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Optimizing Concrete Mix Design

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Optimizing Concrete Mix Design

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Introduction

- Construction Industry is blooming in Hong Kong recently. Numerous projects are in progress include mega infrastructure project, MTRC Railway projects, Hong Kong Housing Authority projects, Government projects, high rise building etc.
- There is an increase in concrete demand.
- More stringent in concrete mix design criteria and requirements.
- Require higher quality of concrete mixes.

Local Projects

➢ Hong Kong – Zhuhai – Macao Bridge Project

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Local Projects

- Hong Kong – Zhuhai – Macao Bridge Project

Local Projects

- Stonecutters Bridge Project

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Local Projects

- Wan Chai Reclamation Project

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Local Projects

- MTRC XRL Project

Local Projects

- Tunneling Works for XRL Project

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Local Projects

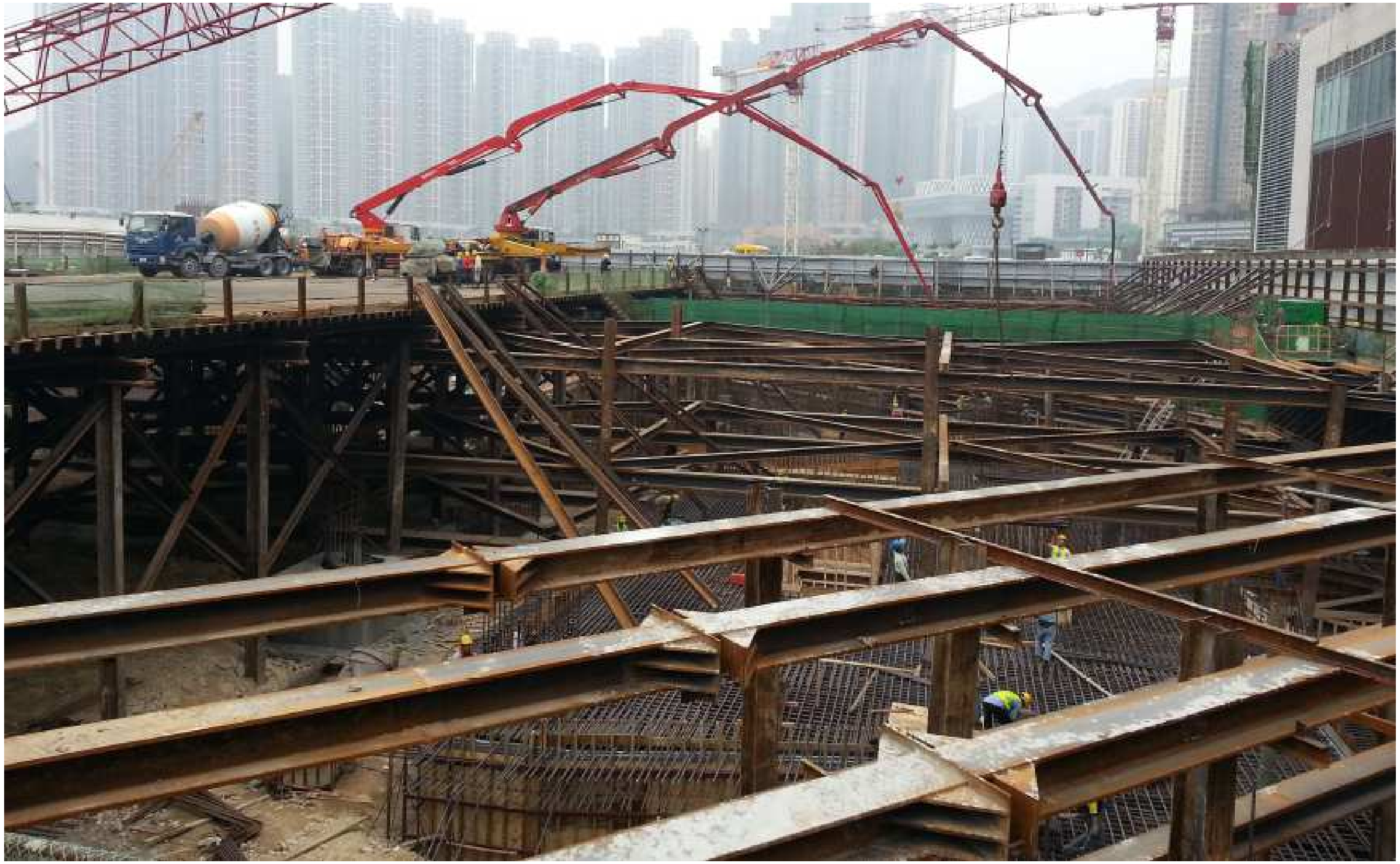
- Highway Project

Local Projects

- International Commercial Centre at West Kowloon

Local Projects

- Foundation Project



Project Requirements in Concrete Design

- In Hong Kong, there are numerous specifications for concrete, major specifications include
  - General Specifications for CEW
  - Building (Construction) Regulations
  - Hong Kong Housing Authority
  - Architectural Services Dept of HKSAR
  - MTRC
  - Hong Kong Electric & China Light Power
  - Ove Arup, AECOM, BV…
  - Various projects' particular specifications……

Project Requirements in Concrete Design

- Different specifications have different concrete design requirements.
- There are inconsistent in the concrete requirements among different specifications. Examples include:
  - Max cementitious content for liquid retaining structure
    - A Particular WSD project - 430kg/m3
    - G.S. - 450kg/m3
    - ASD - 440kg/m3
  - Min cementitious content for Grade 20 Concrete (plain concrete)
    - B.D. - 290kg/m3
    - G.S. - 270kg/m3
    - ASD - 275kg/m3

Project Requirements in Concrete Design

- Recent projects aim for high performance concrete mix design to facilitate the concreting works to suit specific applications.
- Requirements include:
- High compressive strength

  For skyscraper and high rise building to maximize the useable floor area and slim structure
- Durability

  For structure with long design life e.g. 120 years and lower the maintenance cost

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Project Requirements in Concrete Design

- High workability concrete & retention properties

  To facilitate the concreting works and for environmental protection purpose

- Early strength concrete

  To shorten the working cycle and demoulding time

- Low heat of hydration

  For massive structure and prevent thermal effect

Project Requirements in Concrete Design

- Shrinkage reduction

  To minimize shrinkage cracks in water retaining structure

- Anti-corrosion behaviour

  To protect the embedded rebar against corrosion

- Other project special requirements…..

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Project Requirements in Concrete Design

- Examples
- Hong Kong – Zhuhai – Macao Bridge Project
  - Limitation in max cementitious content of 450kg/m3
  - Limitation in max water cement ratio of 0.38
  - Compliance in chloride diffusion test
  - Long workability retention time for marine transportation
  - High PFA content (up to 40%) for durability purpose

Project Requirements in Concrete Design

- Examples
- HATS Project requirements
  - Limitation in max cementitious content of 450kg/m3
  - Limitation in max water cement ratio of 0.38
  - RCPT ≤ 1000 coulombs
  - Sorptivity ≤ 0.07 (mm/min1/2)
  - Long workability retention time for concrete transit
  - Early strength for working cycle including demoulding

Project Requirements in Concrete Design

- Examples
- Highway Project requirements
  - High compressive strength (50MPa)
  - High early strength to reopen the road or minimize the vibration effect (to achieve 12MPa within 4 hours)

Concrete Mix Design

- Concrete mix design is the process to select suitable constituent materials and determine required and specified characteristics of a concrete mixture.
  - Prescriptive approach
  - Performance approach
- Mix design requirements are based on intended use, exposure conditions etc.

Typical Concrete Mix Design Process

- Review of specification requirements for all constraints, e.g. materials, production, and construction methodologies
- Assessing availability of materials
- Selection of materials to ensure the conformity with standard and specifications
- Obtaining data and/or testing of materials
- Identifying influencing of mix design on concrete production and construction materials
- Obtaining approval for mix design

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Basic Factors for Concrete Mix Design

- Grade and strength
- Water cement ratio
- Limitation in max / min cementitious content
- Workability
- Max aggregate size
- Aggregate cement ratio
- Durability considerations (exposure conditions)
- Plastic density
- Applications and construction methods including the spacing of rebar
- Etc..

Methods for Concrete Mix Design

- There are many concrete mix design methods and commonly adopted methods include:
- Building Research Establishment of UK (BRE)
- America Concrete Institute (ACI)
- Volumetric Method

BRE Method

- Formerly developed by British Department of Environment (DOE)
- Applied only for normal weight concrete
- High performance concrete is not covered
- Principle:
  - Use historical and available data
  - Adopt charts and tables

BRE Method

Example:

Specified Requirement

- **For "OPC" Concrete:**

- Characteristic compressive str. (f_c) = 45MPa at 28-day with a 5% defective rate (k = 1.64)
- Design Slump = 100mm
- OPC Class = 52.5N
- Max. aggregate size = 20mm
- Type of fine aggregates = Crushed rock fines
- Relative density of aggregate = 2.7 (SSD condition)
- Past cube compression test result or production data is not available

- **For "OPC + PFA" concrete:**

- Same as above with PFA of proportion (p) = 30%

BRE Method

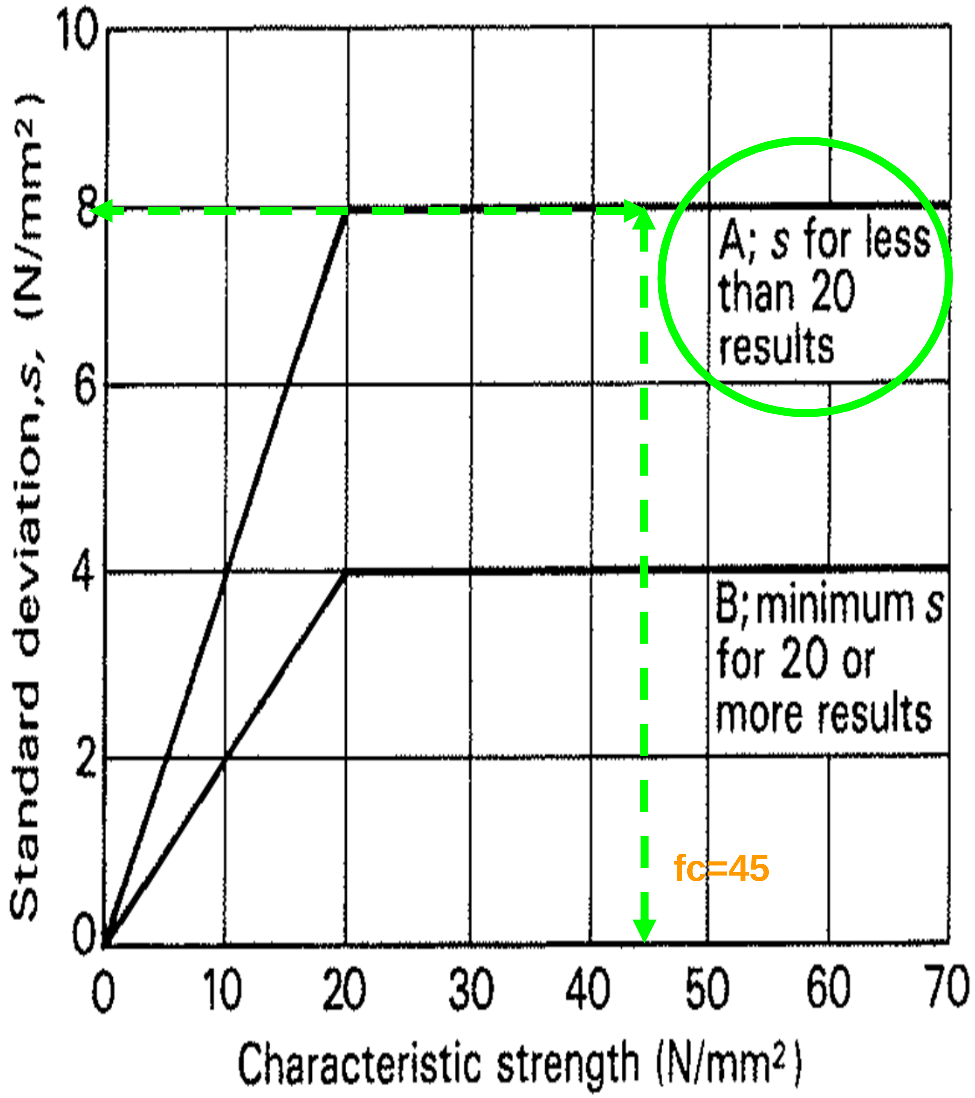

Figure 3

Relationship between standard deviation and characteristic strength

BRE Method

	Mix with OPC	Mix with OPC + PFA (30%)
Step 1: **Target mean strength f_m**	**(Fig. 3)** Margin M = k x s = 1.64 x 8 = 13 MPa Target mean strength $f_m = f_c + M$ = 45 + 13 = 58 MPa	**(Fig. 3)** Margin M = k x s = 1.64 x 8 = 13 MPa Target mean strength $f_m = f_c + M$ = 45 + 13 = 58 MPa

BRE Method

(OPC & OPC+PFA Concrete)

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Table 2 Approximate compressive strengths (N/mm²) of concrete mixes made with a free-water/cement ratio of 0.5

Cement strength class	Type of coarse aggregate	Compressive strengths (N/mm²) Age (days) 3	7	28	91
42.5	Uncrushed	22	30	42	49
	Crushed	27	36	49	56
52.5	Uncrushed	29	37	48	54
	Crushed	34	43	55	61

Throughout this publication concrete strength is expressed in the units N/mm².
1 N/mm² = 1 MN/m² = 1 MPa. (N = newton; Pa = pascal.)

Table 10 Approximate compressive strengths of Portland cement/pfa made with a W/(C + 0.30F) ratio of 0.5

Cement strength class	Type of coarse aggregate	Compressive strength at 28 days (N/mm²)
42.5	Uncrushed	42
	Crushed	49
52.5	Uncrushed	48
	Crushed	55

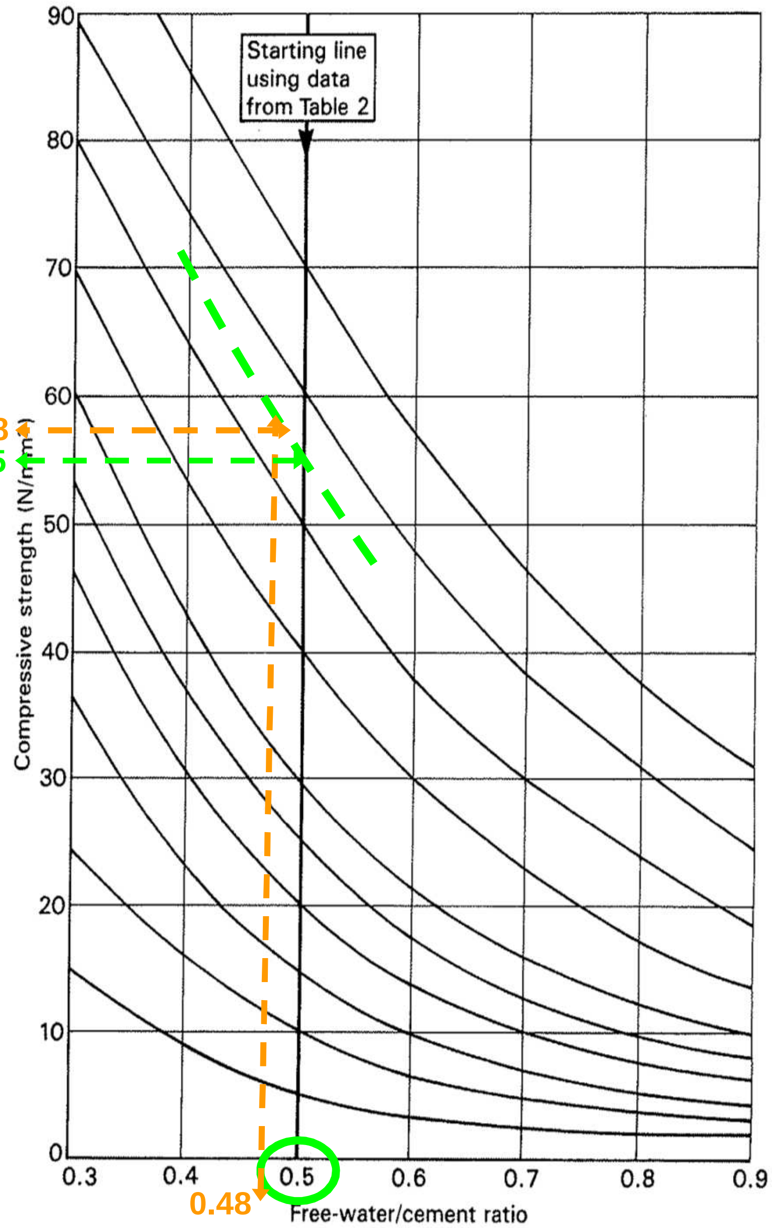

Figure 4
Relationship between compressive strength and free-water/cement ratio

BRE Method

	Mix with OPC	Mix with OPC + PFA (30%)
Step 2: **Selection of target free-water/ cement ratio**	**(Table 2 ; Fig. 4)** Target free-water/cement ratio = 0.48	**(Table 10 ; Fig. 4)** W/(C+eF) where e is cementing efficiency factor = 0.30 F = PFA content Target free W/(C+0.30F) = 0.48

BRE Method

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

Slump (mm)		0–10	10–30	30–60	60–180
Vebe time (s)		>12	6–12	3–6	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:

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

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

Table 9 Approximate free-water contents required to give various levels of workability

Part A: Portland cement concrete

Slump (mm)		0–10	10–30	30–60	60–180
Vebe time (s)		>12	6–12	3–6	0–3
Maximum size of aggregate (mm)	Type of aggregate	Water content (kg/m³)			
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

Part B: Portland cement/pfa concrete

Slump (mm)	0–10	10–30	30–60	60–180
Vebe time (s)	>12	6–12	3–6	0–3
Proportion, p, of pfa to cement plus pfa (%)	Reductions in water content (kg/m³)			
10	5	5	5	10
20	10	10	10	15
30	15	15	20	20
40	20	20	25	25
50	25	25	30	30

BRE Method

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	Mix with OPC	Mix with OPC + PFA (30%)
Step 3: **Selection of free water content (W)**	**(Table 3)** Free water content W = **225 kg/m³**	**(Table 9)** Free water content W = **225 - 20** **= 205 kg/m³**

BRE Method

	Mix with OPC	Mix with OPC + PFA (30%)
Step 4: Determination of cement content (C) PFA content (F) W/(C+F) ratio	Cement content C = 225/0.48 = 469 kg/m^3	Cement content (C) 0.48 = 205 / (C+0.3F) Since F = C /0.7 x 0.3 C = 378 kg/m^3 PFA content (F) F = C/ 0.7 x 0.3 = 162 kg/m^3 Thus, W/(C+F) = 205/(378+162) = 0.38

BRE Method

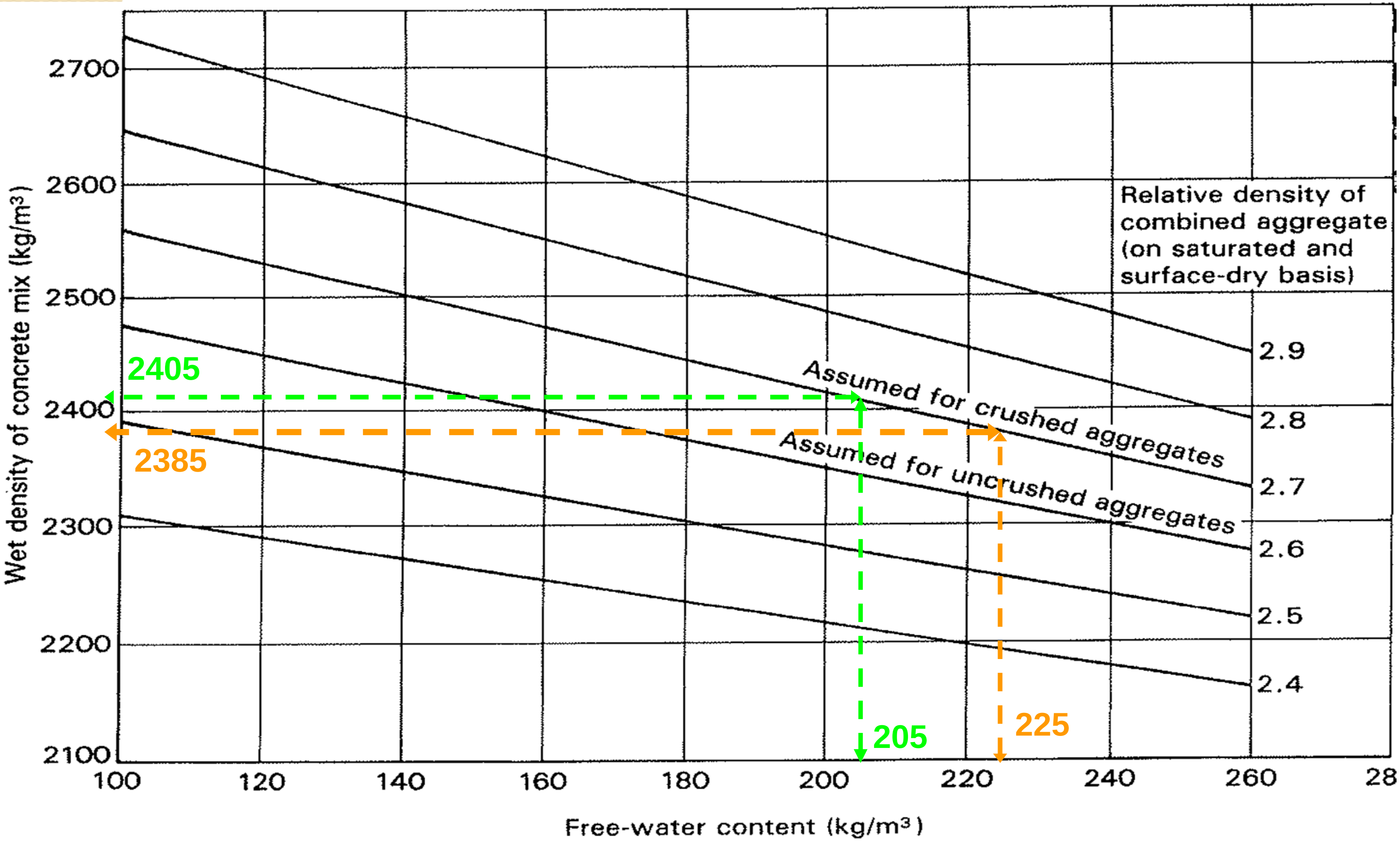

Figure 5 Estimated wet density of fully compacted concrete

BRE Method

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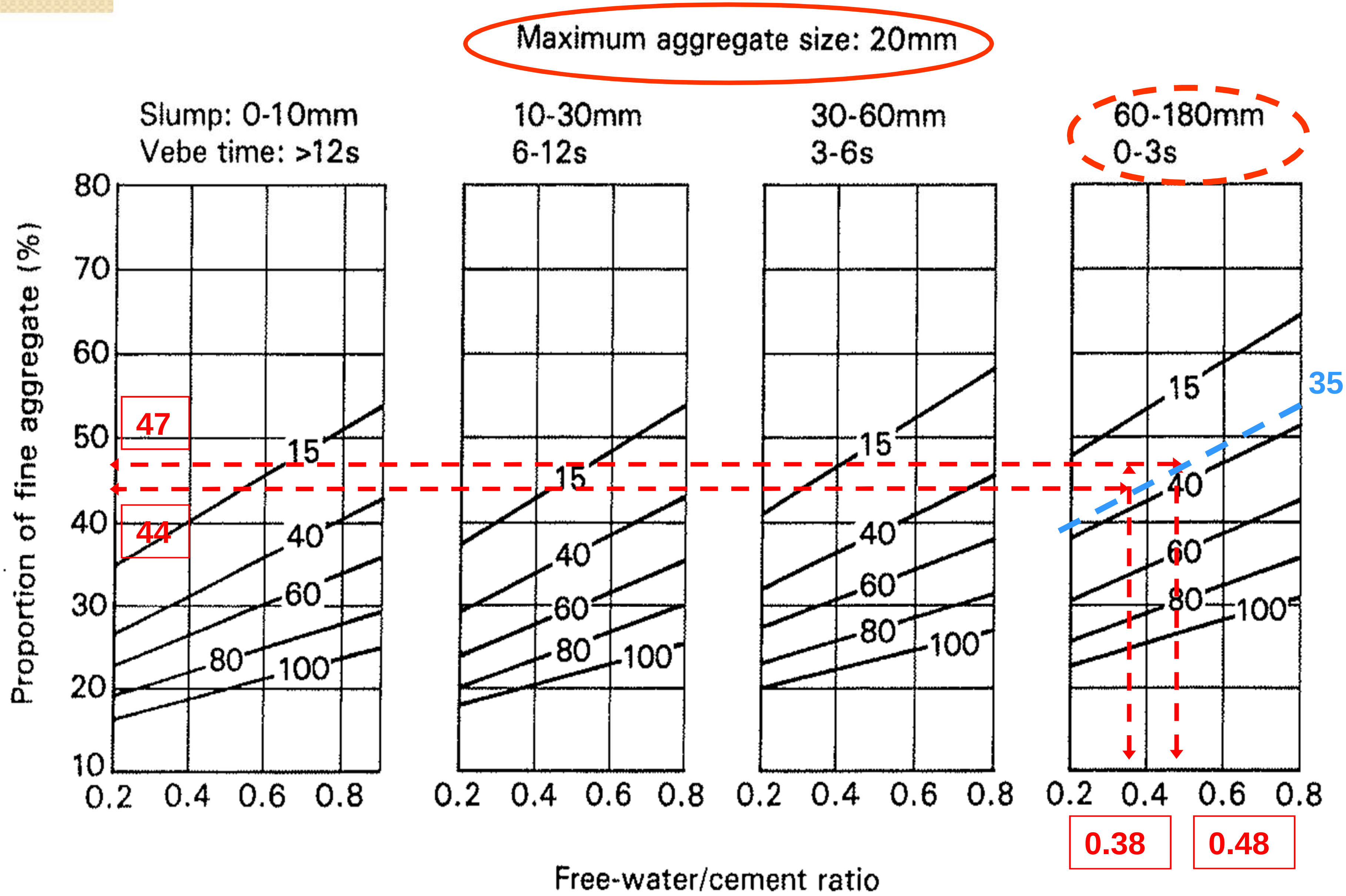
	Mix with OPC	Mix with OPC + PFA (30%)
Step 5: **Determination of total aggregate content (SSD condition)**	**(Fig. 5)** Wet density of concrete D = 2385 kg/m³ Total aggregate content (SSD) = D - C - W = 2385 - 469 – 225 = 1691 kg/m³	**(Fig. 5)** Wet density of concrete D = 2405 kg/m³ Total aggregate content (SSD) = D - C - F - W = 2405 - 378 - 162 - 205 = 1660 kg/m³

BRE Method



Maximum aggregate size: 20mm
Slump: 0-10mm
Vebe time: >12s
10-30mm
6-12s
30-60mm
3-6s
60-180mm
0-3s
Proportion of fine aggregate (%)
80
70
60
50
40
30
20
10
47
44
35
15
40
60
80
100
0.2
0.4
0.6
0.8
0.38
0.48
Free-water/cement ratio

BRE Method

	Mix with OPC	Mix with OPC + PFA (30%)
Step 6: **Selection of fine and coarse aggregate contents**	**(Fig. 6)** Proportion of fine aggregate = 47% Fine aggregate content = 1691 x 0.47 = 795 kg/m^3 Coarse aggregate content = 1691 - 795 = 896 kg/m^3 20mm : 10mm $\simeq$ 2 : 1 20mm = 896 x 2/3 = 597 kg/m^3 10mm = 896 x 1/3 = 299 kg/m^3	**(Fig. 6)** Proportion of fine aggregate = 44% Fine aggregate content = 1660 x 0.44 = 730 kg/m^3 Coarse aggregate content = 1660 - 730 = 930 kg/m^3 20mm : 10mm $\simeq$ 2 : 1 20mm = 930 x 2/3 = 620 kg/m^3 10mm = 930 x 1/3 = 310 kg/m^3

BRE Method

	Mix with OPC	Mix with OPC + PFA (30%)
Preliminary Mix Design Proportion	OPC = 469 kg/m³ 20mm = 597 kg/m³ 10mm = 299 kg/m³ CRF = 795 kg/m³ Water = 225 kg/m³ Wet density = 2385 kg/m³ W/C = 0.48	OPC = 378 kg/m³ PFA = 162 kg/m³ 20mm = 620 kg/m³ 10mm = 310 kg/m³ CRF = 730 kg/m³ Water = 205 kg/m³ Wet density = 2405 kg/m³ W/(C+F) = 0.38

ACI Mix Design

- The most common method adopted in North America which is established by American Concrete Institute.

ACI Method

- Example
- To design a concrete mix for an exterior column located above ground where substantial freezing and thawing may occur.
  - Grade : 35MPa (~5000PSi)
  - Slump ~ 50mm (1 – 2 inch)
  - Max size aggregate: 20mm (~0.75 inch)
  - Cement: Type I, SG: 3.15
  - Coarse aggregate:

    Bulk density (SSD) = 2.7; Absorption capacity = 1%,
    Oven dried unit weight = 100 lb/ft3; Surface moisture = 0
  - Fine aggregate:

    Bulk density (SSD) = 2.65; Absorption capacity = 1.3%,
    Fineness modulus = 2.7, Surface moisture = 3%

ACI Mix Design

- Mix Design Procedure
- Step 1 - Required material information
  - Including sieve analysis for both coarse and fine aggregate, specific gravity etc.

- Step 2 – Choice of slump
  - Normally it is specified by the project. If not, it can be chosen from Table to suit the application.

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ACI Mix Design

- Recommended slumps for various types of construction

Concrete construction	Slump, mm (in.)	
	Maximum*	Minimum
Reinforced foundation walls and footings	75 (3)	25 (1)
Plain footings, caissons, and substructure walls	75 (3)	25 (1)
Beams and reinforced walls	100 (4)	25 (1)
Building columns	100 (4)	25 (1)
Pavements and slabs	75 (3)	25 (1)
Mass concrete	75 (3)	25 (1)

ACI Mix Design

- Step 3 - Maximum aggregate size
  - Maximum size should not be larger than:
    - 1/5 the minimum dimension of structural members
    - 1/3 the thickness of a slab
    - 3/4 the clearance between reinforcement and formwork

ACI Mix Design

- Step 4 - Estimating of mixing water and air content
  - An estimation of the amount of water required for air entrained and non-air entrained concrete can be obtained from Table.
  - Concrete is routinely air entrained in North America.

ACI Mix Design

Approximate mixing water (lb./yd.^{3}) and air content for different slumps and nominal maximum sizes of aggregates

Air-Entrained Concrete

	Maximum aggregate size (in.)							
Slump(in)	0.375	0.5	0.75	1	1.5	2	3	6
1 to 2	**305**	**295**	**280**	**270**	**250**	**240**	**225**	**180**
3 to 4	**340**	**325**	**305**	**295**	**275**	**265**	**250**	**200**
6 to 7	**365**	**345**	**325**	**310**	**290**	**280**	**270**	**-**
Air Content								
Mild	**4.5%**	**4.0%**	**3.5%**	**3.0%**	**2.5%**	**2.0%**	**1.5%**	**1.0%**
Moderate	**6.0%**	**5.5%**	**5.0%**	**4.5%**	**4.5%**	**4.0%**	**3.5%**	**3.0%**
Extreme	**7.5%**	**7.0%**	**6.0%**	**6.0%**	**5.5%**	**5.0%**	**4.5%**	**4.0%**

ACI Mix Design

- Step 5 – Water / Cement Ratio
  - This component is governed by strength and durability requirements.
  - Strength – Related to water cement ratio and referred to 28 days compressive strength.
  - Durability – If there are severe exposure conditions, such as freezing and thawing, exposure to seawater, or sulfates, the w/c ratio requirements may have to be adjusted.

ACI Mix Design

Relationship between water/cement ratio and compressive strength of concrete

28-day Compressive Strength (psi)	Non-AE	AE
2,000	0.82	0.74
3,000	0.68	0.59
4,000	0.57	0.48
5,000	0.48	0.40
6,000	0.41	0.32
7,000	0.33	---

ACI Mix Design

- Step 6 - Calculation of cement content
  - Once the water content and the w/c ratio is determined, the amount of cement per unit volume of the concrete is found by dividing the estimated water content by the w/c ratio.
  - Weight of cement = Weight of water / (w/c)
  - Weight of cement = 280/0.4 = 700 (lb/yd^3)
    = 415 (kg/m^3)

Note:

A minimum cement content is required to ensure good finishability, workability and strength.

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ACI Mix Design

- Step 7 - Estimation of coarse aggregate content
  - The percent of coarse aggregate to concrete for a given maximum size and fineness modulus is given in Table.
  - The value from the table multiplied by oven dried weight of coarse aggregate required per cubic foot of concrete.
  - Volume of coarse aggregate = 0.63 x 27 (ft^3/yd^3)

    = 17.01 (ft^3/yd^3)
  - The oven dried weight of coarse aggregate

    = 17.01 (ft^3/yd^3) x 100 lb/ft^3

    = 1,701 lb/yd^3 (1,009 kg/m3)

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ACI Mix Design

Volume of dry-rodded coarse aggregate per unit volume of concrete for different coarse aggregates and fineness moduli of fine aggregates

	Fineness Modulus						
Max Aggregate (in.)	2.4	2.5	2.6	2.7	2.8	2.9	3
0.375	0.50	0.49	0.48	0.47	0.46	0.45	0.44
0.500	0.59	0.58	0.57	0.56	0.55	0.54	0.53
0.750	0.66	0.65	0.64	0.63	0.62	0.61	0.60
1.000	0.71	0.70	0.69	0.68	0.67	0.66	0.65
1.500	0.75	0.74	0.73	0.72	0.71	0.70	0.69
2.000	0.78	0.77	0.76	0.75	0.74	0.73	0.72
3.000	0.82	0.81	0.80	0.79	0.78	0.77	0.76
6.000	0.87	0.86	0.85	0.84	0.83	0.82	0.81

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ACI Mix Design

- Step 8 - Estimation of fine aggregate content
  - There are two standard methods to establish the fine aggregate content, the mass method and the volume method.
  - Volume method – This method is the preferred method, as it is a somewhat more exact procedure.
  - The volume of fine aggregate is found by subtracting the volume of cement, water, air and coarse aggregate from the total concrete volume.

ACI Mix Design

- Step 8 - Estimation of fine aggregate content
  - Water: 280 lb/ 62.4 lb/ft^3 = 4.49 ft^3 = 0.1271 m^3
  - Cement: 700 lb/(3.15 x 62.4 lb/ft^3) = 3.56 ft^3 = 0.1008 m^3
  - Coarse Agg: 1701 lb/(2.7 x 62.4 lb/ft^3) = 10.10 ft^3 = 0.2860 m^3
  - Air: 6% x 27ft3/yd3 = 1.62 ft3 = 0.0459 m^3

Total = 19.77 ft3 = 0.5598 m^3

ACI Mix Design

- Step 8 - Estimation of fine aggregate content
  - Fine aggregate occupied a volume of:

    $= 27\ ft^3 - 19.77\ ft^3 \quad = 7.23\ ft^3\ (0.2047 m^3)$

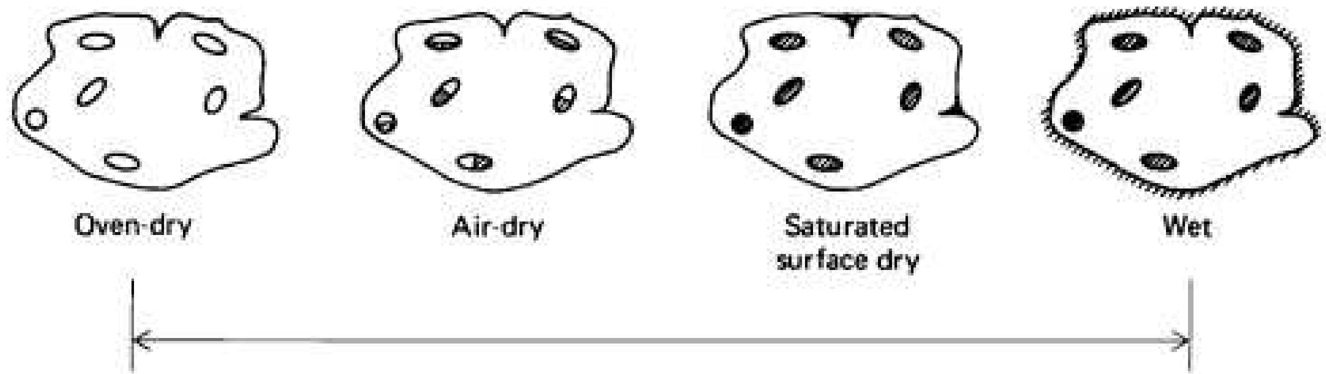
    $= 0.1271\ m^3$
  - Oven dried weight of fine aggregate:

    $7.23\ ft^3 \times 2.65\ (SG) \times 62.4\ lb/ft^3$ (Unit weight of water)

    = 1,196 lb (544kg)

ACI Mix Design

- Step 9 - Adjustment for Moisture in the aggregate
  - The water content of the concrete will be affected by the moisture content of the aggregate.



$$\text{Moisture content } (MC) = AC + SM$$

ACI Mix Design

- Step 9 - Adjustment for Moisture in the aggregate
  - The weight of aggregate from the stockpile is:

    $$Weight_{(stockpile)} = Weight_{(Oven\ dried)}\ (1 + Moisture\ Content)$$

  - The change in the weight water due to the moisture of the aggregate from the stockpile is:

    $$\Delta Weight_{(water)} = Weight_{(Oven\ dried)}\ (Surface\ Moisture)$$

  - $Adjusted\ Weight_{(water)} = Weight_{(water)} - \Delta Weight_{(water)}$

ACI Mix Design

- Step 9 - Adjustment for Moisture in the aggregate
  - Fine aggregate required from the stockpile:

    = 1,196 lb (1+3%+1.3%)

    = 1,247 lb/yd^3 (740 kg/m^3)
  - Coarse aggregate required from the stockpile:

    = 1,701 (1 + 1%)

    = 1,718 lb/yd^3 (1,019 kg/m^3)
  - Required mixing water:

    = 280 lb – 1,196 lb x (4.3% - 1.3%) -
    1,718 lb x (1% - 1%)

    = 244 lb/yd^3 (145 kg/m^3)

ACI Mix Design

- Estimated batch weight
  - Cement: 700 lb/yd^3 (415 kg/m^3)
  - Water: 244 lb/yd^3 (145 kg/m^3)
  - Coarse Agg: 1,718 lb/yd^3 (1,019 kg/m^3)
  - Fine Agg: 1,247 lb/yd^3 (740 kg/m^3)
  - Total: 3,909 lb/yd^3 (2,319 kg/m^3)

ACI Mix Design

- Step 10 - Trial Batch
  - Using the proportions developed in the preceding steps to mix a trial batch of concrete.
  - The fresh concrete shall be tested for slump, unit weight, yield, air content, and its tendencies to segregation, bleeding and finishing characteristics.
  - Hardened samples shall be tested by compressive strength and other characteristics.

Volumetric Method

- Can be used to proportion high performance concrete mixture by incorporating admixtures
- Easily adopted from adequate past experiences and knowledge in the properties of raw materials used

Volumetric Method

- Past experiences and knowledge in:
  - relationship between strength and w/c ratio
  - grading and hardness of aggregates
  - proportion of total fine content in different workability
  - suitably select admixture to minimize total cementitious materials used
  - matrix performance for different proportion of cementitious materials used

Volumetric Method

- The principal is the volume of compacted concrete equal to the sum of the absolute volume of all ingredients
- Require to know the density of all ingredients used
- Formula used:

  Density = Mass/Volume

  Volume (m^3) = Mass (kg)/Density (kg/m^3)

Volumetric Method

- Included air content (entrained and entrapped air), normally 0.8~1% in the mix design
- Aggregates are based on saturated - surface-dry (SSD) conditions

Volumetric Method

- In general, density (kg/m^3) of local raw materials used in the mix design:

Cement (OPC)	~ 3,150
PFA	~ 2,400
GGBS	~ 2,900
Silica Fume (condensed)	~ 2,500
Coarse 20mm & 10mm in SSD	~ 2,600
Crushed rock fines in SSD condition	~ 2,600
Potable water	1,000
Admixtures	depends

Volumetric Method

- General parameters (Examples) based on past experiences/trial results
- OPC 52.5N
- PFA not included
- Max. aggregate size is 20mm
- Dosage of normal water-reducer (lignin based) admixture in 0.8~0.9 L/100 kg cement)

Volumetric Method

Example:

- Specified requirement: same as BRE method mentioned above (i.e. Design 45D/20, 100mm slump)
- Using the general parameters as the table listed above and the following equation for $1m^3$ concrete,

$$(C/3150) + (Agg_c/2600) + (Agg_f/2600) + (W/1000) + (A_m/1100) + Ac = 1\ m^3$$

where,

C	= cement content (kg)
Agg_c	= total “20mm + 10mm” aggregates content (SSD) (kg)
Agg_f	= crushed rock fine aggregate content (SSD) (kg)
W	= water content (kg)
A_m	= admixture content (kg), use density = 1100 kg/m^3
A_c	= air content (0.8~1%)

Volumetric Method

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Step 1: Determination of cement content (C)	Water content is about 200 kg/m^3 and W/C = 0.42, thus Cement content C = 200 / 0.42 = 476 kg
Step 2: Determination of admixture content (A_m)	Provide 0.85 L/100 kg cement of admixture, where S.G.= 1.10, thus Admixture content A_m = (0.85 x 4.76) x 1.10 = 4.45 kg

Volumetric Method

Step 3: Determination of crushed rock fines content (Agg_f)	The cohesiveness and workability required in the mix depends also on the total fine content (i.e. all cementitious materials + total fine aggregates content). In general, for 100mm slump, total fine content is about 0.40 (~40% in volume). That is $(C/3150) + (Agg_f/2600) = 0.4$ $(476/3150) + (Agg_f/2600) = 0.4$ $Agg_f = 647$ kg

Volumetric Method

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Step 4: Determination of total coarse aggregates (20mm+10mm) content (Agg_c)	$(C/3150) + (Agg_c/2600) + (Agg_f/2600) + (W/1000) + (A_m/1100) + Ac = 1\ m^3$ For air content $A_c = 0.9\% = 0.009$, thus, we have, $(476/3150) + (Agg_c/2600) + (647/2600) + (200/1000) + (4.45/1100) + 0.009 = 1\ m^3$ Agg_c (20mm+10mm) = 1,006 kg

Volumetric Method

Step 5: Determination of each 20mm (Agg_{20}) & 10mm (Agg_{10}) contents	Generally, 10mm aggregates (Agg_{10}) is about ~20% to total aggregates content (i.e. coarse + fine) Using 20%, we have, $Agg_{10}/(Agg_c + Agg_f) = 0.2$ $Agg_{10}/(1006 + 647) = 0.2$ $Agg_{10} = 331$ So, $Agg_{20} = 1,006 – 331$ $= 675$ kg

Volumetric Method

	Mix with OPC
Preliminary Mix Design Proportion	OPC = 476 kg/m^3 20mm = 675 kg/m^3 10mm = 331 kg/m^3 CRF = 647 kg/m^3 Water = 200 kg/m^3 Admixture = 4.45 kg/m^3 Wet density = 2,333 kg/m^3 W/C = 0.42

Design Verification

- No matter using which concrete mix design method, trial mix is required to verify the design proportion.
- Design the mix proportions is a starting point.
- During trial mix stage, adjustment may be required to optimize the design mix proportion to suit the actual materials performance and specific applications.
- Further test to determine compatibility of materials and confirm the mix design.
- Field trial for final verification.
- Validate through production.

Theoretical Vs Laboratory Vs Field

Factors Affecting Mix Design

- Materials fluctuations
- Insufficient batching & placing
- Improper curing
- Poor compaction
- Testing
- Site condition and malpractice

Difficulties & Constraints

- Concrete is not magic and still have its limitations although there is great improvement in concrete technology
- Concrete gain strength through cement hydration process and it takes time.
- Contradictory specification requirements
  - e.g. high compressive strength but low tensile splitting strength
  - high PFA content but have to achieve high early strength
  - …

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Difficulties & Constraints

- Limited space in concrete batching plant for storage and handling of constituent materials.
- Stringent regulatory requirements and approval process for relevant permit and license.
- Sustainable materials supply e.g. aggregate supply.

Quality Management System

- Good quality concrete not only the responsibility of Concrete Producers.
- Concrete Producers have the ability to design and produce high standard concrete comply with specifications and requirements to suit the site applications.
- However, workmanship of concreting, compacting, curing cause significant impact to the performance of concrete.

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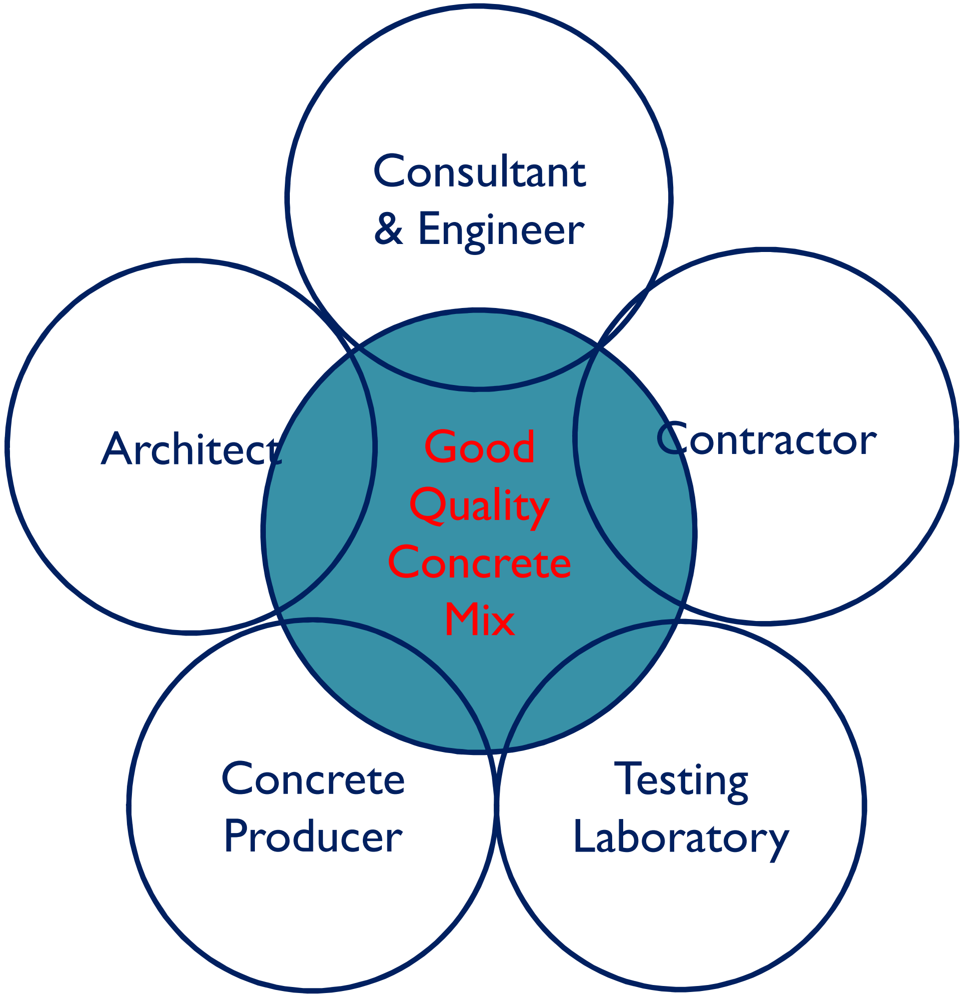
Quality Management System



Quality Management System

- A stringent and high degree of quality control system among the Concrete Producers, Architects, Consultants, Engineers and Contractors shall be established
- The system ensure the high standard concrete to be specified, produced, placed, compacted and cured properly to achieve the desire performance and long term engineering benefits

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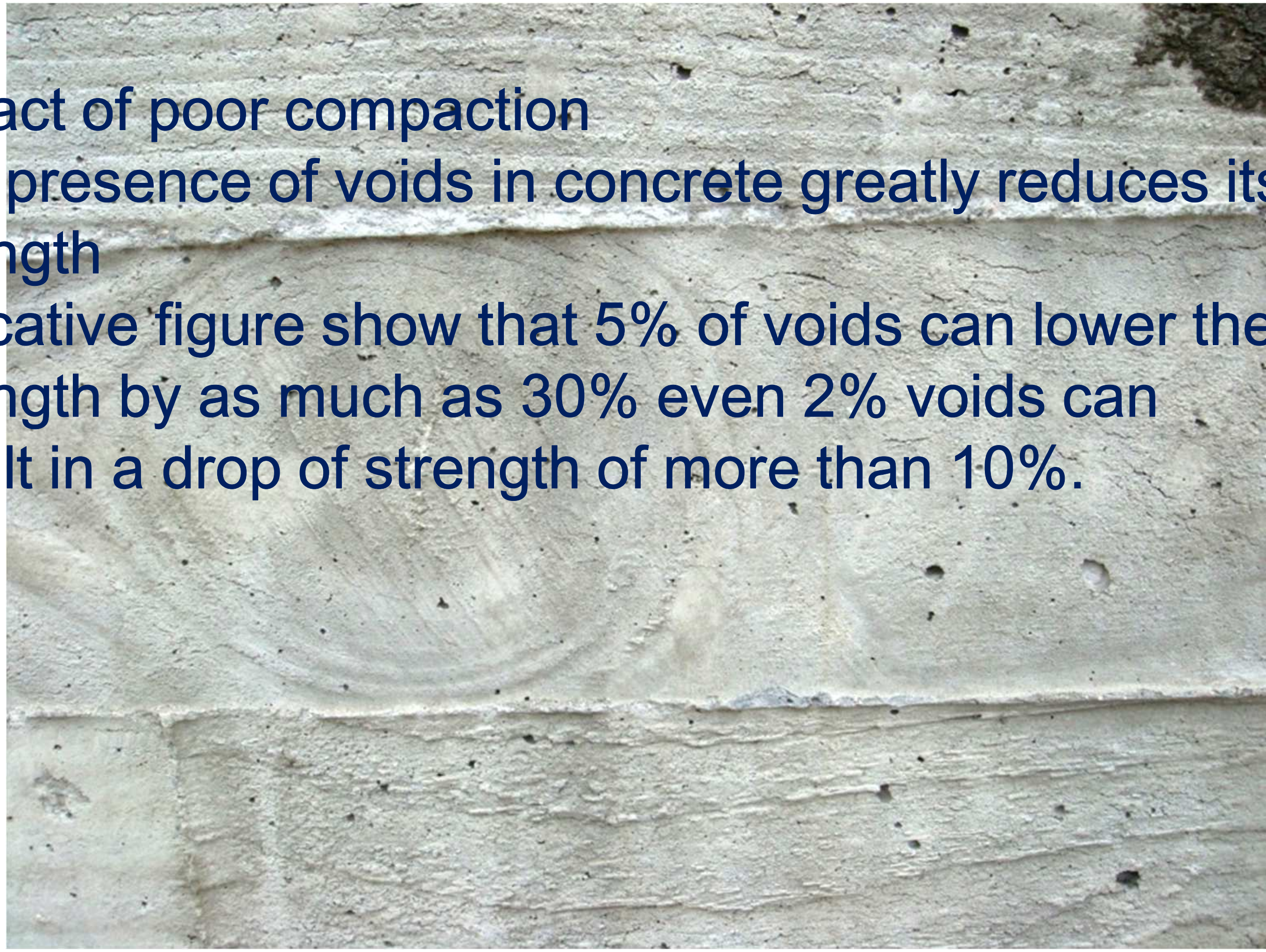
Quality Management System

- Improper curing cause deterioration of strength development and durability of concrete

Quality Management System



- Impact of poor compaction
- The presence of voids in concrete greatly reduces its strength
- Indicative figure show that 5% of voids can lower the strength by as much as 30% even 2% voids can result in a drop of strength of more than 10%.

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Final Words

- Concrete Producers in Hong Kong are capable for design and production of concrete mixes which fully comply with project requirements
- However, since the overall process is under very strict control, production rate is quite often compromised substantially and higher cost is thereby incurred.
- The concrete performance not only the concrete itself.
- A stringent and higher degree of quality control system among the Concrete Producers, Architects, Consultants, Engineers and Contractors is required

~ End ~

Thank You