# Design of Concrete Mix and Field Applications

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# Presentation Outline

- Introduction
  - Concrete
  - Design of Concrete Mixes

- Approaches to Mix Design
  - American Method of Mix Proportion
  - British Method
  - Nigerian Concrete Mix Design Manual
  - Mix Selection for High Strength/High Performance Concrete

- Worked Examples
  - Example 1: American Method
  - Example 2: British Method
  - Example 3: Nigerian Concrete Mix Design

# Introduction

- Concrete is the largest manufactured product used by human society
- Design of concrete mix ⟹ appropriate selection of different ingredients of concrete as required for specific purpose
- This exercise must result in a mixture that meets the following requirements:
  - Fresh state → Can be transported without segregation, placed, compacted and finished (if necessary) with available equipment
  - Hardened state → satisfactorily meet the required strength, durability and dimensional stability
- It implies:
  - determination of an appropriate and economical combination of concrete constituents
  - that can be used for a first trial batch to produce a concrete
  - towards a good balance between the various desired properties of the concrete at the lowest possible cost

# Introduction (Contd.)

- Concrete in the recent times are specified in the form of minimum required strength which comes along with
  - material specification and
  - expected w/c or W/B ratio depending on the type and category of concrete being prepared
- **Table 1:** Strength classes for normal weight concrete according to BS EN 206-1:2001 and classification according to *fib* Model Code 2010 (Dehn, 2012)

| Concrete type | Strength class $f_{ck,cyl}/f_{ck,cube}$ | | | | | | |
|---|---|---|---|---|---|---|---|
| **Low strength concrete** | C8/10 | C12/15 | C16/20 | | | | |
| **Normal strength concrete** | C20/25 | C25/30 | C30/37 | C35/45 | C40/50 | C45/55 | C50/60 |
| **High strength concrete** | C55/67 | C60/75 | C70/85 | C80/95 | C90/105 | C100/115 | |
| **Ultra-high strength concrete*** | C110/130, C120/140 | | | | | | |

*not included in BS EN 206-1:2001;
*fck,cyl* = the Cylinder strength while *fck,cube*= cube strength

- The strength classes (Table 1) can guide the requisite approach to the mix proportioning and materials selection for practical application which is the focus of this workshop

# Approaches to Design Of Concrete Mixes

- Approaches to concrete mix design are generally two:
  - American Method of Mix Proportioning and
  - The British Mix (i.e. D.O.E.) Method
    - The two basic methods are modified at respective environment/countries based on available materials and domiciled therein e.g. the Nigerian Concrete Mix Design Manual
    - HSC/HPC however further requires additional attention on inclusion of additional SCMs such as silica fume and other admixtures in the mix proportioning process
- Output of a structural design process (e.g. a concrete beam) might be given as 25 – 410 concrete with R-bars details attached
- The Professional Builder on site has to select appropriate materials from the neighbourhood, at appropriate proportion to give the requisite strength and durability performance taking cognisance of
  - the workability (in terms of slump and slump retention) as required for the
  - construction procedure (handling, transporting and placing) and
  - the curing method to be adopted for achieving the performance specified for the concrete.

# Approaches to Design of Concrete Mixes (Contd.)

- Basic factors of consideration in material selection process for NSC

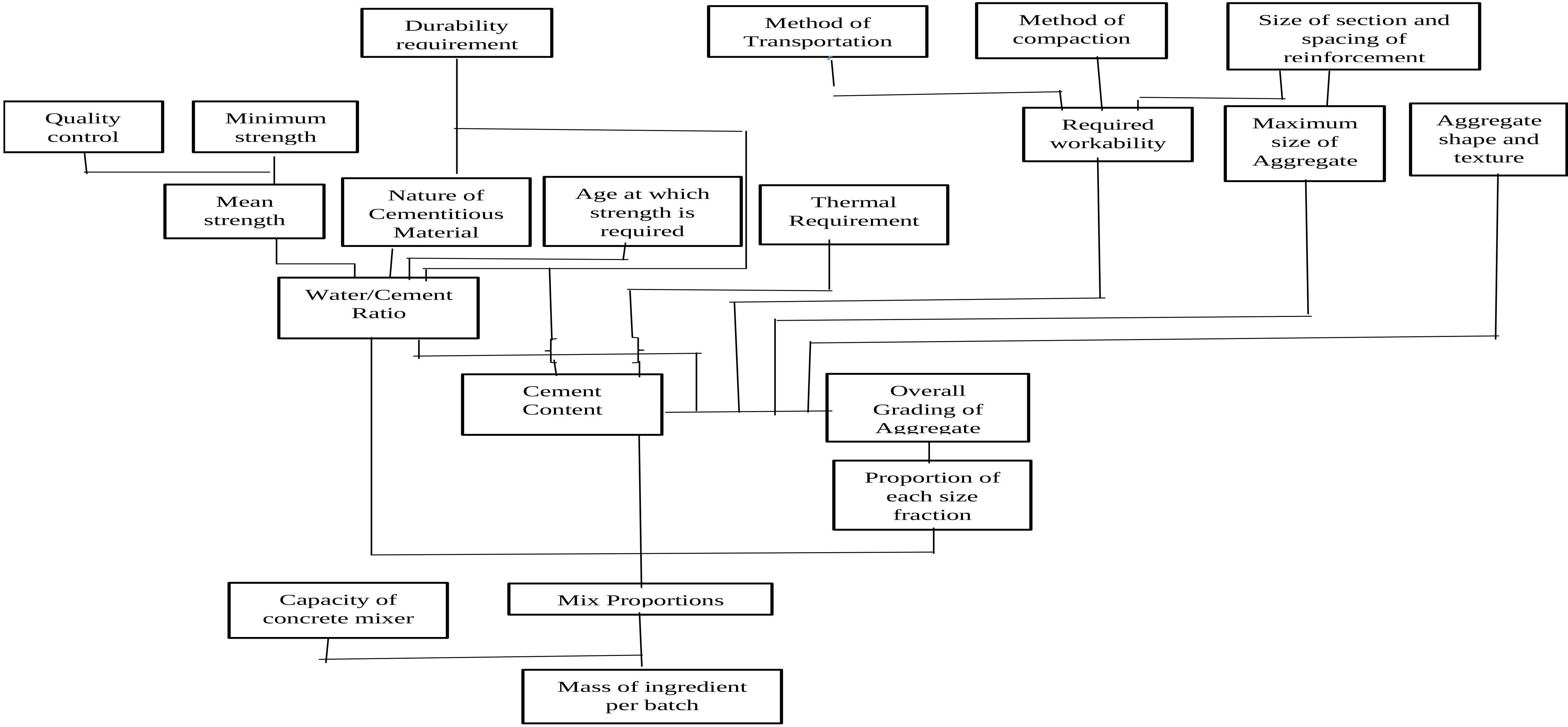


**Figure 1: Basic Factors in the process of mix selection**

# Approaches to Design of Concrete Mixes (Contd.)

## American Method of Mix Proportioning

**Step1 - Choice of slump** (workability requirement and avoidance of segregation)

**Step 2 - Choice of maximum aggregate** (geometric requirement)
- member size &
- spacing of R-bars / based on availability

**Step 3 – Estimate of water content and air content** (Use Table14.5 of Neville (2012)
- maximum size of aggregate, its shape, texture and grading
- the content of entrained air,
- the use of admixtures with plasticizing or water reducing properties and temperature of concrete

**Step 4 – Selection of w/c ratio** (guided by strength and durability requirements)

$f_{cr}{}' = f_c + 1.343\sigma$ (1) → 99% > $f_c$

$f_{cr}{}' = f_c + 2.33\sigma - 3.5$ (2) → 99% no value < $f_c$ - 3 MPa

**Step 5 - Calculation of cement content** (Step 3 outcome / Step 4 outcome)

**Step 6 - Estimate of coarse aggregate content** (Use Table 14.6, Neville (2012)

**Step 7 - Estimate of fine aggregate content**

Abs. Vol. of F/Agg = Abs. Vol. of Conc. – Abs. Vol. (water, cement, entrained air & C/Agg)

**Step 8– Estimate of water and air content**
- Cast trial mix, check slump and make appropriate adjustment

# Approaches to Design of Concrete Mixes (Contd.)

## British Mix Design

**Step 1 – Compressive strength for determination of w/c ratio** (Use Table 14.9 & Fig. 14.12 (Neville, 2012)

- $f_m = f_c + k\sigma$ (3), $f_m$ = target mean strength; $k = 1.64$ (3) now to replace (1) & (2)

**Step 2 - Determination of water content** (Use Table 14.10 Neville, 2012)

Workability, maximum aggregate size and its type (crushed or uncrushed) guides decision

**Step 3 - Determination of cement content** (similar to step 5 of American Method)

This is simply dividing the outcome of Step 1 by outcome of step 2

**Step 4 - Determination of the total aggregate content** (Use Fig. 14.13 Neville, 2012)

•Read off fresh density of fully compacted concrete for appropriate water content and S.G. of aggregates

•Total Agg. Content = Fresh Density of Concrete – Weight of (water, cement and air)

**Step 5 - Determination of proportion of F/Agg from Total Agg Content** (Fig. 14.14 & Table 14.11 Neville (2012). Governing factors here are

- the maximum size of aggregate; level of workability; w/c and Percentage of fine aggregate passing the 600 µm sieve
- F/Agg content = Proportion of F/Agg * Total Agg content
- C/Agg. Content = Total Agg. Content – F/Agg. content
- Use the calculated weights to cast trial mix, check slump and make adjustment

# Approaches to Design of Concrete Mixes (Contd.)

## Nigerian Concrete Mix Design Procedure

**Step 1 – Determination of target mean strength**

$f_m = f_c + k\sigma$ (3), $f_m$ = target mean strength; $k = 1.64$ (3) still subsist as in the British Method

**Step 2 - Determination of water-cement ratio** (Fig 4.1 of the Manual is used)

grade of cement and durability requirements are of concern here

Relationship between Strength and w/c ratio is given in Fig. 4.1 of the Manual

Steps 1 & 2 in the Nigerian Method is similar to Step 1 of the British Method

**Step 3 - Determination of water content** (Table 5 of the Manual)

Read off water content from Table 5 of the Manual (modified form of Table 14.9 of Neville, 2012) Workability, maximum aggregate size and its type (crushed or uncrushed) is of concern

**Step 4 - Determination of cement content**

This is same as Step 3 of the British Method. Simply outcome of Step 3 divided by outcome of Step 2

**Step 5 - Determination of aggregate content -** Governing factors here are

- Fresh density of fully compacted concrete for all NSC is assumed as 2400 kg/m$^3$
- Calculate Total Agg content (as done in British Method) = Density of Concrete – Wt. of (water, cement & air)
- Obtain the proportion of F/gg (Fig. 4.2 to 4.5) and then F/Agg content = Proportion of F/Agg * Total Agg content
- C/Agg. Content = Total Agg. Content – F/Agg. Content
- Use the calculated weights to cast trial mix, check slump and make adjustment

# Approaches to Design of Concrete Mixes (Contd.)

- Mix Selection for HSC/HPC – This is unique b/c
  - Use of Superplasticiser now enhances low W/B in HSC/HPC
  - HPC has one or more SCM which replaces a significant amount of cement
  - Presence of SF in HPC causes significant changes in properties of fresh and hardened concrete
  - Workability of HPC can be adjusted using superplasticisers without altering the W/B
- ACI 363 R-92
  - specified the required target strength $f_{cr}{}'$ (MPa) same as in ACI 211-1 as mentioned in Equation (1) & (2)
- Mehta & Monteiro (2014)
  - Max. size – 10 to 15 mm;
  - slump range – 200 to 250 mm;
  - 2 % entrapped air for non-air entrained HPC, can be increased to 5 to 6 % and suggested an optimum aggregate volume of 65%
- Aītcin (1998)
  - 5 Step different mix characteristics
    - the W/B;
    - the water content;
    - the superplasticiser dosage;
    - the coarse aggregate content and
    - the entrapped air content (assume value)

# Approaches to Design of Concrete Mixes (Contd.)

- The Mix Design Procedure for HPC

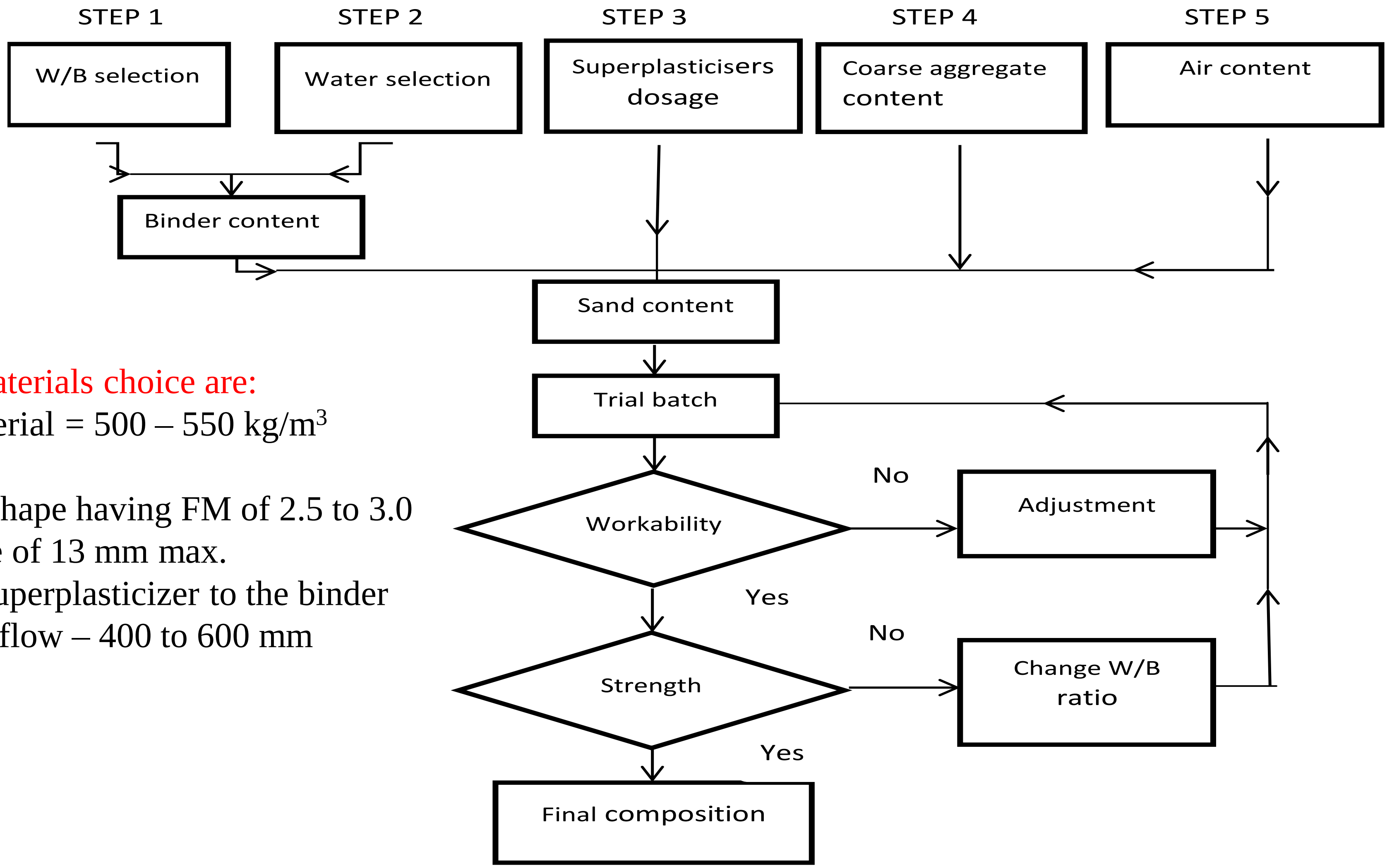


Figure 2: Mix Design Process for HPC (Aitcin,1998)

Basic Guides on Materials choice are:

- Content of cementitious material = 500 – 550 kg/m$^3$
- 10 % max. silica fume
- F/Agg type - round particle shape having FM of 2.5 to 3.0
- C/Agg type – Irregular shape of 13 mm max.
- Check compatibility of the superplasticizer to the binder
- Workability check by slump flow – 400 to 600 mm

# Worked Examples

- Example 1 – American Method

**Question 1:**

Design a concrete for a mean 28-day cylinder compressive strength of 35 MPa and 50 mm slump, using ordinary Portland cement. The maximum size of well-shaped, angular aggregate is 20 mm, its bulk density is 1600 kg/m$^3$, and its specific gravity is 2.64. The available fine aggregate has a fineness modulus of 2.60 and a specific gravity of 2.58. No air entrainment is required.

**Solution:**

Step 1: **Slump** (specified) = 50 mm

Step 2: **Max size Agg**. = 20 mm

Step 3: **Water requirement** = 190 kg/m$^3$ (Table 14.5, Neville (2012))

Step 4: **Water/cement ratio**, Read off from Fig. 14.2, Neville (NB: Cylinder strength is 80% of cube strength)
Cylinder strength is 35 MPa (i.e. 44 MPa cube strength) give w/c = **0.48**

Step 5: **cement content** $= \frac{water\ content}{w/c} = \frac{190}{0.48} = 395$ kg/m$^3$

Step 6: **Estimate of coarse aggregate content**
Given FM of F/Agg = 2.6; Table 14.6, Neville gives as bulk volume of C/Agg = 0.64,
hence multiply by bulk density gives 0.64 * 1600 = 1020 kg/m$^3$

Step 7: **Estimate of fine aggregate content** (Absolute volume of the various materials are then calculated)
Solid volume of cement, assuming usual specific gravity of 3.15, is 395/ (3.15 x 1000) = 0.126 m$^3$
Solid volume of coarse aggregate is 1020/ (2.64 x 1000) = 0.396 m$^3$
Volume of entrapped air, (see Table 14.5, Neville(2012)) is 2 / 1000 = 0.020 m$^3$
Hence, total volume of all ingredients except fine aggregate = 0.732 m$^3$

# Worked Examples (Contd.)

- Example 1 – American Method (Contd.)

therefore, the required volume of fine aggregate is 1.000 – 0.732 = 0.268 $m^3$

Mass of the fine aggregate is then 0.268 x 2.58 x 1000 = 690 $kg/m^3$

Steps 1 to 7 therefore gives list the estimated mass of each of the ingredients in $kg/m^3$ concrete as follows:

| | |
|---|---|
| Water | 190 |
| Cement | 395 |
| Coarse | 1020 |
| Fine aggregate, dry | 690 |

Therefore, the density of concrete is 2295 $kg/m^3$

**Table 14.5**: Approximate Mixing water and Air Content Requirements for Different Slumps and Nominal Maximum Sizes of Aggregates given in ACI 211.1-91

| Slump, mm | Water, kg/m3 of concrete for indicated nominal maximum sizes of aggregate | | | | | | | |
|---|---|---|---|---|---|---|---|---|
| | 9.5 | 12.5 | 19 | 25 | 37.5 | 50 | 75 | 150 |
| **Non air-entrained concrete** | | | | | | | | |
| 20 to 50 | 207 | 199 | 190 | 179 | 166 | 154 | 130 | 113 |
| 75 to 100 | 228 | 216 | 205 | 193 | 181 | 169 | 145 | 124 |
| 150 to 175 | 243 | 228 | 216 | 202 | 190 | 178 | 160 | |
| Amount of entrapped air, per cent | 3.0 | 2.5 | 2.0 | 1.5 | 1.0 | 0.5 | 0.3 | 0.2 |
| **Air-entrained concrete** | | | | | | | | |
| 20 to 50 | 181 | 175 | 168 | 160 | 150 | 142 | 122 | 107 |
| 75 to 100 | 202 | 193 | 184 | 175 | 165 | 157 | 133 | 119 |
| 150 to 175 | 216 | 205 | 197 | 184 | 174 | 166 | 154 | |
| **Total air content, (per cent) for:** | | | | | | | | |
| Improvement of workability | 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 |
| Extreme exposure | 7.5 | 7.0 | 6.0 | 6.0 | 5.5 | 5.0 | 4.5 | 4.0 |

# Worked Examples (Contd.)

- Example 2 – British Method

**Question 2:**

Select a mix to satisfy requirements of a 28-day cube compressive strength of 44 MPa; a slump of 50 mm; uncrushed aggregate with a maximum size of 20 mm; specific gravity of aggregate of 2.64; 60 % of the fine aggregate passes the 600 um sieve; no air entrainment required; ordinary Portland cement (OPC) to be used.

**Solution:**

**Step 1: Compressive strength for determination of w/c ratio**

Table 14.9, Neville (2012) – OPC; uncrushed aggregate gives 28-day strength as 42 MPa.

Using Figure 14.12 (Neville, 2012) we got w/c of required concrete ($f_{ck,cube}$ of 44 MPa) = **0.48**

**Step 2: Determination of water content**

From Table 14:10, for 20 mm uncrushed and 50 mm slump, water content = **180 kg/m$^3$**

**Step 3: Determination of cement content**

The cement content = $\frac{water\ content}{w/c} = \frac{180}{0.48}$ = **375 kg/m$^3$**

**Step 4: Determination of the total aggregate content**

Figure 14.13, for water content of 180 kg/m$^3$ ; aggregate specific gravity of 2.64

we read off the fresh density of concrete as = **2400 kg/m$^3$**

The total aggregate content is therefore = 2400 – 375 – 180 = **1845 kg/m$^3$**

**Step 5**: Figure 14.14, using max Agg size (20 mm), slump (50 mm), 60 % of F/Agg passing 600 um sieve at a w/c of 0.48 gives proportion of fine aggregate as 32 % (by mass of total aggregate).

Hence the F/Agg content is 0.32 x 1845 = **590 kg/m$^3$**

# Worked Examples (Contd.)

- Example 2 – British Method (Contd.)

The coarse aggregate content therefore is 1845 – 590 =**1255 kg/m³**.

The material to be used for trial mix are therefore summarised as follows:

| | |
|---|---|
| Water | = 180 |
| Cement | = 375 |
| Fine aggregate | = 590 |
| Coarse aggregate | = 1255 |
| Density of concrete | = 2400 $kg/m^3$ |

Outcome of the mix design procedure is often presented in a Mix Design Table shown in Appendix attached

Table 14.9: Approx. Compressive Strength of Concretes Made with a Free W/C Ratio of 0.5 According to British Method

| Type of cement | Type of coarse aggregate | Compressive strength* (MPa (psi) at the age of (days) | | | |
|---|---|---|---|---|---|
| | | 3 | 7 | 28 | 91 |
| Ordinary Portland (Type I) Sulphate resisting Portland (Type V) | Uncrushed | 22 (3200) | 30 (4400) | 42 (6100) | 49 (7100) |
| | Crushed | 27 (3900) | 36 (5200) | 49 (7100) | 56 (8100) |
| Rapid-hardening Portland (Type III) | Uncrushed | 29 (4200) | 37 (5400) | 48 (7000) | 56 (7800) |
| | Crushed | 34 (4900) | 43 (6200) | 55 (8000) | 61 (8900) |

# Worked Examples (Contd.)

- Example 3 – Nigerian Concrete Mix Design Method

**Question 3:**

Design a concrete mix using grade 42.5 Portland cement far a characteristic strength of 30 MPa and a slump range of 60 -180mm is expected at fresh state. The coarse aggregate is to be 20 mm crushed granite, while the fine aggregate is sharp river sand. The design is to be based on the Nigerian Concrete Mix Design Manual.

**Table 5: Approx. Free Water content required to give various level of workability**

| Maximum size of coarse aggregate (mm) | Aggregate Type | Slump (mm) | |
|---|---|---|---|
| | | 30-60 | 60-180 |
| 20 | Uncrushed | 180 | 205 |
| | Crushed | 210 | 235 |
| 40 | Uncrushed | 160 | 185 |
| | Crushed | 190 | 215 |

Solution to Question 3:

**Step 1: Determination of Target Mean Strength.**

We are given $f_c$ = 30 MPa and using $\sigma$ = 4 and k = 1.64

Hence using Eqn 3 $f_m = f_c + k\sigma$ i.e. $f_m$ = 30 + 1.64 (4) = **36.563**

**Step 2: Determination of Water-Cement Ratio**

Fig. 4.1 of the Manual shows that when using 42.5 Nigerian cement, the w/c for 37 MPa concrete = **0.55**

**Step 3: Determination of Water Content**

We are expected to use 20 mm max. aggregate (crushed) as C/Agg. And achieve a 60 – 180 mm slump at the fresh state, hence from Table 5, read off the free water content = **235 kg/m³**

**Step 4: Determination of Cement Content**

Cement content = $\frac{water\ content}{w/c} = \frac{235}{0.55}$ = **427.27** kg/m³ to the nearest 5 kg/m³ gives **425 kg/m³**

# Worked Examples (Contd.)

- Example 3 – Nigerian Concrete Mix Design Method (Contd.)

Solution to Question 3 Contd.

**Step 5: Determination of Aggregate Content**

The Manual recommends fresh density of NSC be taken as **2400 kg/m$^3$**

Hence Total Aggregate content **=** Fresh Density of Concrete – Wt. of (water + cement +air)

= 2400 – (235 + 425 + 0) = **1740 kg/m$^3$**

Fig. 4.4 of the Manual (Using upper limit of 20 mm) gives Proportion of F/Agg. = 35 %

Hence F/Aggregate content = 0.35 * 1740 = 609 kg/m$^3$ to the nearest 5 kg/m$^3$ = **610 kg/m$^3$**

C/Agg content = Total Aggregate content – F/Agg content = 1740 – 610 **= 1130 kg/m$^3$**

The material to be used for trial mix are therefore summarised as follows:

| | |
|---|---|
| Water | = 235 kg/m$^3$ |
| Cement | = 425 kg/m$^3$ |
| Fine aggregate | = 610 kg/m$^3$ |
| Coarse aggregate | = 1130 kg/m$^3$ |
| Density of concrete | = 2400 kg/m$^3$ |

These can further be calculated to the specific volumes or number of cubes to be cast in trial mixes.

The various methods also encourage developing these calculations into a Concrete Mix Design Guide as shown in the Appendix attached.

# Conclusion

- The following should be noted for site application of mix design
  - All cement brands to be used must be clearly labeled with strength grade
  - A site trial mix design should be carried out for suitability
  - Cubes should be cast during trial mix and tested prior commencement of construction
  - Coarse aggregate should be wetted to keep them at SSD
  - w/c ratio have to be strictly adhered to on site
  - Cement should be properly stocked in water proof area and not in direct contact with the floor
  - Cubes (minimum of three) at every batch should be cast for 28days strength testing

# Appendix – Tables and Charts

- Table 14.6 and Fig. 14.2 Neville

**Table 14.6** Bulk Volume of Coarse Aggregate per Unit Volume of Concrete[14.5]

| *Maximum size of aggregate* | | *Bulk volume of oven-dry rodded coarse aggregate per unit volume of concrete for fineness modulus of fine aggregate of:* | | | |
|---|---|---|---|---|---|
| *mm* | *in.* | *2.40* | *2.60* | *2.80* | *3.00* |
| 9.5 | $\frac{3}{8}$ | 0.50 | 0.48 | 0.46 | 0.44 |
| 12.5 | $\frac{1}{2}$ | 0.59 | 0.57 | 0.55 | 0.53 |
| 20 | $\frac{3}{4}$ | 0.66 | 0.64 | 0.62 | 0.60 |
| 25 | 1 | 0.71 | 0.69 | 0.67 | 0.65 |
| 37.5 | $1\frac{1}{2}$ | 0.75 | 0.73 | 0.71 | 0.69 |
| 50 | 2 | 0.78 | 0.76 | 0.74 | 0.72 |
| 75 | 3 | 0.82 | 0.80 | 0.78 | 0.76 |
| 150 | 6 | 0.87 | 0.85 | 0.83 | 0.81 |

The values given will produce a mix with a workability suitable for reinforced concrete construction. For less workable concrete, e.g. that used in road construction, the values may be increased by about 10 per cent. For more workable concrete, such as may be required for placing by pumping, the values may be reduced by up to 10 per cent.

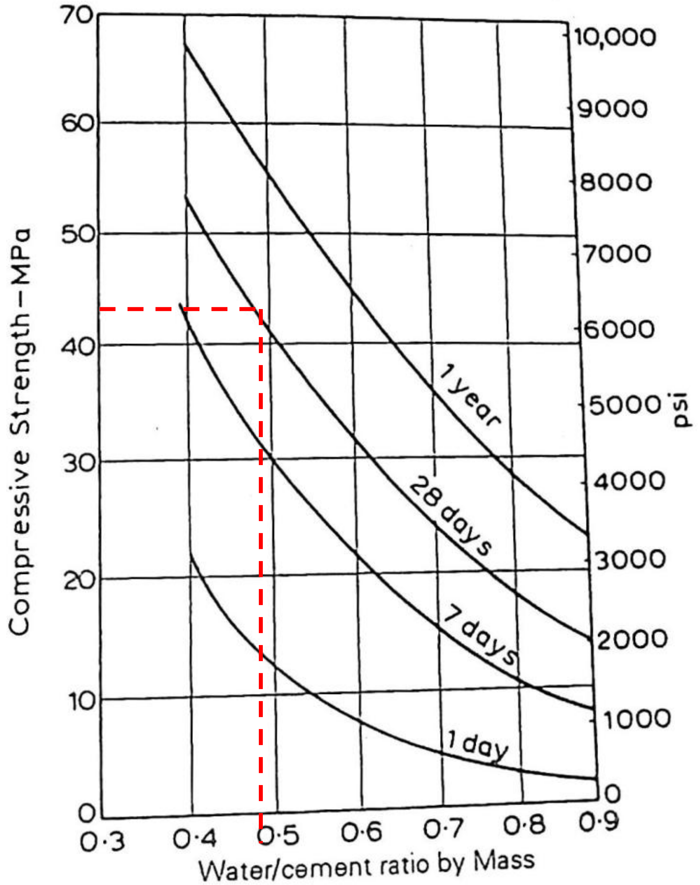


*Fig. 14.2* Relation between compressive strength and water/cement ratio for 102 mm (4 in.) cubes of fully compacted concrete for mixes of various proportions made with typical British ordinary Portland cements of the late 1970s. The values used are conservative estimates

# Appendix – Tables and Charts

- Fig. 14.12 and Table 14.10

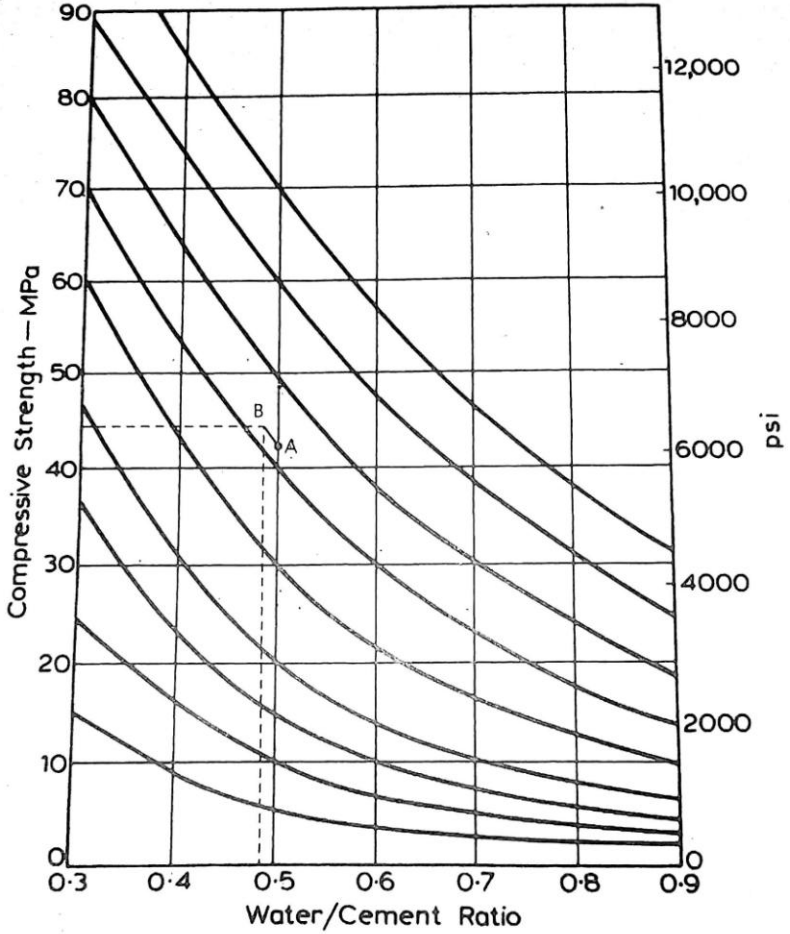


*Fig. 14.12* Relation between compressive strength and free water/cement ratio for use in the British mix selection method[14.11] (see Table 14.9) (Crown copyright)

**Table 14.10** Approximate Free Water Contents Required to Give Various Levels of Workability According to the 1997 British Method[14.11] (Crown copyright)

| *Aggregate* | | *Water content, kg/m³ (lb/yd³) for:* | | | | |
|---|---|---|---|---|---|---|
| *Max size mm (in.)* | *Type* | *Slump, mm (in.)* | *0–10 (0–½)* | *10–30 (½–1)* | *30–60 (1–2½)* | *60–180 (2½–7)* |
| | | *Vebe time, s* | *>12* | *6–12* | *3–6* | *0–3* |
| 10 (⅜) | Uncrushed | | 150 (255) | 180 (305) | 205 (345) | 225 (380) |
| | Crushed | | 180 (305) | 205 (345) | 230 (390) | 250 (420) |
| 20 (¾) | Uncrushed | | 135 (230) | 160 (270) | 180 (305) | 195 (330) |
| | Crushed | | 170 (285) | 190 (320) | 210 (355) | 225 (380) |
| 40 (1½) | Uncrushed | | 115 (195) | 140 (235) | 160 (270) | 175 (295) |
| | Crushed | | 155 (260) | 175 (295) | 190 (320) | 205 (345) |

# Appendix – Tables and Charts

- Fig. 14.13 Neville (2012)

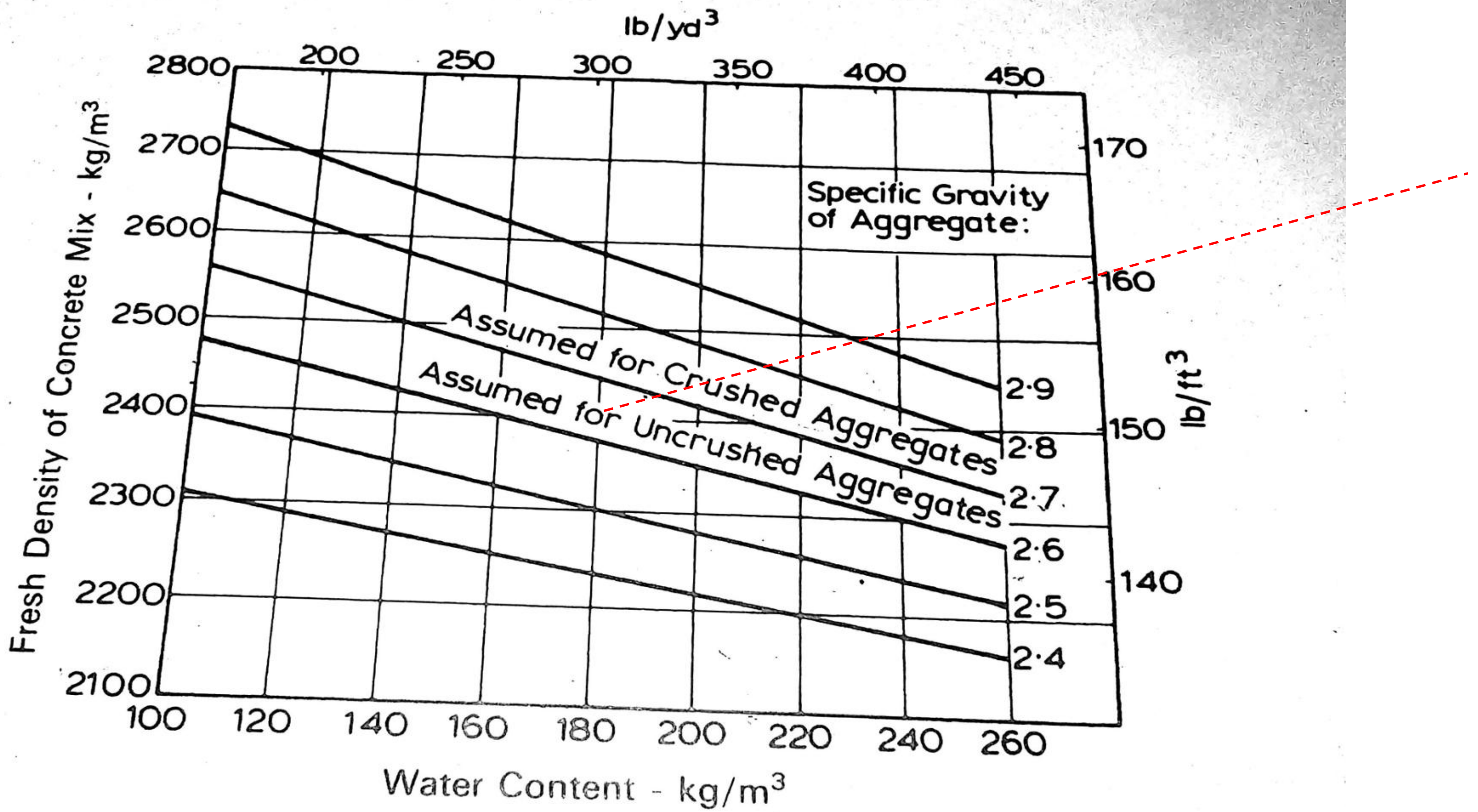


*Fig. 14.13* Estimated wet density for fully compacted concrete[14.11] (specific gravity is given for saturated and surface-dry aggregate) (Crown copyright)

# Appendix – Tables and Charts

- Fig. 14.14 (a & b), Neville (2012)

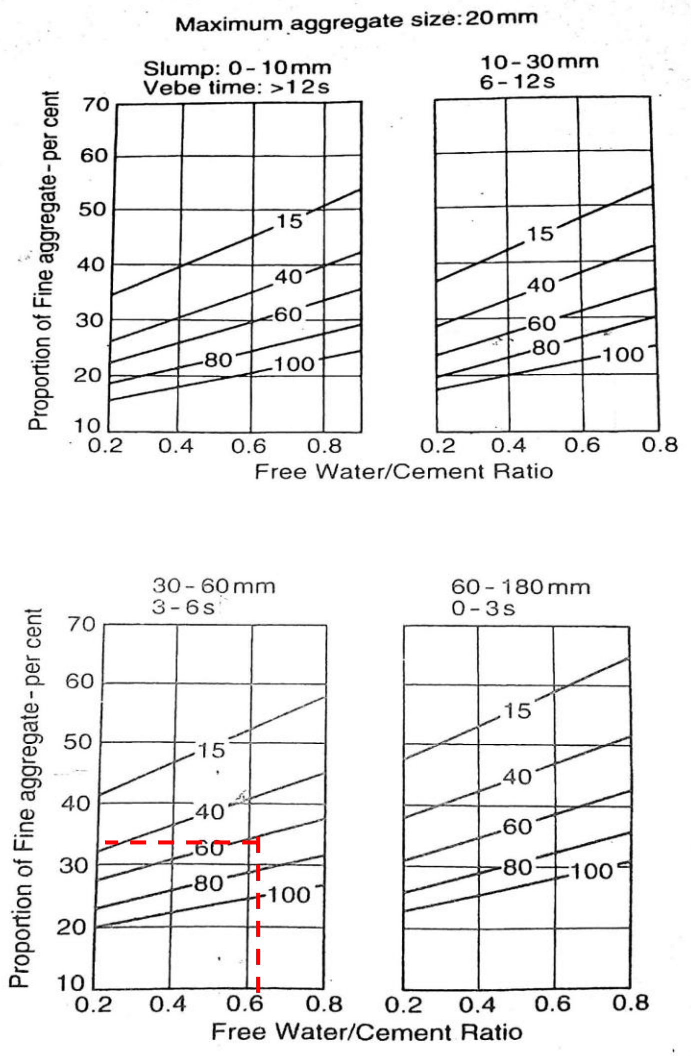


Fig. 14.14 Recommended proportion of fine aggregate (expressed as percentage of total aggregate) as a function of free water/cement ratio for various workabilities and maximum sizes[14.11] (numbers refer to percentage of fine aggregate passing 600 μm sieve) (Building Research Establishment; Crown copyright)

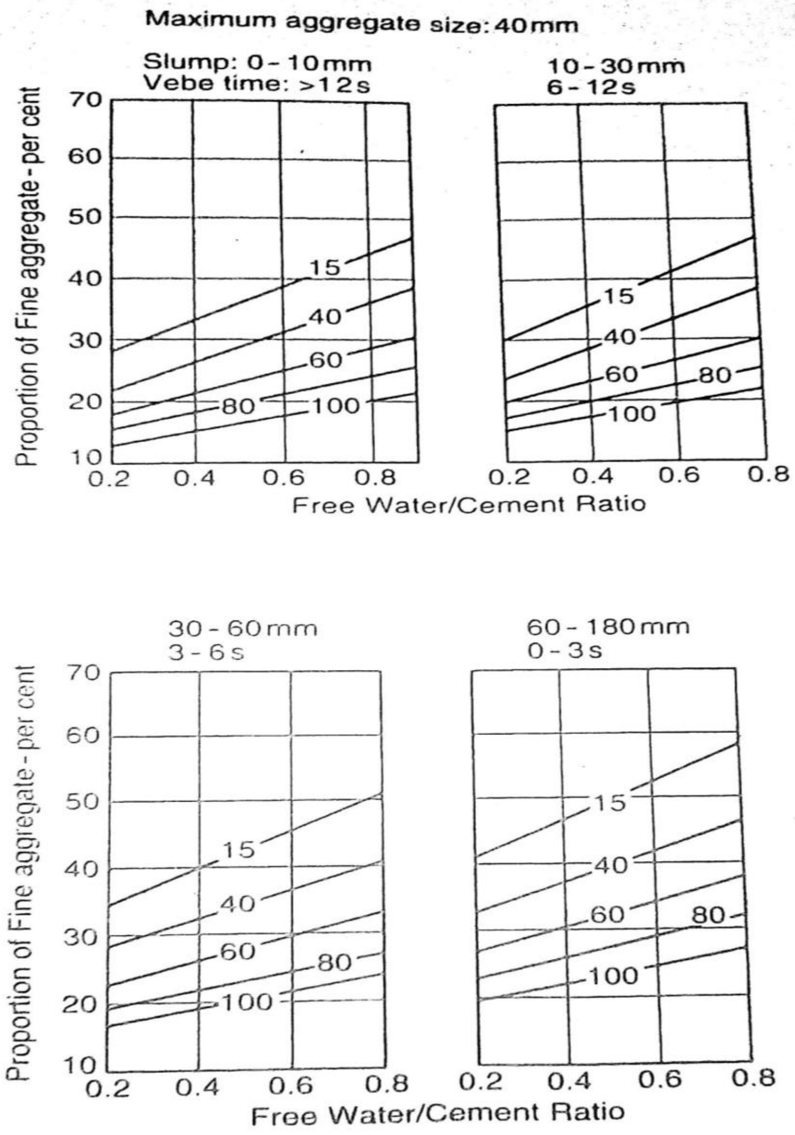


*Fig. 14.14 continued*

# Appendix – Tables and Charts

- Fig. 4.1 Nigerian Concrete Mix Design Manual

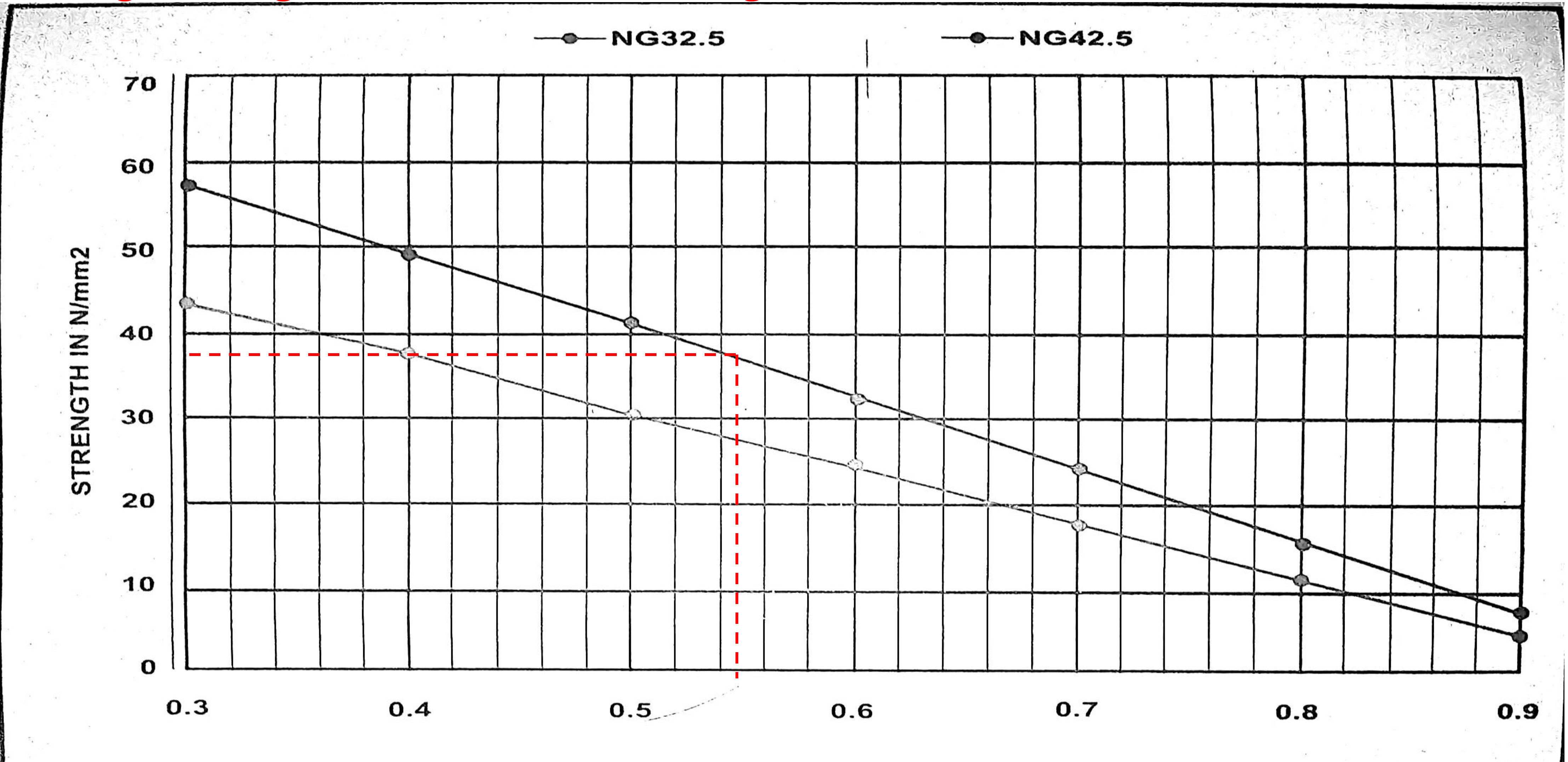


Fig. 4.1 - strenghth versus Water/Ceement Ratio for Nigerian Cements

# Appendix – Tables and Charts

- Fig. 4.4 Nigerian Manual

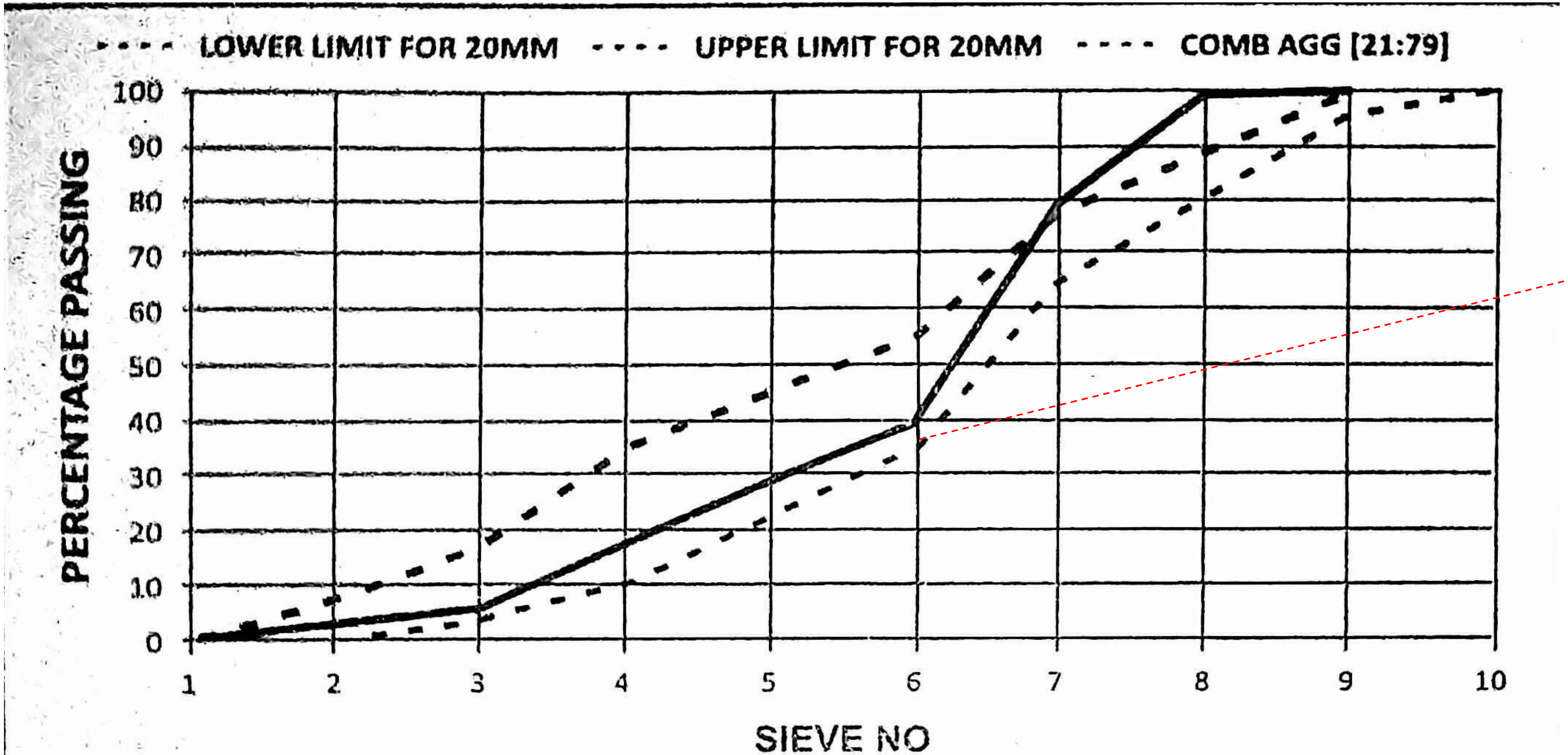


Fig. 4.4 - Combined aggregate grading curve for 21% fines and 79% coarse

# Concrete Mix Design Guide

| Mix Design For Grade ____ Concrete (Using Grade ________ Cement) | | | |
|---|---|---|---|
| S/No | Item | Units | |
| | **Material Data**<br>Cement Grade:<br>Aggregate Type: Coarse<br>Aggregate Type: Fine | | |
| 1 | **Step 1** | | |
| 1.1 | Characteristic Strength | MPa | |
| 1.2 | Standard Deviation | MPa | |
| 1.3 | Marging | MPa | |
| 1.4 | Target Mean Strength | MPa | |
| 2 | **Step 2** | | |
| 2.1 | Free water/cement ratio | | |
| 2.2 | Maximum free water/cement ratio | | |
| 3 | **Step 3** | | |
| 3.1 | Slump | mm | |
| 3.2 | Maximum Aggregate size | mm | |
| 3.3 | Free water content | $kg/m^3$ | |
| 4 | **Step 4** | | |
| 4.1 | Cement content | $kg/m^3$ | |
| 4.2 | Maximum cement content | $kg/m^3$ | |
| 4.3 | Minimum cement content | $kg/m^3$ | |
| 4.4 | Modified free water/cement ratio | | |
| 5 | **Step 5** | | |
| 5.1 | Concrete density | $kg/m^3$ | |
| 5.2 | Proportion of fine aggregate (%) | | |
| 5.3 | Fine aggregate content | $kg/m^3$ | |
| 5.4 | Coarse aggregate content | $kg/m^3$ | |
| | **Trial Mixes**<br>Water (kg)<br>Cement (kg)<br>Fine aggregate (kg)<br>Coarse aggregate (kg( | 100mm cube | 150mm cube |

# Thanks for your attention