20 percent, imparts strength, excess causes slow setting

3. Alumina – Al2 O_3 – around 6 percent imparts quick setting, excess lowers strength

4. Iron Oxide – Fe_2O_3 – around 3 percent, imparts color, helps in fusion and imparts hardness and strength to cememt forming tricalcium aluminoferrite

and hardness, excess causes cracks and unsoundness

6. Sulphur Trioxide – SO_3 - around 2 percent, makes cement sound, excess makes unsound

7. Sodium, Potasium Oxide – K_2O, Na_2O – around 1 percent, excess makes unsound

Hydration of Cement: When water is added to cement, anhydrous(dry) constituent compounds of cement start reacting and forming hydration products C-S-H (tobermorite gel), with reactions as follows

$$2C_3S + 6H_2O \rightarrow C_3S_2H_2O + 3\,Ca(OH)_2\ ,$$

$$2C_2S + 4H_2O \rightarrow C_3S_2H_2O + Ca(OH)_2$$

$$C_3A + 6H_2O \rightarrow C_3AH_2O$$ this is rapid and retarded by adding gypsum

Heat of Hydration and Strength:

Hydration of cement compound is exothermic and the quantity of heat per gram of unhydrated cement, evolved upon complete hydration at a given temperature, is defined as heat of hydration. Methods to find is ASTM C186-82. C_3S, C_2S, C_3A and C_4AF produces 502, 260, 867, 419 joules per gm respectively. So, by reducing proportions of C_3A and C_3S, heat of hydration can be reduced.

[see attached sheet]

Types of cement: Q: What are the types of cement?

Major Types — characteristics

- ✓ Ordinary Portland Cement (BS), Type- I (ASTM), most common, high C_3S
- Modified Cement (BS), Type- II (ASTM), low heat gen., for mod. sul. action
- Rapid –hardening Portland cement (BS), Type-III (ASTM), rapid st. dev. due to high C_3S content, high fineness, for emergency works
- Low heat Portland cement (BS), Type-4 (ASTM), for large gravity dams, low amount of C_3S and high C_2S, slow rate of development of strength
- Sulphate resisting PC (BS), Type-5 (ASTM), good for resisting sulfate attack
- ✓ Portland blast-furnace cement (BS), Type-IS(ASTM), for mass concrete
- ✓ Portland – pozzolan cement (BS), Type IP, P and I(PM) –ASTM, for mass concrete

✓ ← বেশি use হয়

Other types

- Special rapid hardening/ Ultra-high early strength cement রাস্তা repair করতে
- Super sulfate cement ocean এর কাছাকাছি
- White and Coloured cement decoration purpose এ
- Expansive cement crack repair এর জন্য
- High-alumina cement Rapid hardening cement
- Hydrophobic cement [illegible]
- Oil-well cement কূপ খনন, বানাতে
- Readyset cement
- Masonry cement brick wall এ use হয়
- Pozzolana cement
- Natural cement = [illegible]

Testing of Cement:

Laboratory tests:

- Fineness
- Setting time
- Strength
- Soundness
- Heat of hyrdration
- Chemical composition

Field tests: Q: What are the field Tests of cement?

- Colour, uniformly greenish grey
- Physical, no lumps
- Cool feeling inside bag
- When pressed between fingers, smooth feeling
- When thrown on water, the particles should float for sometime
- A thick paste on a glass when kept under water for 24 hrs, should set and not crack.

Specification: - as per sheet and test results given sheet - 11

MORTAR:

What is it?:

Mortar is a paste generally made by mixing cementing and binding material [lime or cement] and an inert material with water

Why is required?

Mortars are usually required to join bricks, stones blocks etc.

What are the types and uses?

Types:

- on the basis of binding material

- Cement mortar – mix from Portland cement or its varieties, sand and water
- Lime mortar
- Gypsum mortar
- Mud mortar

- on the basis of application

- Brick laying mortar
- Finishing mortar
- Special mortar – for acoustics, X-ray shielding, plugging concrete at oil fields etc

Classification/Types of Plasters:

- Lime plaster – lime and sand at 1:2-3, mixed with water, kept for 24 hrs and then laid 3.8-1/2 thick on soaked surface, the plastered surface to be kept moist for two wks
- Surki plaster – 1 part lime plus 1.5 to 2.0 part surki plus water
- Lime-surki plaster – sand is added to prevent shrinkage, sand, suliki, lime in 1:1:1
- Neeru or lime putty – from quick lime puty
- Mud plaster – selected mud plus cow dung or saw dust মাটির ঘরে use
- Stucco plaster – decorative plaster made of lime, white stone, gypsum and oxides of coloring , applied in two or three coats
- Gypsum plaster – natural ground gypsum when heated to temp. of 140oF is called plaster of paris, mixed with sand at 1.3 plus water
- Mosaic plaster – mixture of ½ inch down stone chips plus cement in the ratio 2:1 plus water, polished and then waxed
- ✓ Cement plaster – Portland cement plus sand in the ratio 1:2 plus water, applied to scrapped, cleaned and soaked wall in single coat – this is used in most buildings

✓ বেশি use হয়

Pointing:

What is it and where is required?
How is done?
What are the ingredients?

What is it?
Pointing is the finishing off (with trowel) of the mortar in the rough brick joints of walls

Why is done?
It is done -- to protect the joints from atmospheric agencies, and
to improve the appearance of the structure

How is done?

- Prior to pointing all mortar joints are raked out ছিড়ে ফেলা।
- Loose mortar and dust are brushed out
- Joints are filled with lime or cement mortar by well pressing
- Finished pointing is kept wet for 4 days

CE201: Sept. 2015: Lecture 4-5

#10

CONCRETE TECHNOLOGY — Neville & Brooks

2 Cement

Ancient Romans were probably the first to use concrete – a word of Latin origin – based on *hydraulic cement*, that is a material which hardens under water. This property and the related property of not undergoing chemical change by water in later life are most important and have contributed to the widespread use of concrete as a building material. Roman cement fell into disuse, and it was only in 1824 that the modern cement, known as Portland cement, was patented by Joseph Aspdin, a Leeds builder.

Portland cement is the name given to a cement obtained by intimately mixing together calcareous and argillaceous, or other silica-, alumina-, and iron oxide-bearing materials, burning them at a clinkering temperature, and grinding the resulting clinker. The definitions of the British Standard (BS 12: 1978) and of the American Standard (ASTM C 150–84) are on those lines; no material, other than gypsum, water, and grinding aids may be added after burning.

Manufacture of Portland cement

From the definition of Portland cement given above, it can be seen that it is made primarily from a combination of a calcareous material, such as limestone or chalk, and of silica and alumina found as clay or shale. The process of manufacture consists essentially of grinding the raw materials into a very fine powder, mixing them intimately in predetermined proportions and burning in a large rotary kiln at a temperature of about 1400 °C (2550 °F) when the material sinters and partially fuses into clinker. The clinker is cooled and ground to a fine powder, with some gypsum added, and the resulting product is the commercial Portland cement used throughout the world.

The mixing and grinding of the raw materials can be done either in water or in a dry condition; hence, the names wet and dry process. The mixture is fed into a rotary kiln, sometimes (in the wet process) as large as 7 m (23 ft) in diameter and 230 m (750 ft) long. The kiln is slightly inclined. The mixture is fed at the upper end while pulverized coal (or

other source of heat) is blown in by an air blast at the lower end of the kiln, where the temperature may reach about 1500 °C (2750 °F). The amount of coal required to manufacture one tonne (2200 lb) of cement is between 100 kg (220 lb) and about 350 kg (770 lb), depending on the process used.

As the mixture of raw materials moves down the kiln, it encounters a progressively higher temperature so that various chemical changes take place along the kiln. First, any water is driven off and CO_2 is liberated from the calcium carbonate. Further on, the dry material undergoes a series of chemical reactions until, finally, in the hottest part of the kiln, some 20 to 30 per cent of the material becomes liquid, and lime, silica and alumina recombine. The mass then fuses into balls, 3 to 25 mm ($\frac{1}{8}$ to 1 in.) in diameter, known as clinker.

Afterwards, the clinker drops into coolers, which provide means for an exchange of heat with the air subsequently used for the combustion of the pulverized coal. The cool clinker, which is very hard, is interground with gypsum in order to prevent flash-setting of the cement. The ground material, that is cement, has as many as 1.1×10^{12} particles per kilogramme (0.5×10^{12} per lb).

A single kiln of modern design (using the dry process) can produce as much as 6200 tonnes of clinker a day. To put this figure into perspective we can quote the annual cement production figures for 1984: 70 million tonnes in the US and 13.5 million tonnes in the UK. Expressing the cement consumption (which is not the same as production because of imports and exports) in another way, we can note that, in 1984, the quantity of cement per capita was 325 kg (716 lb) in US and 244 kg (537 lb) in UK; the highest consumption in a large industrialized country was 678 kg (1494 lb) in Italy. Another figure of interest is the consumption of about 2000 kg (4400 lb) per capita in Saudi Arabia, Qatar and United Arab Emirates.

Basic chemistry of cement

We have seen that the raw materials used in the manufacture of Portland cement consist mainly of lime, silica, alumina and iron oxide. These compounds interact with one another in the kiln to form a series of more complex products, and, apart from a small residue of uncombined lime which has not had sufficient time to react, a state of chemical equilibrium is reached. However, equilibrium is not maintained during cooling, and the rate of cooling will affect the degree of crystallization and the amount of amorphous material present in the cooled clinker. The properties of this amorphous material, known as glass, differ considerably from those of crystalline compounds of a nominally similar chemical composition. Another complication arises from the interaction of the liquid part of the clinker with the crystalline compounds already present.

Nevertheless, cement can be considered as being in frozen equilibrium, i.e. the cooled products are assumed to reproduce the equilibrium

Mar 15

CE201 Sept 2015 : Lecture 4-5 #11

BANGLADESH UNIVERSITY OF ENGINEERING AND TECHNOLOGY (BUET)

DEPARTMENT OF CIVIL ENGINEERING

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BRTC Bureau of Research, Testing & Consultation

CONCRETE LABORATORY

BRTC No. : 1100-16957/11-12/CE; 24/8/2011

Sent by : Quality Assurance & Environment Manager, Heidelberg Cement Bangladesh Ltd., SYMPHONY, Gulshan, Dhaka

Ref. No. : Letter; 24/8/2011

Project : -

Sample : Cement [Brand name: LOOSE/RUBY; ID: P- August,' 11] Our ID: MS-129

Date of Casting : 27/8/2011

Test Results of Portland Composite Cement (PCC)

ASTM C109	Age	3 days	7 days	28 days
	Date	30-Aug-11	3-Sep-11	24-Sep-11
Compressive strength, psi (MPa)	In figure	**2270 psi** (15.7 MPa)	**3400 psi** (23.4 MPa)	**5310 psi** (36.6 MPa)
	In words	Two thousand two hundred seventy	Three thousand four hundred	Five thousand three hundred ten
Standard Requirements for PCC Type-IP/IS ASTM C595 ✓		1890 psi 13.0 MPa	2900 psi 20.0 MPa	3620 psi 25.0 MPa
Mixing water temperature		22 °C	Curing water temperature	20.5 - 25°C

→ specification

Water for Normal Consistency ASTM C187	Initial setting time (minutes) ASTM C191		Final setting time (minutes) ASTM C191	
	Standard requirement, ASTM C595 ✓	Test result	Standard requirement, ASTM C595 ✓	Test result
24%	Not less than 45 min.	**139**	Not more than 420 min.	**423**

specification

Fineness (specific surface), m²/kg ASTM C204 (air permeability method)	
✓ Standard requirement, ASTM C595	Test result
****	****

Wt. of Cement Bag = ****

Note: Sample was received in unsealed condition.

Countersigned *by*:

Test performed *by*:

Dr. Md. Shamsul Hoque, Professor

Dr. Md. Mazharul Hoque, Professor

Important Notes: Samples as supplied to us have been tested in our laboratory. BRTC does not have any responsibility as to the representative character of the samples required to be tested. It is recommended that samples are sent in a secure and sealed cover/packet/container under signature of the competent authority. In order to avoid fraudulent fabrication of test results, it is recommended that all test reports are collected by duly authorized person, and not by the Contractor/Supplier.

Lecture 6-7 #12

Concrete; Components; Concrete properties, Tests and Specifications

CONCRETE:

- Definition & History
- Characteristics of Concrete
- Classification of Concrete
- Concrete as a Material
- Concrete Components
- Concrete Mix Design and Production
- Concrete Curing
- Properties
- Tests and Specifications

Defn. & History:

- Any mass or product made by the use of a cementing medium – product of reaction between hydraulic cement and water

- forms the basis of our modern society
- as old as the manufacture of cement and cementitious materials

– basically mixture of aggregates bound by the hydrated cement paste.

Characteristics:

- Should have required compressive strength
- On hardening should exhibit minimum shrinkage
- Must be adequately dense
- Should be economical
- Must be adequately durable
- Should have minimum thermal expansion
- Should provide the required finish
- Should have sufficient water tightness
- Should have minimum creep

Classification of Concrete: According to design,

- Plain cement concrete
- Reinforced cement concrete (RCC)
- Pre-stressed cement concrete (PCC)
-

According to purpose

- LW concrete, for precast struc. Units for partition and wall lining
- Cellular or aerated concrete, for roof slab, precast units, heat and sound insulation
- Sawdust concrete, for heat and sound insulation
- Vacuum concrete, for extra strength in rcc
- White & coloured concrete, for ornamental, road parking
- High early strength concrete, construction in cold weather
- No-fines concrete, saves cement, good insulator for sound, does not segregregate

Concrete Production: Production of good concrete also depends on,

- Mixing of concrete – types, hand and machine mixing, 1 min for 1 m^3 plus ¼ min for add $1m^3$, or 20 revolutions of mixer per batch
- Transportation of concrete –must be transported to the place of final placement ASAP by a suitable method [by buckets or by pumps] so that segregation does not occur
- Placement of concrete –should be placed in its required position and should not be thrown or dumped from distance, in layers which will follow one another
- Compaction of concrete – process of consolidating concrete after placing in position, manually by steel rod and mechanically by using vibrators

Testing of Concrete:

- On fresh concrete
  - Workability
  - Wet unit weight
- On hardened concrete
- Laboratory tests
  - Compressive strength
    - On cylinders, 100mmx200mm, 150mmx300mm
    - On cubes, 100mm, 150mm
  - Tensile strength
    - Split cylinder test
    - Flexure test on beam
  - Pull out tests
- Field tests
  - On cores of 50mm, 75mm, 100mm diameter visualization – কেমন crack আছে কিনা
- Non-destructive tests of concrete
  - Rebound test – to estimate compressive strength
  - Dynamic or vibration tests – to estimate strength and elastic properties
  - Radioactive or nuclear methods – to determine moisture and cement content
  - Magnetic or electric methods – to determine cover, reinforcement, thickness etc ray, electricity pass করে

assumed value দিবে core test করলে value দিবে

Specifications: as mentioned in different projects ✗

Questions: [ref. sheet of concrete]

What is concrete? What are the characteristics of good concrete?

What are the components of concrete and their functions?

What are the factors affecting the properties of concrete?

What is workability? How do you measure workability?

Why is curing needed? What are the methods?

#13

CE 201 : Sept 2015
Lecture 7

CONCRETE

Cement Concrete:

Cement + Fine Aggregate (Sand) + Coarse Aggregate (Khoa or Stone chips) + Water
(binder) (filler)

PROPERTIES OF FRESH CONCRETE

Fresh Concrete: freshly mixed concrete which can be molded to any shape.

Special Terms:

Segregation: Segregation refers to the separation of the components of fresh concrete resulting in a non-uniform mix. In general it means separation of coarse aggregate from mortar.

Causes: (1) Badly proportioned mix: larger particle size, high proportion of large particles, sufficient matrix (mortar) not available to bind and contain the aggregate; (2) High specific gravity of coarse aggregate; (3) Change in particle shape away from smooth, well rounded particle to odd; (4) Insufficient mix: mixes that are too dry or too wet; (5) Dropping of concrete from heights; (6) Discharge of concrete from a badly designed mixer.

Remedy: (1) Correctly proportioning the mix; (2) Proper handling, transportation, placing, compacting and finishing; (3) Re-mixing the concrete when segregation is observed; (4) Use of air-entraining admixtures

Bleeding: Bleeding is defined as the appearance of water on the surface of concrete, after it has consolidated but before it has set. Water segregates from the mix and thus bleeding is a special form of segregation. It is caused by the inability of the solid constituents (aggregates) of the mix to hold all the mixing water when they settle downwards.

Problems: (1) When bleeding occurs, the top surface of the concrete becomes wet. If this water is trapped by superimposed concrete, porous, weak, non-durable concrete results; (2) If bleeding water is re-mixed during finishing of the top surface (i.e., with a paste that has excess water-cement ratio), a weak wearing surface will be formed; (3) Some rising water may get trapped under large aggregate or reinforcing bars, leaving weak zones in concrete and reducing bond.

Tendency to bleeding depend largely upon the properties of cement and also affected by certain chemical factors. Usually less bleeding occurs when cement has a high alkali content or when $CaCl_2$ is added. In general bleeding can be reduced by: (1) proper proportioning, and uniform and complete mixing; (2) using finer cement; (3) use of air-entraining admixtures; (4) using rich mixes instead of lean mixes; (5) by reducing water content while maintaining an acceptable *workability*. ← remedies of bleeding

Consistency: Consistency is the general term used to indicate the degree of fluidity or degree of mobility (degree of wetness). Wet concrete is more workable than dry concrete, but concretes of the same consistency may vary in workability.

Workability: It is a measure of the amount of work required to place concrete and to compact it thoroughly (i.e., a measure of the ease with which concrete can be compacted). Concrete should be such that it can be transported, placed, and finished sufficiently easily and without segregation. A concrete satisfying all these conditions is said to be workable.

Pg. 1

Factors affecting Workability of Fresh Concrete:

(1) Water content of the mix: The higher the water content, the higher the fluidity. Higher water content increases the ease with which concrete can be compacted, i.e., increases workability. But at the same time, higher water content reduces strength. Higher water content also increases *segregation* and *bleeding*.

Water content (i.e., water-cement ratio) is related to grading of aggregate. Finer particles have more surface area and hence require more water. Therefore, for a given quantity of water and paste, bigger size of aggregate will give higher workability.

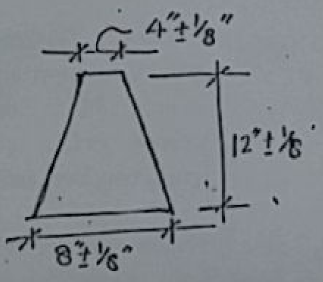
(2) Aggregate mix proportions: Amount of aggregate and relative proportions of fine and coarse aggregate affect workability. For a constant water-cement ratio, as aggregate/cement ratio goes up, workability goes down. A deficiency in fine aggregate (FA) results in "harsh mix" and may lead to

segregation ("Harsh mix is one that lacks desired consistency because of a deficiency in mortar or aggregate fines). An excess of fine aggregate (FA) leads to more permeable and less economical concrete, although the mixture will be easily workable.

(3) Aggregate Properties:
Gradation: A well graded aggregate provides less void in a given volume and increase workability.
Shape and Texture: Rounded and spherical particles produce more workable concrete. Such particles offer less frictional resistance than angular particles. Rough textured, porous aggregates require more water to wet their surface and hence less water will be available to provide workability.

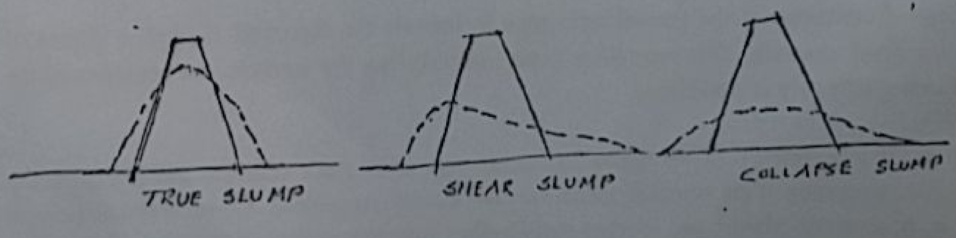
(4) Admixtures: Air-entraining, water reducing and set retarding admixtures will improve workability. (Note: Entrained air acts as fine aggregate of very low surface friction and considerable elasticity).

V. Imp *Measurement of Workability*



Slump Test:

- Concrete is placed in 4 layers in a mold (frustum of a cone) approximately ¼ of the height of the mold.
- Each layer is tamped 25 times by a tamping rod, 5/8" in diameter.
- After the top layer has been rodded, the top layer is struck plain with a trowel.
- The mold is removed by raising it slowly and vertically. This allows the concrete to subside.
- The "subsidence" is referred to as "*Slump*" of concrete.
- When other parameters are kept fixed, *slump* is a function of *water-cement ratio*.



Pg. 2

(6) Curing: Curing is the procedure for promoting hydration of cement during early stages of hardening. It is done to control temperature and flow of moisture from and into the concrete. Hydration proceeds at a maximum rate under condition of saturation. Thus the objective of curing is to keep concrete saturated. The following figure shows effect of moist curing on the strength of concrete.

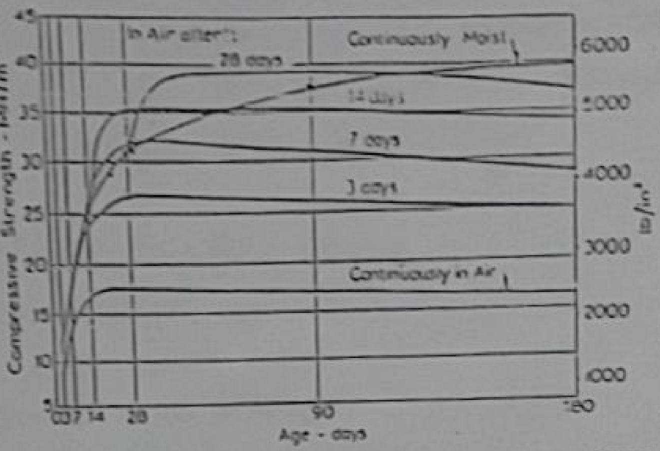


Fig. 1.24. The influence of moist curing on the strength of concrete with a water/cement ratio of 0.50

একটি নির্দিষ্ট cement এর জন্য। cement change হলে graph change হবে।

Evaporation of water from concrete depends on: (i) temperature (absolute temperature and temperature difference between concrete and surrounding surface), (ii) relative humidity (RH), (iii) wind, (iv) surface to volume ratio of concrete specimen.

Methods of Curing

(1) Water Curing: Involves supply of additional moisture, and prevention of moisture loss. It is the most wide used method. In water curing, supply of water can be accomplished by ponding (e.g., provide a layer of water on horizontal surface), spraying, sprinkling or use of saturated covering. Spraying is an excellent method when water is plentiful and runoff is not a problem.

(2) Sealed/Membrane Curing: It involves prevention of loss of moisture. Water-proofing papers, polyethylene and plastic sheets, curing membranes are the most widely used materials for sealed curing.

(3) Steam Curing: It is done in a closed chamber, especially for pre-cast concrete.

Period of Curing: Usually for 7 days for ordinary Portland Cement Concrete.

Effect of Age on Strength: Rate of gain of strength is faster at the beginning and then gets reduced with age. 28-day strength is taken as full strength of concrete, but strength gain occurs slowly beyond 28 days (70-75% in 28 days; 90-95% in one year). Concrete with low w/c ratio gains strength faster than concrete with high w/c ratio. Normally, $f_{c,28} = 1.3$ to $1.7 f_{c,7}$. Usually, $f_{c,7}$ not less than $2/3 f_{c,28}$. In hot climate, early strength gain is high due to quicker hydration reaction and ratio of 28-day to 7-day strength ($f_{c,28}/f_{c,7}$) tend to be lower than that in cooler weather.

Pg. 5

#14
CONCRETE MIX DESIGN

CE 201: Sept. 2015
Lecture 7
L-8-1

Q.1. What is Mix Design? (object of mix design)

– The process of selecting suitable ingredients of concrete and determining their relative quantities with the object of producing, as economically as possible concrete of certain minimum properties notably consistence, strength and durability.

Q. 2. Various Purposes for Mix Design.

i) Approximate design for
- estimating cost
- preparing trial mixes
- checking submitted designs

ii) Safe design for instant use.

iii) Accurate design for safety and economy
- ~~for a single single specifications~~
- for multiple specifications (একই building এ বিভিন্ন কাজে বিভিন্ন ধরনের concrete use করা)
- to meet quality assurance requirements.

iv) Comparisons of performance of different materials or mixes (different ratio)

3. Methods to Suit Purposes for Mix Design.

i) Laboratory trial mix(es)
ii) Full-scale trial mix(es)
iii) Previous production data bank
iv) 'Ready-to use' standard data
v) 'Simplified' methods of design
vi) 'Comprehensive' methods of design

4. Aspects to be Covered by Mix Design Methods

- Workability
- Cohesion
- Plastic density and yeild
- Mix proportions
- Batch quantities
- Strength
- Durability parametus
- Air content
- Special properties e.g. surface finish

L-8-3

#15
CE 201 : Sept 2015
Lecture 7
(M. A. Aziz)

$\frac{W}{C}$, $\frac{C}{A_f + A_c}$, and $\frac{A_f}{A_c}$

and A_c can be found. C represents the cement content in pounds per cubic yard of the concrete and W is the water content in the same units.

When an additional ingredient, such as pozzolana, is present, additional term of similar form is to be added to the Eq 10.9.

When entrained air is present, and its presence is, say p percent of the volume of the concrete, the right hand side of the Eq. 10.9

would read as $27\left(1 - \frac{P}{100}\right)$

If the aggregate contains free moisture whose weight is, say, m per cent of the weight of the dry aggregate, then the weight of the added water W and of (wet) aggregate must be adjusted. The weight of free water in A pound of aggregate is x such that

$$\frac{m}{100} = \frac{x}{A-x} \quad 10.10$$

whence, $x = A \times \frac{m}{100+m}$ 10.11

This weight is added to A to give the weigth of wet aggregate per batch, $A\left(1 + \frac{m}{10+m}\right)$, and is subtracted from W

to give the weight of added water, $W - \frac{Am}{100+m}$

Generally, each size fraction of aggregate has a different moisture content, and the correction should be applied to A_f A_c, etc., with an appropriate value of m.

Combining Aggregates to Obtain Particular Type Grading: While there are no ideal gradings, it is desirable to proportion the available materials in such a way that the grading of the combined aggregate is properly achieved Suppose the gredings of the fine aggregate and two coarse aggregates (size fractions are listed in Table 10.9) are desired to combine the materials so as to appropriate to the coarsest grading According to British standard, 24 percent of the total aggregate should pass though 3/16 inch sieve (B.S.) and 50 per cent through ¾ inch sieve.

Table 10.9 Example of Combining Aggregates to obtain a Type Grading

B.S. Sieve Size	cumulative percentage passing for Fine aggregate (1)	$\frac{3}{16}$-¾ inch (2)	¾-1½ inch (3)	(1) × 1 (4)	(2)×0.94 (5)	(3)×2.59 (6)	(4) + (5) + (6) (7)	Grading of combined aggregates (8)
1½"	100	100	100	100	94	259	453	100
¾"	100	99	13	100	93	34	227	50
⅜"	100	33	8	100	31	21	152	34
3/16"	99	5	2	99	5	5	109	24
No. 7	76	0	0	76	0	0	76	17
No. 14	58			58			58	13
No. 25	40			40			40	9
No. 52	12			12			12	3
No. 100	2			2			2	½

Let x, y and z be the proportions of fine, 3/16 to ¾ inch, and ¾ to 1½ inch aggregates respectively. Then to satisfy the condition that 50 percent of the combined aggregate should pass through ¾ inch B.S. sieve, we have

$$1.0x + 0.99y + 0.13z = 0.5(x+y+z) \quad 10.12$$

The condition that 24 percent of the combined aggregate should pass through 3/16 inch B.S. sieve, can be witten as

$$0.99x + 0.05y + 0.02z = 0.24\,(x+y+z) \quad 10.13$$

From these two equations (Eqs. 10.12 and 10.13), it is found

$$x : y : z = 1 : 0.94 : 2.59 \quad 10.14$$

i.e the aggregates are combined in the proportions 1 : 0.94 : 2.59.

Example: A concrete mix with a mean compressive strength of 5,000 psi at 28 days is required for use in a road slab. Ordinary Portland cement will be used. Compaction will be effected by vibration The aggregate/cement ratio is 7.2.

24 per cent and 50 percent of the total aggregate should pass through 3/16 and ¾ inch B.S. sieves respectively.

বই থেকে বাকি অঙ্ক দেখাতে হবে।

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There are three ways in which any particular ratio of a mix is expressed. They are given below :—

(i) *Real Mix*—This is the ratio expressed on the basis of dry materials as obtained in the design procedure, to give the necessary strength. This in fact is the theoretical ratio, giving the exact quantities of the aggregate and water.

(ii) *Field Mix*—The real mix has to be modified to suit the field conditions, such as moisture in aggregate, state of atmosphere, exact volume of slump, etc.

(iii) *Nominal Mix*—Concrete is generally classified on the basis of certain nominal ratio as suitable for different types of works, as 1 : 1½ : 3; 1 : 2 : 4; 1 : 3 : 6 and 1 : 4 : 8. See Art. No. 224. The actual ratio used for the purpose of measurement of aggregate per unit quantity of cement depends upon the real and field mixes. The nominal mix ratios give a basic distinction between the different grades of concrete.

Art. 236. Design of Concrete Mix—The design of a concrete mix consists in specifying the ratios in which the available types of coarse and fine aggregates should be mixed per bag of cement, to develop a given strength in conrete. There are four different methods used for the purpose :—

(i) Fineness Modulus Method.
(ii) Minimum Voids Method.
(iii) Design by Trial Mixes.
(iv) Arbitrary Method.

1 # **Art. 237. Fineness Modulus Method**—Fineness Modulus Curves : Relation with strength of concrete.

Considering the combined behaviour of the various ingredients of concrete, the design of concrete mix for a specific strength could be based on the following four factors.

(a) *Fineness modulus* of combined or total aggregate.

(b) *Volume of combined* or total *aggregate* to a unit volume of cement.

#17 L-8-4

CE 207: Sep 15 (Aziz, Kalkarni) Lecture 8

Since the strength of concrete depends upon the quantity of cement used, in general, for a unit volume of aggregate, and that since richer mixes are required with the smaller size of the aggregate, relations are established between the size of the aggregate and ratio of cement to aggregate volume, with respect to strength. Thus,

(c) *Size of aggregate* also plays an important part.

(d) *Slump value* for concrete also has to be considered, since the water-cement ratio directly influences the strength.

In figs. 81 and 82 are shown two types of graphs, one for vibrated concrete and the other for concrete consolidated by hand, to explain the relations between the above four factors and strength. This is illustrated in the following example by using the above design graphs.

Fineness Modulus Method

Art. 238. Design of Concrete Mix—It is required to produce concrete of strength of 3000 lbs. per sq. in. after 28 days, using 3/4" aggregate for normal machine-mixed and hand-compacted concrete in R. C. C. work.

Fine aggregate : 3/16" to No.100 size F_{1} = 3.18; river sand.
Coarse aggregate : 3/4" size F_{2} = 6.15; broken stone.
Cement used is "Normal Setting Cement."

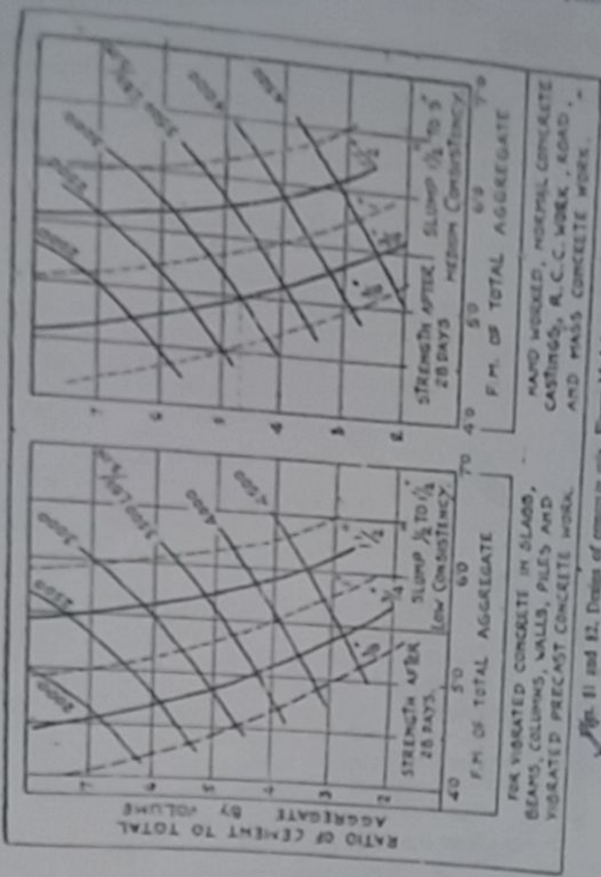
Satisfactory control is exercised on the field conditions. Applying the above data to the graph in fig. 82, and using ¾" aggregate curve, we have, the fineness modulus for the combined aggregate is 5.0 and the volume of compacted combined aggregate is 4.67 for 1 cu. ft. of cement.

Ratio of sand to broken stone.

Real mix. The quantity of sand x is given by—

$$x = \frac{6.15 - 5.00}{5.00 - 3.18} = \frac{1.15}{1.82} = 0.63$$

i. e. if crushed stone = 100 c. ft. then the quantity of sand = 63 c.ft. or, in every 100 cu. ft. of the sum of combined



Figs. 11 and 12. Design of concrete mix. Fineness Modulus method.

aggregate, 38.5 cu. ft is sand and 61.5 cu. ft. is crushed stone. After testing, the shrinkage factor for this ratio is found to be 0.8. Then the compact volume of 4.67 cu. ft. of combined aggregate equals 5.84 cu. ft. of loose aggregate of which 2.25 cu. ft. is sand and 3.57 is crushed stone.

∴ Real Mix ratio is given by—

Cement		Sand		Crushed stone
1	:	2.25	:	3.57 ≈ 08

This falls into the category of 1 : 2 : 4 nominal mix concrete.

To Calculate the Field Mix—If the sand and coarse aggregates are wet, the percentage of moisture in each should be determined, and from the graph, due allowance for bulking for these moisture contents should be made. The ratio has to be then modified. Thus, if for 1 percent moisture in sand and for 3 percent moisture in crushed stone, the respective bulkings are 22 and 8 percent, then the Field Mix Ratio is :—

Cement	Sand	Crushed stone
1	2.75	4.00

Ratio for batch of 1 bag of cement :—

One bag of cement : 3.3 cu. ft. of wet sand : 4.8 cu. ft. wet stone.

The quantity of water required for the mixture could be determined from the relations between the water-cement ratio and slump. Due allowance should be made for the moisture present in the aggregate. The quantity of water is expressed in gallons per bag of cement.

2 # **Art. 239. Minimum Voids Method**—This method is based on the assumption that the fine aggregate fills in the voids of the coarse aggregate and that cement fills in the voids of the fine aggregate. In this case it is generally necessary that about 5 to 10 percent more of fine aggregate and cement should be used than that indicated by the voids in each, to ensure a proper filling and a dense concrete. A higher value has to be allowed for ...

16 Joya

CE - 2/1

Jukma siz

22(?) 2...

Set - (2)

Lecture 8:

Concrete Mix Design, Factors, Blending of Aggregates, Mix Design: Old Methods; Statistics and Quality Control for Concrete Mix Design

CONCRETE MIX DESIGN:

1. What is mix design?
2. Purposes of mix design
3. Methods to suit purposes for mix design
4. Aspects to be covered by mix design
5. Basic factors in the process of mix design
6. Variable factors for Normal Structural Concrete
7. Mix ratios
8. Mix design old methods

1 – 7: as in sheet supplied [Sheet # 14]

Blending of Aggregates:

Blending of aggregates means combining aggregates of different grading to get a type or specified grading. This can be done by

- Trial and error method
- Graphical method
- Equation method

Reference: Dr. MA Aziz, AM Nevile Chapter 10

Concrete Strength:

The strength to be developed in a hardened concrete is a variable quantity. The source of variability are:

- Variations in mix ingredients
- Variations in concrete
  - Making
  - Placing
  - Curing and
  - Testing
- Variations in sampling procedure
- Variations in testing procedure

Q. Why does the concrete strength vary?

Quality Control:

The process of taking measures in order to minimize the variability in the resultant product of any construction material is called quality control.

Strength requirement for mix design:

[In ideal condition, strength of concrete at any point of the structure should be higher than the minimum required strength.]

[In UK, this minimum strength is called f_{min}, the specified characteristic strength or characteristic strength.]

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
  - Target mean strength, f_m in UK and [British Method]
  - Reqd. avg. strength or reqd. avg. comp. strength, f'_{cr} in USA [ACI method]

** 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.

Statistical Behaviour of Concrete: [sheet # 18]

Statistical Terms:

- Normal distribution curve, comp. strength of concrete
- Mean strength
- Variance
- Standard deviation
- Coefficient of variance

** Mix ratios are always as - **Cement : Fine Agg. : Coarse Agg.**

S# 18

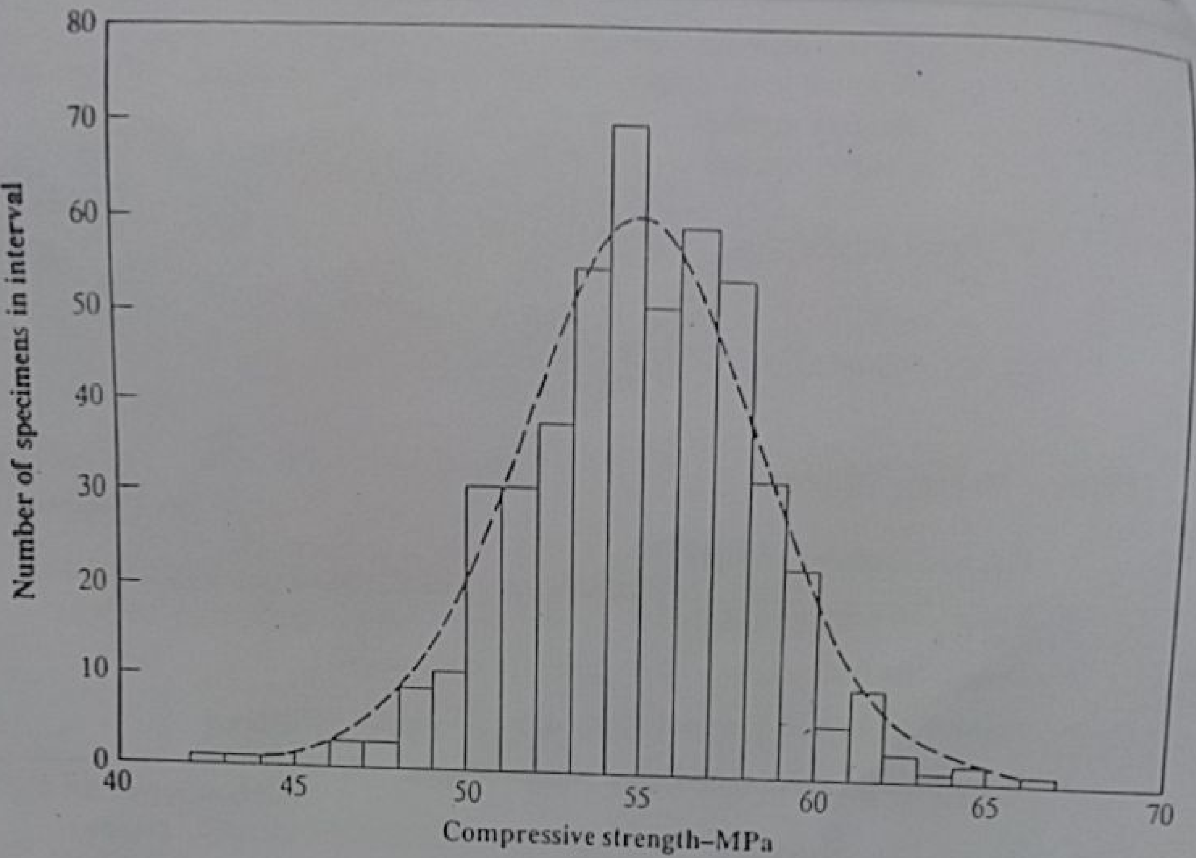


Fig. 17.1: A histogram of strength values

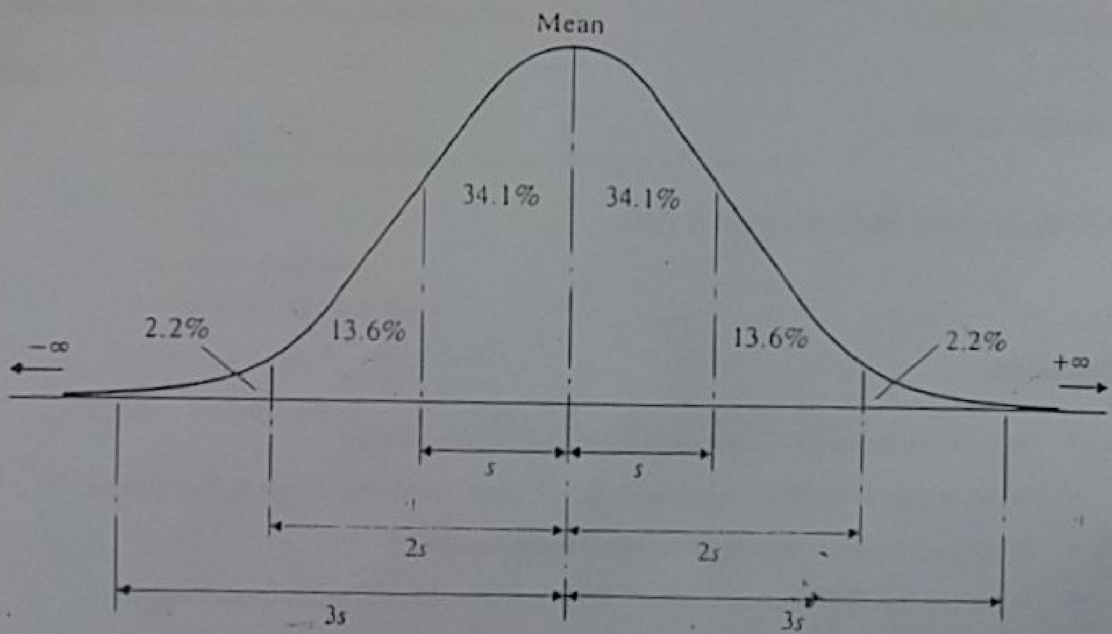


Fig. 17.2: Normal distribution curve; percentage of specimens in intervals of one standard deviation shown

concrete strength 3s পর্যন্ত কমবা বেশি হতে পারে। তাই যাতে কোন point এই এর মান min এর চেয়ে কম না হয় এজন্য min strength এর সাথে 3s + করে design করতে হবে।

6

Lecture 3:

Concrete Mix Design: British Method of Mix Design

Strength Determination for Mix Design

- In ideal condition, strength of concrete at any point of the structure should be higher than the minimum required strength.

- In UK, this minimum strength is called f_{min}, the specified characteristic strength or characteristic strength.

- 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
  - Target mean strength, f_m in UK and
  - Reqd. avg. strength or reqd. avg. comp. strength, f'_{cr} in USA

Design করার সময় required এর চেয়ে একটু বেশি পরিমাণ strength নিয়ে কাজ করব, সেটাই fm.

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

** In British method, this additional strength is called **margin**, $M = k.s$

- k= Himsworth constant, and
- s= standard deviation

∴ Target mean strength, $f_m = f_c + k.s$

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

Statistical Behaviour of Concrete: (sheet # 18)

Statistical Terms:
- Normal distribution curve, comp. strength of concrete
- Mean strength
- Variance
- Standard deviation
- Coefficient of variance

SALIENT FEATURES FOR BS METHOD

- Design of normal concrete mixes – 2nd edition 1997
  - British method (1987)
  - Current British method (1981)
  - Modified Road Note No.4 method

- Developed by Teychenne D C, Franklin R E and Entroy H C
- The principle of the method is to obtain mix proportion in an attempt to produce concrete having the required
  - Workability
  - Strength

- The method employs
  - Target mean strength
  - Slump or V-B value for workability in mm (slump value)
  - Free water to cement ratio (w/c)
  - SSD coarse and fine aggregate
  - Fine aggregate grading (BS 882)

- Results of the method are
  - Kg of coarse aggregate
  - Kg of fine aggregate
  - Kg of cement, and
  - Kg of water, for 1 cubic metre of fresh concrete

Mix Design Process:

Mix design is done in five stages,

Stage 1: Selection of target water/cement ratio using,

- Characteristic strength, given
- Standard deviation, from Fig. 3
- Value of 'k' which depends on % defectives
  - *For 10% defectives, k=1.28*
  - *For 5% defectives, k=1.64*
  - *For 2.5% defectives, k=1.96*
  - *For 1% defectives, k=2.33*

k=3
3s হলে হয়, যাতে কোন point এ stress কমানা পরে। কিন্তু এটা economical না। তাই,
f_m =

- Target mean strength, $f_m = f_c + k.s$
- Aggregate type and cement type
- Approx. compressive strength for w/c=0.5 from Table 2
- **Result of stage 1 is w/c from Fig.4**

So, we need characteristic strength, value of 's' from Fig.3, value of 'k'; Table 2 and Fig. 4

Stage 2: Selection of free water content, from

- Aggregate type, crushed or uncrushed
- Aggregate maximum size, 10mm, 20mm, 40mm
- Slump, mm or V-B, sec
- **Result of stage 2 is approx. free water content (kg/m^3) from Table 3**

Stage 3: Determination of cement content

Cement content = result of stage 2 / result of stage 1

W/C from Stage 1, and 'W' from Stage 2 Therefore C= .....

Stage 4:

The method employs

○ Tar...

Mix Design Problem - British Method

Math

A concrete is to be manufactured for casting of superstructure elements of a girder bridge. Design stipulations are as follows:

Characteristic strength = 43 MPa $= f_c$

More than 40 results of cube strengths are available

Moderate quality control is expected i.e 5% defectives is allowed

Aggregate type = crushed gravel

Maximum size of aggregate = 20 mm

Cement type: OPC [Ordinary Portland Cement]

Workability is measured by slump and is 10 – 30 mm

Maximum free water cement ratio is 0.50

Minimum cement content is 350 kg/m^3

Relative density of combined aggregate on SSD basis is 2.62

Fine aggregate grading comprises with grading zone 2 of BS 882 [nearly centerline]

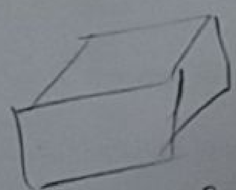
$f_m = f_c + ks$
$= 43 + 1.64 \times 4$
$= 49.56$

BS m

a) Find the ingredients for 1m^3 of fresh concrete

b) If the absorption of fine and coarse aggregates are 2 and 1 percent respectively, find the quantities of the ingredients considering oven-dry aggregates for a trial mix for casting nine 150 mm cubes.

Figures and Tables are required for the solution.



$(0.15)^3$

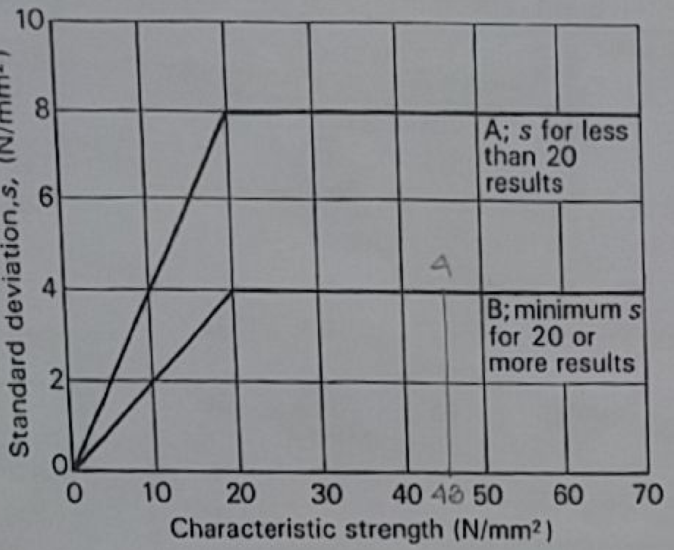


Figure 3
Relationship between standard deviation and characteristic strength

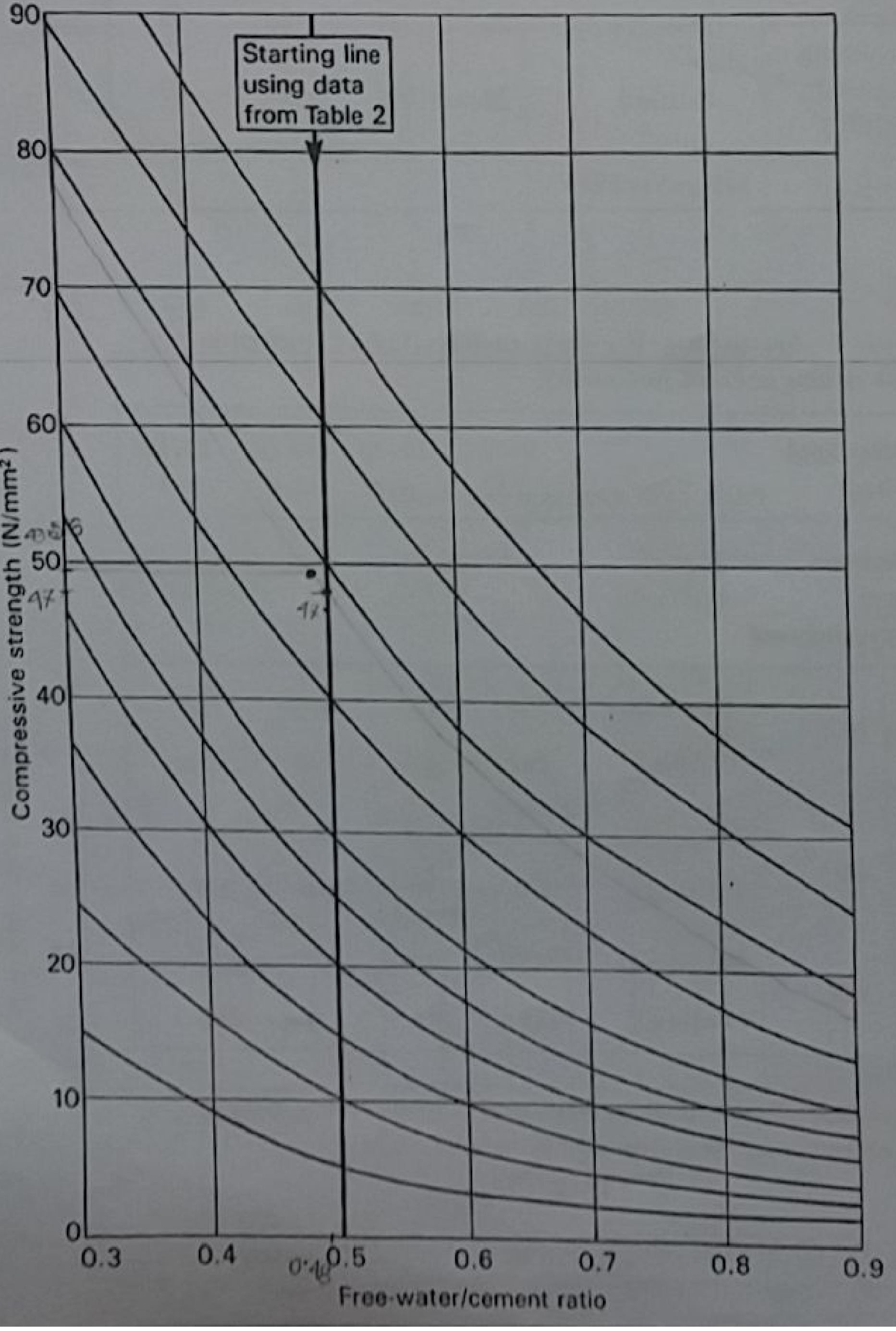


Figure 4
Relationship between compressive strength and free-water/cement ratio

Table 2 Approximate compressive strengths (N/mm²) of concrete mixes made with a free-water/cement ratio of 0·5

Type of cement	Type of coarse aggregate	Compressive strengths (N/mm²) Age (days) 3	7	28	91
Ordinary Portland (OPC) or sulphate-resisting Portland (SRPC)	Uncrushed	18	27	40	48
	Crushed	23	33	47	55
Rapid-hardening Portland (RHPC)	Uncrushed	25	34	46	53
	Crushed	30	40	53	60

$1 N/mm^2 = 1 MN/m^2 = 1 MPa$

Table 3 Approximate free-water contents (kg/m³) required to give various levels of workability

Slump (mm) V-B (s)		0–10 >12	10–30 6–12	30–60 3–6	60–180 0–3
Maximum size of aggregate (mm)	Type of aggregate				
10	Uncrushed	150	180	205	225
	Crushed	180	205	230	250
20	Uncrushed	135	160	180	195
	Crushed	170	190	210	225
40	Uncrushed	115	140	160	175
	Crushed	155	175	190	205

Note: When coarse and fine aggregates of different types are used, the free-water content is estimated by the expression

$$\frac{2}{3} W_f + \frac{1}{3} W_c$$

where W_f = Free-water content appropriate to type of fine aggregate
and W_c = free-water content appropriate to type of coarse aggregate.

Lecture 10: #21

Jaya
Zakaria Sir
CE = 2-1 set ③
Sheet # 21, 22

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
  - strength
  - durability
  - density and
  - 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

p = cement like material
= cementitious "
exp - 8 lab sheet
" - 9

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

pcc – cement + Flyash/ pozzolona

...formation, estimates given in ACI 211.1-91 may be employed

- 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

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 water

- 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

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

$f_{avg} = f_c + M$
Margin ↑

- 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 BD mostly used

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

Step 5: Calculation of cement content C

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

Client বলে দিবে → আমরা আগে বের করব then client-এর requirement অনুযায়ী check করব

CA **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%

Step 7: Estimation of fine aggregate content FA by weigh method (similar to BS method)

- 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

in most cases Agg. AD condition এ থাকবে।

pumping concrete হলে → reduce করতে হয় CA by 10%, কারণ High workability প্রয়োজন পড়ে। তখন পানি বাড়াতে হয় ও CA কমাতে হয়

Example: Page 14 – sheet supplied

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cold weather, and the presence of chemical admixtures not formulated especially for acceleration.

Because of the possible adverse effects on finishing time and consequent labor costs, in some cold climates the proportion of other cementitious materials in the blend may have to be reduced below the optimum amount for strength considerations. Some Class C fly ashes may affect setting time while some other cementitious materials may have little effect on setting time. Any reduction in cement content will reduce heat generation and normally prolong the setting time.

ACI 211.1-91 (2002) Dec 2015.

CHAPTER 5 -- BACKGROUND DATA

5.1 To the extent possible, selection of concrete proportions should be based on test data or experience with the materials actually to be used. Where such background is limited or not available, estimates given in this recommended practice may be employed.

5.2 The following information for available materials will be useful:

5.2.1 Sieve analyses of fine and coarse aggregates.

5.2.2 Unit weight of coarse aggregate.

5.2.3 Bulk specific gravities and absorptions of aggregates.

5.2.4 Mixing-water requirements of concrete developed from experience with available aggregates.

5.2.5 Relationships between strength and water-cement ratio or ratio of water-to-cement plus other cementitious materials, for available combinations of cements, other cementitious materials if considered, and aggregates.

5.2.6 Specific gravities of portland cement and other cementitious materials, if used.

5.2.7 Optimum combination of coarse aggregates to meet the maximum density gradings for mass concrete as discussed in Section 5.3.2.1 of Appendix 5.

5.3 Estimates from Tables 6.3.3 and 6.3.4, respectively, may be used when items in Section 5.2.4 and Section 6.3.5 are not available. As will be shown, proportions can be estimated without the knowledge of aggregate-specific gravity and absorption, Section 5.2.3.

CHAPTER 6 -- PROCEDURE

6.1 The procedure for selection of mix proportions given in this section is applicable to normal weight concrete. Although the same basic data and procedures can be used in proportioning heavyweight and mass concretes, additional information and sample computations for these types of concrete are given in Appendixes 4 and 5, respectively.

6.2 Estimating the required batch weights for the concrete involves a sequence of logical, straightforward steps which, in effect, fit the characteristics of the available materials into a mixture suitable for the work. The question of suitability is frequently not left to the individual selecting the proportions. The job specifications may dictate some or all of the following:

6.2.1 Maximum water-cement or water-cementitious material ratio.

6.2.2 Minimum cement content.

6.2.3 Air content.

6.2.4 Slump.

6.2.5 Maximum size of aggregate.

6.2.6 Strength.

6.2.7 Other requirements relating to such things as strength overdesign, admixtures, and special types of cement, other cementitious materials, or aggregate.

6.3 Regardless of whether the concrete characteristics are prescribed by the specifications or are left to the individual selecting the proportions, establishment of batch weights per yd^3 of concrete can be best accomplished in the following sequence:

6.3.1 *Step 1. Choice of slump* -- If slump is not specified, a value appropriate for the work can be selected from Table 6.3.1. The slump ranges shown apply when vibration is used to consolidate the concrete. Mixes of the stiffest consistency that can be placed efficiently should be used.

Table 6.3.1 — Recommended slumps for various types of construction*

Types of construction	Slump, in. Maximum†	Slump, in. 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.

6.3.2 *Step 2. Choice of maximum size of aggregate* -- Large nominal maximum sizes of well graded aggregates have less voids than smaller sizes. Hence, concretes with the larger-sized aggregates require less mortar per unit volume of concrete. Generally, the nominal maximum size of aggregate should be the largest that is economically available and consistent with dimensions of the structure. In no event should the nominal maximum size exceed one-fifth of the narrowest dimension between sides of forms, one-third the depth of slabs, nor three-fourths of the minimum clear spacing between individual reinforcing bars, bundles of bars, or pretensioning strands. These limitations are sometimes waived if workability and methods of consolidation are such that the concrete can be placed without honeycomb or void. In areas congested with reinforcing steel, post-tension ducts or conduits, the proportioner should select a nominal maximum size of the aggregate so concrete can be placed without excessive segregation, pockets, or voids. When high strength concrete is desired, best results may be obtained with reduced nominal maximum sizes of aggregate since these produce higher strengths at a given water-cement ratio.

ACI MANUAL OF CONCRETE PRACTICE : PART-1-2008
BUET Central Library : No. 106016 dt. 10/01/09. [Pg. 1-7 to Pg. 1-18 for L2T1 : Dec. 2015]

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

Slump, in.	Water, lb/yd³ of concrete for indicated nominal maximum sizes of aggregate							
	3/8 in.*	1/2 in.*	3/4 in.*	1 in.*	1-1/2 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**,††

*The quantities of mixing water given for air-entrained concrete are based on typical total air content requirements as shown for "moderate exposure" in the table above. These quantities of mixing water are for use in computing cement contents for trial batches at 68 to 77 F. They are maximum for reasonably well-shaped angular aggregates graded within limits of accepted specifications. Rounded aggregate will generally require 30 lb less water for non-air-entrained and 25 lb less for air-entrained concretes. The use of water-reducing chemical admixtures, ASTM C 494, may also reduce mixing water by 5 percent or more. The volume of the liquid admixtures is included as part of the total volume of the mixing water. The slump values of more than 7 in. are only obtained through the use of water-reducing chemical admixture; they are for concrete containing nominal maximum size aggregate not larger than 1 in.

†The slump values for concrete containing aggregate larger than 1½ in. are based on slump tests made after removal of particles larger than 1½ in. by wet-screening.

‡These quantities of mixing water are for use in computing cement factors for trail batches when 3 in. or 6 in. nominal maximum size aggregate is used. They are average for reasonably well-shaped coarse aggregates, well-graded from coarse to fine.

§Additional recommendations for air-content and necessary tolerances on air content for control in the field are given in a number of ACI documents, including ACI 201, 345, 318, 301, and 302. ASTM C 94 for ready-mixed concrete also gives air-content limits. The requirements in other documents may not always agree exactly, so in proportioning concrete consideration must be given to selecting an air content that will meet the needs of the job and also meet the applicable specifications.

**For concrete containing large aggregates that will be wet-screened over the 1½ in. sieve prior to testing for air content, the percentage of air expected in the 1½ in. minus material should be as tabulated in the 1½ in. column. However, initial proportioning calculations should include the air content as a pecent of the whole.

††When using large aggregate in low cement factor concrete, air entrainment need not be detrimental to strength. In most cases mixing water requirement is reduced sufficiently to improve the water-cement ratio and to thus compensate for the strength-reducing effect of air-entrained concrete. Generally, therefore, for these large nominal maximum sizes of aggregate, air contents recommended for extreme exposure should be considered even though there may be little or no exposure to moisture and freezing.

‡‡These values are based on the criteria that 9 percent air is needed in the mortar phase of the concrete. If the mortar volume will be substantially different from that determined in this recommended practice, it may be desirable to calculate the needed air content by taking 9 percent of the actual mortar volume.

6.3.3 *Step 3. Estimation of mixing water and air content* -- The quantity of water per unit volume of concrete required to produce a given slump is dependent on: the nominal maximum size, particle shape, and grading of the aggregates; the concrete temperature; the amount of entrained air; and use of chemical admixtures. Slump is not greatly affected by the quantity of cement of cementitious materials within normal use levels (under favorable circumstances the use of some finely divided mineral admixtures may lower water requirements slightly -- see ACI 212.1R). Table 6.3.3 provides estimates of required mixing water for concrete made with various maximum sizes of aggregate, with and without air entrainment. Depending on aggregate texture and shape, mixing water requirements may be somewhat above or below the tabulated values, but they are sufficiently accurate for the first estimate. The differences in water demand are not necessarily reflected in strength since other compensating factors may be involved. A rounded and an angular coarse aggregate, both well and similarly graded and of good quality, can be expected to produce concrete of about the same compressive strength for the same cement factor in spite of differences in *w/c* or *w/(c + p)* resulting from the different mixing water requirements. Particle shape is not necessarily an indicator that an aggregate will be either above or below in its strength-producing capacity.

Chemical admixtures -- Chemical admixtures are used to modify the properties of concrete to make it more workable, durable, and/or economical; increase or decrease the time of set; accelerate strength gain; and/or control temperature gain. Chemical admixtures should be used only after an appropriate evaluation has been conducted to show that the desired effects have been accomplished in the particular concrete under the conditions of intended use. Water-reducing and/or set-controlling admixtures conforming to the requirements of ASTM C 494, when used singularly or in combination with other chemical admixtures, will reduce significantly the quantity of water per unit volume of concrete. The use of some chemical admixtures, even at the same slump, will improve such qualities as workability, finishability, pumpability, durability, and compressive and flexural strength. Significant volume of liquid admixtures should be considered as part of the mixing water. The slumps shown in Table 6.3.1, "Recommended Slumps for Various Types of Construction," may be increased when chemical admixtures are used, providing the admixture-absolute volume. The equivalent $w/(c + p)$ ratio by volume will have to be recomputed for this condition since F_v has been changed from that originally assumed in this example

$$\frac{w}{c+p} = \frac{3.15\left(\frac{w}{c}\right)}{3.15(1-F_v) + G_p(F_v)}$$

$$= \frac{(3.15)(0.60)}{3.15(0.75) + 2.40(0.25)}$$

$$= \frac{1.89}{2.36 + 0.60} = \frac{1.89}{2.96} = 0.64$$

Total cementitious material would be 270 ÷ 0.64 = 422 lb. Of this weight 20 percent (F_w = 0.20) would be fly ash; (422)(0.20) = 84 lb of fly ash and 422 - 84 = 338 lb of cement.

6.3.5 *Step 5. Calculation of cement content* -- The amount of cement per unit volume of concrete is fixed by the determinations made in Steps 3 and 4 above. The required cement is equal to the estimated mixing-water content (Step 3) divided by the water-cement ratio (Step 4). If, however, the specification includes a separate minimum limit on cement in addition to requirements for strength and durability, the mixture must be based on whichever criterion leads to the larger amount of cement.

The use of pozzolanic or chemical admixtures will affect properties of both the fresh and hardened concrete. See ACI 212.

6.3.6 *Step 6. Estimation of coarse aggregate content* -- Aggregates of essentially the same nominal maximum size and grading will produce concrete of satisfactory workability when a given volume of coarse aggregate, on an oven-dry-rodded basis, is used per unit volume of concrete. Appropriate values for this aggregate volume are given in Table 6.3.6. It can be seen that, for equal workability, the volume of coarse aggregate in a unit volume of concrete is dependent only on its nominal maximum size and the fineness modulus of the fine aggregate. Differences in the amount of mortar required for workability with different aggregates, due to differences in particle shape and grading, are compensated for automatically by differences in oven-dry-rodded void content.

The volume of aggregate in ft³, on an oven-dry-rodded basis, for a yd³ of concrete is equal to the value from Table 6.3.6 multiplied by 27. This volume is converted to dry weight of coarse aggregate required in a yd³ of concrete by multiplying it by the oven-dry-rodded weight per ft³ of the coarse aggregate.

6.3.6.1 For more workable concrete, which is sometimes required when placement is by pump or when concrete must be worked around congested reinforcing steel, it may be desirable to reduce the estimated coarse aggregate content determined using Table 6.3.6 by up to 10 percent. However, caution must be exercised to assure that the resulting slump, water-cement or water-cementitious materials ratio, and strength properties of the concrete are consistent with the recommendations in Sections 6.3.1 and 6.3.4 and meet applicable project specification requirements.

6.3.7 *Step 7. Estimation of fine aggregate content* -- At completion of Step 6, all ingredients of the concrete have been estimated except the fine aggregate. Its quantity is determined by difference. Either of two procedures may be employed: the weight method (Section 6.3.7.1) or the absolute volume method (Section 6.3.7.2).

6.3.7.1 If the weight of the concrete per unit volume is assumed or can be estimated from experience, the required weight of fine aggregate is simply the difference between the weight of fresh concrete and the total weight of the other ingredients. Often the unit weight of concrete is known with reasonable accuracy from previous experience with the materials. In the absence of such information, Table 6.3.7.1 can be used to make a first estimate. Even if the estimate of concrete weight per yd³ is rough, mixture proportions will be sufficiently accurate to permit easy adjustment on the basis of trial batches as will be shown in the examples.

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. exp 10

These volumes are selected from empirical relationships to produce concrete with a degree of workability suitable for usual reinforced construction. For less workable concrete, such as required for concrete pavement construction, they may be increased about 10 percent. For more workable concrete see Section 6.3.6.1.

†See ASTM C 136 for calculation of fineness modulus.

volume } yard³ — ASI
in³ — BS

Table 6.3.7.1 — First estimate of weight of fresh concrete

Nominal maximum size of aggregate, in.	First estimate of concrete weight, lb/yd³*	
	Non-air-entrained concrete	Air-entrained concrete
3/8	3840	3710
1/2	3890	3760
3/4	3960	3840
1	4010	3850
1 1/2	4070	3910
2	4120	3950
3	4200	4040
6	4260	4110

*Values calculated by Eq. (6-1) for concrete of medium richness (550 lb of cement per yd³) and medium slump with aggregate specific gravity of 2.7. Water requirements based on values for 3 to 4 in. slump in Table 6.3.3. If desired, the estimated weight may be refined as follows if necessary information is available: for each 10 lb difference in mixing water from the Table 6.3.3 values for 3 to 4 in. slump, correct the weight per yd³ 15 lb in the opposite direction; for each 100 lb difference in cement content from 550 lb, correct the weight per yd³ 15 lb in the same direction; for each 0.1 by which aggregate specific gravity deviates from 2.7, correct the concrete weight 100 lb in the same direction. For air-entrained concrete the air content for severe exposure from Table 6.3.3 was used. The weight can be increased 1 percent for each percent reduction in air content from that amount.