CONCRETE MIX DESIGN FORMAT FOR COMPUTERS AS PER IS10262-2009

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Abstract

Concrete is one of the most widely used construction material across the globe in various civil infrastructure activities. It is also a material which is difficult to produce consistently to meet the prescribed specifications. Concrete is a composite material consisting of a cementitious paste (cement+ water) and inert aggregate (coarse and fine) filler materials. Properties and quality of locally available component materials, tools and equipment used for proportioning, mixing and vibrating, skills of the workers and supervision involved and exposure conditions etc., affect the properties of the concrete. Quality of concrete is evaluated against its performance in meeting the requirements of strength, durability and serviceability in hardened state and workability in fresh condition. These requirements vary based on the intended functional units like columns, beams, foundations, pre stressed concrete and pavements etc. and also from country to country. Several countries have stipulated standards for these parameters. To achieve these specified properties, suitable constituent materials need to be selected and they should be used in certain proportions. These proportions are arrived at based on experience and some empirical relations. It shall also be done in a cost effective manner. At the initial stage data about proposed constituent materials and the variables that influence the mix design need to be collected. This data includes desired strength of concrete, type of cement-Ordinary Portland/Portland pozzolana, quantity of cement and admixtures, water cement ratio, sizes and properties of aggregates, workability requirements based on location points of placing and transportation of the concrete on the job etc. Durability of concrete both in plastic and hardened state will be influenced by the environmental conditions it will be exposed to like weather, submergence in water, burial under soil and exposure to chemical fumes etc. These conditions can lead to deterioration of concrete. In India the recommendations of IS 10262 for designing concrete mixes are followed. It provides formulas, tables and other information for deciding water cement ratio, water content, quantities of coarse and fine aggregate etc. This code need to be studied in conjunction with IS 456 and other IS codes for relevant data. Preliminary theoretical quantities of the concrete constituents can be obtained by following the steps illustrated in the examples given in the code. These quantities need to be endorsed by conducting tests on laboratory and filed/plant trial mixes. Materials from the same sources need to be used in both trial mixes. Suitable adjustments shall be made to the theoretical quantities to arrive at actual quantities to produce concrete that meets the stipulated specifications. A lot of variables like grade of concrete, specific gravity of materials, zone of sand, shape of aggregate etc., many provisions specified in the codes, multiple steps, several repetitions and numerous calculations are involved in obtaining a reliable concrete mix design. Manually handling these computations is tedious. With the size, complexity and importance of structures, accuracy of procedures and calculations increases further. Computer aided programs and spreadsheets can help a lot in reducing the labour involved in this work. They can be made user friendly by including the provisions of the codes, tables, formulas and other data. The results can be tabulated in the desired format for both one cum of concrete and desired quantity of concrete. Design calculations for alternative constituent materials like fly ash and M-sand that help in conserving nature which may have considerably different properties, are also presented.

Keywords: Mix Design, Cement, Concrete, Admixture, M-Sand, Flow chart

I. INTRODUCTION

Concrete is a key construction material across globe. It is used in various civil engineering infrastructure projects like Dams, Bridges, flyovers, Sky scrapers, industrial structures, highways, tunnels, water treatment facilities, ports, airports and stadiums etc. It is very versatile material and can be moulded in any shapes like square, rectangular, circular and into a variety of architecture features. All types of structural elements like footings, columns, walls, beams, slabs, floors, piers and piles etc can be casted with concrete. Concrete is the most popular material used in foundations for all types of structures because it is strong, durable and can sustain the attack by moisture. Main ingredients of concrete are - a cementitious paste (cement+ water) and inert aggregate (coarse and fine) filler materials. Cast in place and precast concrete are two methods of application of concrete. Cast in place concrete or poured concrete is the common method of application of concrete in construction. Precast concrete can be adopted when space and time are constrained and for achieving better quality. Concrete is exposed to static and dynamic loads like self weight, floor loads, wind, seismic, wave and machine and floor loads etc in several combinations. Plain concrete is used in structural elements subjected to compressive stresses. In members subjected to tensile stresses, concrete is inserted with reinforcement and is called reinforced concrete. Whether it is plain or reinforced concrete or cast in place or precast, the quantitative proportions of its ingredients plays a vital role in achieving its intended purpose and objectives.

II. MIX DESIGN – AN OVERVIEW

Unlike cement which is a homogeneous material, concrete is considered as a heterogeneous mixture. Preparing the concrete that meets the requirements is not a pure science as preparing a chemical mixture in laboratory. Ratio of the quantities of ingredients per unit quantity of specified concrete is not a universally fixed one. It depends not only on the nature and quality of ingredients and desired properties of output. Storage of ingredients, method of mixing – manual or machine mixing, degree of supervision and control, transportation, placing and compacting the concrete, curing and workmanship etc also influences the mix proportions. Concrete mix design consist a series of steps to arrive at most economical ratio of quantities - choosing suitable ingredients, determination of their properties, assuming certain parameters based on code and project provisions and past experience, estimating material quantities, preparing trial mixes, testing in laboratory and field, adjusting quantities based on test results etc.

Concrete consists of cement, water, fine and coarse aggregates in various percentages. To enhance its properties sometimes admixtures are added. Cement and admixtures are factory made. There are more than ten varieties of cement and different grades viz., 33, 43 and 53 based on its compressive strength. Aggregates and water are locally available materials. The source, particle size distribution and shape of grains of aggregates vary from place to place. Water shall also meet certain specifications. Freshly prepared concrete is liquid and hardens quickly due to chemical reaction between cement and water. The ingredients are mixed in various quantities to produce a concrete which meets the objectives specified by the codes and project requirements. Sufficient workability is the criteria to be met during mixing, transporting, placing and compacting the concrete. In the hardened state, it shall possess i) the strength and stability requirement of ultimate state ii) meet the deflection and cracking criteria of serviceability state and iii) durable enough to resist weathering action and chemical attacks etc during its life time in various exposure conditions. Required minimum strength in compression of concrete at 28 days in MPa is represented by the grade of concrete viz**.,** M20, M30**,** and so on. The "M" points to Mix and Number after M (M20, M30) refers to specified compressive strength.

This wide variety of ingredients and various desired requirements of output concrete makes the mix design a tricky task. A lot of data need to be handled, adjustments need to be made based on deviations in properties of ingredients and iteration need to be performed based on test results etc. Computer software tools can be employed if procedures with a series of steps incorporating relevant data and suggesting necessary adjustments are developed. In this chapter mix design flowchart based on IS 10262-2009 and procedure with illustrative examples is presented so that readers can develop their own computer applications with ease.

III. FACTORS GUIDING MIX DESIGN

The desired traits of end product in different stages like bleeding, segregation, uniformity, permeability and durability etc., are the main guiding factors that influence the concrete mix design. Properties of ingredients, workmanship and quality control in mixing, placing, compacting and finishing, water cement ratio, quantity of cement etc., also play a vital role in the design mix. Mix design used for fresh concrete affect the properties of hardened concrete also. Weather conditions during in the initial stages and exposure conditions during working life also affect the mix design. Code specifications, past experience, testing laboratory and field specimens help in arriving at optimum mix design.

1. **Exposure Environment:** Concrete structures whether they are build above or below the ground or submerged in water come across variety of environmental conditions and chemical attacks. Severe rain, alternate wet and dry conditions, freeze and thaw, saline water and sulfate attack etc fall under these conditions. IS 456:2000 (Fourth revision, Table 3) has classified them from mild to extreme exposure conditions. Concrete may undergo deterioration and may require repair and maintenance to perform its function during its life cycle. Lower water-cement ratio, maintaining minimum cement quantity, using special cements and cementitious materials etc can reduce the impact of these exposure conditions on the durability of concrete.

2. **Compressive strength:** Concrete whether plain or reinforced shall possess minimum compressive strength prescribed by the project specifications. It is called characteristic compressive strength and described as grade of concrete like M30 etc. IS 456 recommends the minimum grade of concrete to be used in various exposure conditions as shown in Table 1.

   The term mean compressive strength to describe strength higher than characteristic compressive strength is also used in some codes. It is calculated using standard deviations given in Table 2 as explained in solved examples.

Table 1: Minimum cement quantity according to IS:456

Minimum cement quantity, maximum water-cement ratio, and minimum grade of concrete for different exposures with normal-weight aggregates of 20mm nominal maximum size

Exposure	Plain concrete			Reinforced concrete		
	Minimum cement quantity (kg/m³)	Maximum free water-cement ratio	Minimum grade of concrete	Minimum cement quantity (kg/m³)	Maximum free water-cement ratio	Minimum grade of concrete
Mild	220	0.60	+	300	0.55	M20
Moderate	240	0.60	M15	300	0.50	M25
Severe	250	0.50	M20	300	0.45	M30
Very severe	260	0.45	M20	340	0.45	M35
Extreme	280	0.40	M25	360	0.40	M40

Table 2: Assumed standard deviations (clause 9.2.4.2 and Table 11 of IS:456-2000)

Grade of concrete	Assumed standard deviation (N/mm^2)
M10 & M15	3.5
M20 & M25	4.0
M30 to M50	5.0

Strength development in concrete is influenced by kind and amount of cement, water/cement ratio, biggest size, grading and shape of aggregates, admixtures and curing etc. Strength varies in opposite to water/cement ratio, when other parameters are fixed. The maximum water-cement ratio shall not exceed the limit mentioned in IS 456 as shown in Table 1 as it affects the other properties. Strength can be increased by varying water to cement proportion, using higher cementitious materials, adding admixtures, minimizing bleeding and segregation, adopting proper finishing and curing measures etc.

3. **Durability:** Life span and performance of concrete deteriorates when exposed to harsh weather and harmful environments. Sulfate attacks, Alkali-silica reactions, corrosion and freeze-thaw cycles etc are some examples for these environmental conditions. Lower water cement ratio, cement quantity not less than prescribed in Table 1, use of special cements and cementitious materials and suitable aggregate composition can help in enhancing the durability.

4. **Workability:** The ease of mixing, placing, compacting and finishing of concrete and mortar is reflected in its workability. Concrete having low workability is difficult to use in narrow beams and columns, beam – column intersections and other congested places etc. It results in insufficient compaction and affects the strength and durability. Higher water cement ratio produces high workable concrete mixture which is prone to bleeding and segregation. Workability needs adjustment based on applied conditions like amount

and spacing of reinforcement and accessibility of point of application etc. Water quantity plays crucial role in modifying workability. Instead of increasing water quantity to achieve higher workability, water reducing admixtures can be employed. Spherical shaped aggregates can also enhance workability. Workability is popularly expressed in slump test measurements. Degree of workability for various placing conditions is given in IS 456.

5. **Water:** Water suitable for drinking can be used in concrete. Non potable water whch does not contain chlorides, sulfates, alkalies, solids and oils etc in harmful quamtities can also be used. Strength, durability and setting time will be altered , corrosion, staining and efflorescence etc are the other ill effects of impurities in water. Higher water quantity may facilitate workability but reduce strength and durability. Highest water quantity based on nominal maximum size of aggregate is specified in IS10262 as shown in Table 3.

Table 3: Maximum Water Quantity per Cubic Metre of Concrete for Nominal

Maximum Size of Aggregate (Clauses 4.2. A-5 and B-5 – IS 10262-2009)

Sl No	Nominal Maximum Size of Aggregate mm	Maximum Water Quantity kg
(1)	(2)	(3)
i)	10	208
ii)	20	186
iii)	40	165

6. **Cement:** Highly expensive ingredient in concrete is Cement and it should be used judiciously. Higher workability and smooth surface finish can be achieved by increasing cement. At the same time higher cement quantity can generate cracks in the concrete. Reduction of cement quantity affects the strength and durability of concrete. Minimum and maximum cement quantities are usually specified in project requirements. Variety of cements is available to meet the end use and exposure environments.

7. **Water to Cement proportion:** The binding agents of cement paste i.e., water and cement are added in a certain proportion in a concrete mix. The fraction of water to cement by weight is called water/cement ratio, w/c ratio. It is a critical parameter in mix design as it impacts all properties of concrete. Lower w/c ratio increases strength and durability. Higher w/c ratio increases workability and permeability. Highest w/c proportion is specified in the span of 0.4 to 0.6 by IS 456 as shown in Table 1 based on exposure condition. It is decreasing with increasing severity. W/C ratio can be optimized by adding water reducing admixtures.

8. **Aggregates:** Locally available materials such as gravel, crushed stone and sand etc are used as aggregates in concrete mix. They are inert materials but their surface should be clean from any chemical coatings. Their properties such as size, shape and texture varies from site to site. Hence it is difficult to produce uniform concrete across any state or country. Naturally available sand is more popular as fine aggregate. Manufactured sand

(M-sand) with proper gradation obtained by crushing hard stones is gaining adaptability. Proper combination of well graded coarse and fine aggregates improves the strength and durability. Uniform gradation produces a dense concrete with a better packing of particles. It reduces the water requirement and enhances workability. Gap graded aggregates require more water and tend to cause segregation and shrinkage cracks. The volume of coarse aggregate based on its nominal biggest size and grading zone of fine aggregate per unit volume of concrete is given in IS 10262 as shown in Table 4.

Table 4: Volume of Coarse Aggregate per Unit Volume of Total Aggregate for Different Zones of Fine Aggregate (Clauses 4.4, A-7 and B-7 - IS 10262-2009)

Sl No	Nominal maximum size of aggregate	Volume of Coarse Aggregate[1)] per Unit Volume of Total Aggregate for Different Zones of Fine Aggregate			
	mm	Zone IV	Zone III	Zone II	Zone I
(1)	(2)	(3)	(4)	(5)	(6)
i)	10	0.50	0.48	0.46	0.44
ii)	20	0.66	0.64	0.62	0.60
iii)	40	0.75	0.73	0.71	0.69
[1)] Volumes are based on aggregates in saturated surface dry condition					

Bigger size particles requires less cement and produce a leaner mix where as small size particles increases surface area and induce higher strength due to better bonding with cement paste. In case of reinforced concrete, biggest size of the particles shall be less than the distance between reinforcement bars.

9. **M-Sand:** Quantity of Manufactured sand (M-sand) as fine aggregate can be estimated based on grading zone and making allowance for its Free (surface) water and moisture absorption

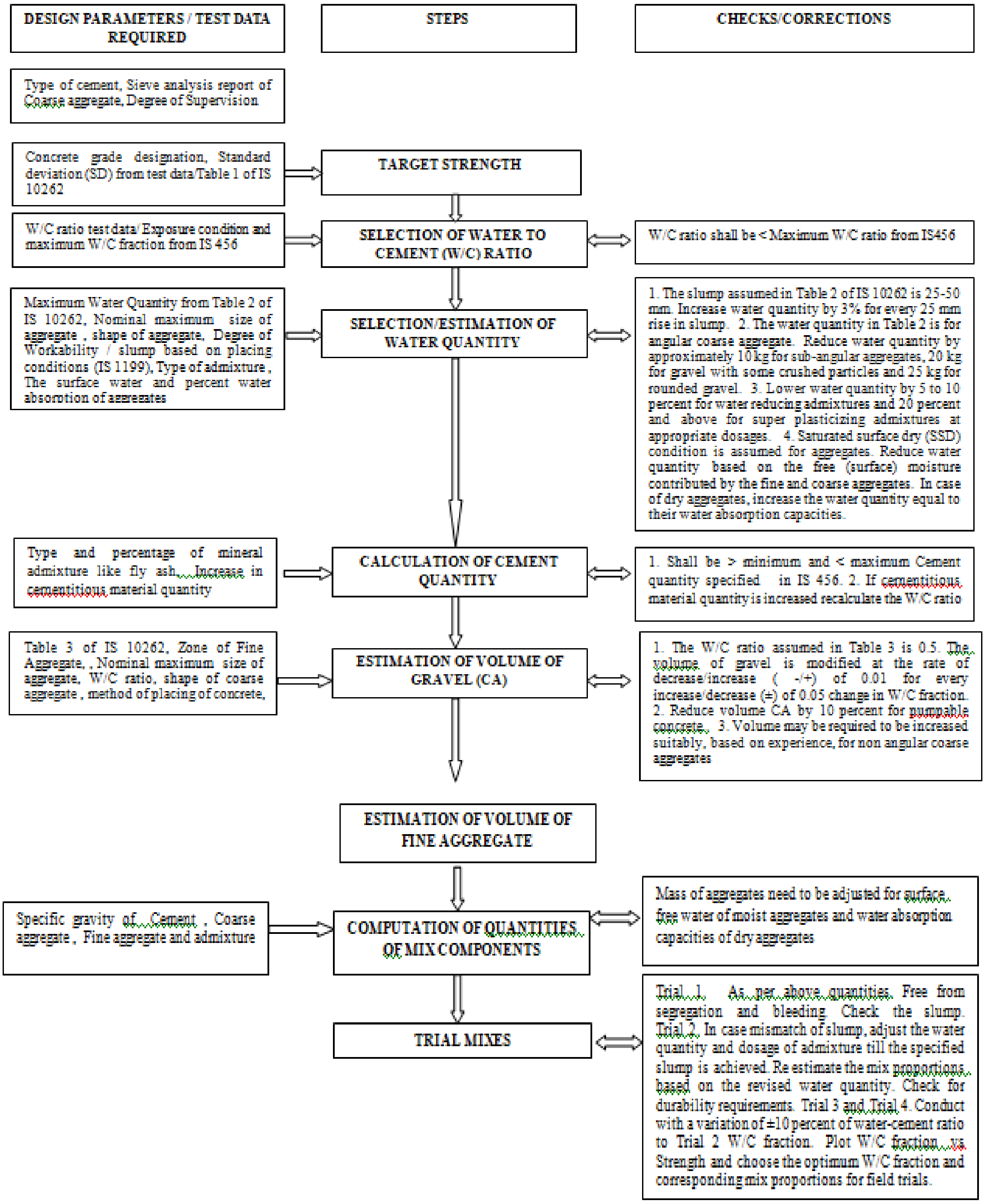
10. **Admixtures:** Performance of concrete can be enhanced by altering its properties through addition of some substances called admixtures to concrete mix. Chemical admixtures help in reducing water quantity (plasticizers, super plasticizers), Accelerating and retarding the setting time (accelerators and set retarders), slow down corrosion (corrosion inhibiting), control drying shrinkage and cracking (shrinkage reducing) etc. Mineral admixtures also called as cementitious materials can partially replace cement quantity. Fly ash, silica fume and blast furnace slag etc are mineral admixtures added to concrete to enhance its strength, workability and durability. The quantities of these admixture to be used in concrete mix depends manufacturer recommendations and relevant codes. Proportions of concrete mix design need to be adjusted when these admixtures are added to the concrete**.**

11. **Quality control:** Quality control in choosing right materials, batching, mixing , workmanship and supervision etc can influnce the properties of concrte in fresh and hardened state. It can be npticed from testing of specimens. The deviation of results from the mean strength shall be with in specified limits.

IV. MIX DESIGN FLOWCHART AND PROCEDURES AS PER IS 10262-2009

Mix design calls for input data from engineers, design parameters as per project specifications and data from testing of materials. Using this data calculations are carried out in sequential steps. The results of the calculations need to be verified and modified with respect to the limits specified in the relevant codes and material properties. Trial mixes are casted and tested at specified time intervals. If the test results do not satisfy mean strength criteria, the design calculations are repeated with changes in materials or their quantities or both till the desired results are achieved. All these steps, design parameters and checks and corrections are illustrated in a flowchart and procedures in detail as shown below. Based on this flow chart and procedures engineers can develop computer models and calculation spread sheets for easy and repeated calculations.

1. Flowchart


DESIGN PARAMETERS / TEST DATA REQUIRED
STEPS
CHECKS/CORRECTIONS
Type of cement, Sieve analysis report of Coarse aggregate, Degree of Supervision
Concrete grade designation, Standard deviation (SD) from test data/Table 1 of IS 10262
TARGET STRENGTH
W/C ratio test data/ Exposure condition and maximum W/C fraction from IS 456
SELECTION OF WATER TO CEMENT (W/C) RATIO
W/C ratio shall be < Maximum W/C ratio from IS456
Maximum Water Quantity from Table 2 of IS 10262, Nominal maximum size of aggregate , shape of aggregate, Degree of Workability / slump based on placing conditions (IS 1199), Type of admixture , The surface water and percent water absorption of aggregates
SELECTION/ESTIMATION OF WATER QUANTITY
1. The slump assumed in Table 2 of IS 10262 is 25-50 mm. Increase water quantity by 3% for every 25 mm rise in slump. 2. The water quantity in Table 2 is for angular coarse aggregate. Reduce water quantity by approximately 10 kg for sub-angular aggregates, 20 kg for gravel with some crushed particles and 25 kg for rounded gravel. 3. Lower water quantity by 5 to 10 percent for water reducing admixtures and 20 percent and above for super plasticizing admixtures at appropriate dosages. 4. Saturated surface dry (SSD) condition is assumed for aggregates. Reduce water quantity based on the free (surface) moisture contributed by the fine and coarse aggregates. In case of dry aggregates, increase the water quantity equal to their water absorption capacities.
Type and percentage of mineral admixture like fly ash. Increase in cementitious material quantity
CALCULATION OF CEMENT QUANTITY
1. Shall be > minimum and < maximum Cement quantity specified in IS 456. 2. If cementitious material quantity is increased recalculate the W/C ratio
Table 3 of IS 10262, Zone of Fine Aggregate, , Nominal maximum size of aggregate, W/C ratio, shape of coarse aggregate , method of placing of concrete,
ESTIMATION OF VOLUME OF GRAVEL (CA)
1. The W/C ratio assumed in Table 3 is 0.5. The volume of gravel is modified at the rate of decrease/increase (-/+) of 0.01 for every increase/decrease (±) of 0.05 change in W/C fraction. 2. Reduce volume CA by 10 percent for pumpable concrete. 3. Volume may be required to be increased suitably, based on experience, for non angular coarse aggregates
ESTIMATION OF VOLUME OF FINE AGGREGATE
Specific gravity of Cement , Coarse aggregate , Fine aggregate and admixture
COMPUTATION OF QUANTITIES OF MIX COMPONENTS
Mass of aggregates need to be adjusted for surface free water of moist aggregates and water absorption capacities of dry aggregates
TRIAL MIXES
Trial 1. As per above quantities. Free from segregation and bleeding. Check the slump. Trial 2. In case mismatch of slump, adjust the water quantity and dosage of admixture till the specified slump is achieved. Re estimate the mix proportions based on the revised water quantity. Check for durability requirements. Trial 3 and Trial 4. Conduct with a variation of ±10 percent of water-cement ratio to Trial 2 W/C fraction. Plot W/C fraction vs Strength and choose the optimum W/C fraction and corresponding mix proportions for field trials.

2. Procedure

Step 1: Collect all the required project specifications and test data as shown below

<table>
<tr><th colspan="2">Item</th><th colspan="6">Data</th></tr>
<tr><td rowspan="2">Concrete</td><td>Grade designation</td><td colspan="6"></td></tr>
<tr><td>Type of Concrete</td><td colspan="6"></td></tr>
<tr><td rowspan="4">Cement</td><td>Type of Cement</td><td colspan="6"></td></tr>
<tr><td>Lowest cement quantity</td><td colspan="6"></td></tr>
<tr><td>Highest cement quantity</td><td colspan="6"></td></tr>
<tr><td>Specific gravity</td><td colspan="6"></td></tr>
<tr><td>Mineral admixture</td><td>Type</td><td colspan="6"></td></tr>
<tr><td></td><td>Specific gravity</td><td colspan="6"></td></tr>
<tr><td rowspan="12">Aggregate</td><td>Maximum nominal size</td><td colspan="6"></td></tr>
<tr><td>Type and Shape of aggregate</td><td colspan="6"></td></tr>
<tr><td></td><td colspan="5">Gravel</td><td>Fine aggregate</td></tr>
<tr><td>Specific gravity</td><td colspan="5"></td><td></td></tr>
<tr><td>Water absorption</td><td colspan="5"></td><td></td></tr>
<tr><td>Free (surface) moisture</td><td colspan="5"></td><td></td></tr>
<tr><td rowspan="6">Sieve analysis gradation</td><td rowspan="2">IS Sieve size mm</td><td colspan="3">Analysis of gravel Fraction</td><td>Remarks</td><td rowspan="6"></td></tr>
<tr><td>I</td><td>II</td><td>Combined (x% of I + y% of II)</td><td rowspan="5">Conforming to IS 383</td></tr>
<tr><td>20</td><td></td><td></td><td></td></tr>
<tr><td>10</td><td></td><td></td><td></td></tr>
<tr><td>4.75</td><td></td><td></td><td></td></tr>
<tr><td>2.36</td><td></td><td></td><td></td></tr>
<tr><td colspan="2">Highest water to cement fraction</td><td colspan="6"></td></tr>
<tr><td colspan="2">Workability</td><td colspan="6"></td></tr>
<tr><td colspan="2">Exposure environment</td><td colspan="6"></td></tr>
<tr><td colspan="2">Method of concrete placing</td><td colspan="6"></td></tr>
<tr><td colspan="2">Degree of supervision</td><td colspan="6"></td></tr>
<tr><td colspan="2">Chemical admixture type conforming to IS 9103</td><td colspan="6"></td></tr>
</table>

Step 2: Calculate Target mean strength of Concrete

$f'_{ck} = f_{ck} + 1.65\ s$

where f'_{ck} = target mean compressive strength at 28 days,

f_{ck} = characteristic compressive strength at 28 days corresponding to grade of concrete. Minimum grade of concrete can be chosen from IS 456 based on exposure condition and type of concrete (Plain/Reinforced) and s = standard deviation, From Table 1 of IS 10262-2009 Values of s are to be increase by 1N/mm^2 if proper supervision and control in preservation of cement, weigh batching of all ingredients and regulated nixing of water etc. are not followed

Step 3: Decide Water-Cement fraction

From IS 456, based on exposure condition and type of concrete (Plain/Reinforced), Maximum permissible water-cement ratio can be picked. Based on experience and test data, water-cement ratio less than max W-C ratio can also be adopted.

Step 4: Determination of Water quantity
Table 2 of IS 10262-2009 stipulates highest water quantity for angular coarse and saturated surface dry gravel and for a slump of 25 to 50 mm without any admixtures.
a). If the slump is more than 50 mm rise water quantity by 3% for every 25 mm rise in slump.
b). Reduce water quantity by approximately 10 kg for sub-angular aggregates, 20 kg for gravel with some crushed particles and 25 kg for rounded gravel.
c). Lower water quantity by 5 to 10 percent for water decreasing admixtures and 20 percent and above for super plasticizing admixtures at appropriate dosages.
d). Saturated surface dry (SSD) condition is assumed for aggregates. Reduce water quantity based on the free (surface) moisture contributed by the fine and coarse aggregates. In case of dry aggregates, increase the water quantity equal to their water absorption capacities.

Step 5: Determination of Cement/Cementitious (cement +mineral admixture) material Quantity
Cement/Cementitious material quantity in kg/m^3 = water quantity in litres determined in step 4 / water-cement ratio decided in step 3
It shall not be less than the minimum cement quantity and not more than maximum cement quantity specified in IS 456 and by the project.

If mineral admixture is used
In some special conditions, cementations material quantity is increased based on experience and trial.
Then calculate the revised cementitious material quantity and modified water-cement ratio.
Revised cementitious material quantity = Cementitious material quantity * [1+ (%increase/100)]
Modified water-cement ratio = water quantity/ Revised cementitious quantity
Select the percentage xx of mineral admixture to be used based on project requirement and quality of materials.
Mineral admixture quantity @ xx% of total cementitious material quantity = Revised cementitious material quantity * xx/100
Cement quantity = Revised cementitious material quantity - Mineral admixture quantity

Step 6: Fractions of Coarse and Fine aggregate quantity by volume
From Table 3 of IS 10262-2009 volume of coarse aggregate can be obtained corresponding to 20 mm size aggregate and zone of fine aggregate for a water-cement ratio of 0.50 .
a) Modify the proportion of volume of coarse aggregate at the rate of 0.01 decrease/ increase (-/+) for every increase/decrease (±) of 0.05 change in W/C ratio.
b) Reduce the volume CA by 10 percent for pumpable concrete
c). Volume may be required to be increased suitably, based on experience, for non angular coarse aggregates
fraction of volume of fine aggregate quantity = 1 – proportion of volume of coarse aggregate

Step 7: Calculation of quantities of ingredients
The mix calculations per unit volume of concrete shall be as follows:
a) Volume of concrete = 1 m^3
b) Volume of cement m^3 = (Mass of cement calculated as in step 5 * 1) /(Specific gravity of cement 1000)

c) Volume of water m^3 = (Mass of water calculated as in step 4 * 1) /(Specific gravity of water 1000)
d) Volume of chemical admixture (super plasticizer) (@ 2.0 percent by mass of cementitious material)

Mass of admixture, kg = Mass of cement calculated as in step 5 *0.02
Volume, m^3 = (Mass of admixture * 1) /(Specific gravity of admixture * 1000)

e) Volume of aggregates (coarse + fine) = [Volume of concrete – (Volume of cement + Volume of water + Volume of admixture)]

= [a- (b +c +d)]

f) Mass of gravel, kg = volume of aggregates calculated in step e x fraction of coarse aggregate calculated as in step 6 x Specific gravity of coarse aggregate x 1000
g) Mass of fine aggregate, kg = volume of aggregates calculated in step e x fraction of fine aggregate calculated as in step 6 x Specific gravity of fine aggregate x 1000

Step 8: Trial Mixes
Conduct 4 trials. Check the slump, durability requirements and strength. Plot Water-Cement ratio vs Strength and choose the optimum W/C fraction and corresponding mix proportions for field trials.

Trial 1: Quantities for Mix as calculated above
Cement = kg/m^3
Water = kg/m^3 or litres/ m^3
Fine aggregate = kg/m^3
Coarse aggregate = kg/m^3
Chemical admixture = kg/m^3
Water-cement ratio =
Concrete should be free from segregation and bleeding. Check the slump.

Trial 2: In case mismatch of slump, adjust the water quantity and dosage of admixture till the specified slump is achieved. Re estimate the mix proportions based on the revised water quantity. Check for durability requirements.

Trial 3 and Trial 4: Conduct with a variation of ±10 percent of water-cement ratio to Trial 2 W-C ratio.

V. SOLVED EXAMPLES

Mix design examples using different types and shapes of coarse aggregates and with and without addition of fly ash are explained below. They will help in application of various steps and verification of results if calculations are done in computer models developed based on the flowchart presented earlier

Example 1: Design M25 concrete as per the data given below.

Step 1: Collect all the required project specifications and test data as shown below

<table>
<tr><th colspan="2">Item</th><th colspan="6">Data</th></tr>
<tr><td rowspan="2">Concrete</td><td>Grade designation</td><td colspan="6">M25</td></tr>
<tr><td>Type of Concrete</td><td colspan="6">Reinforced Cement Concrete</td></tr>
<tr><td rowspan="4">Cement</td><td>Type of Cement</td><td colspan="6">Grade 53 conforming to IS 12269</td></tr>
<tr><td>Lowest cement quantity</td><td colspan="6">300</td></tr>
<tr><td>Highest cement quantity</td><td colspan="6">450 kg/m^3</td></tr>
<tr><td>Specific gravity</td><td colspan="6">3.15</td></tr>
<tr><td rowspan="2">Mineral admixture</td><td>Type</td><td colspan="6">Nil</td></tr>
<tr><td>Specific gravity</td><td colspan="6">-</td></tr>
<tr><td rowspan="12">Aggregate</td><td>Maximum nominal size</td><td colspan="6">20</td></tr>
<tr><td>Type and Shape of aggregate</td><td colspan="6">Crushed granite and Sub angular</td></tr>
<tr><td></td><td colspan="5">Gravel</td><td>Fine aggregate</td></tr>
<tr><td>Specific gravity</td><td colspan="5">2.67</td><td>2.6</td></tr>
<tr><td>Water absorption</td><td colspan="5">0.5%</td><td>nil</td></tr>
<tr><td>Free (surface) moisture</td><td colspan="5">nil</td><td>2%</td></tr>
<tr><td rowspan="6">Sieve analysis gradation</td><td rowspan="2">IS Sieve size mm</td><td colspan="3">Analysis of Coarse Aggregate Fraction</td><td>Remarks</td><td rowspan="6">Conforming to Zone I IS 383</td></tr>
<tr><td>I</td><td>II</td><td>Combined (55% of I + 45% of II)</td><td rowspan="5">Confor ming to IS 383</td></tr>
<tr><td>20</td><td>100</td><td>100</td><td>100</td></tr>
<tr><td>10</td><td>10</td><td>50</td><td>28</td></tr>
<tr><td>4.75</td><td></td><td>10</td><td>4.5</td></tr>
<tr><td>2.36</td><td></td><td></td><td></td></tr>
<tr><td colspan="2">Highest water to cement fraction</td><td colspan="6">0.50</td></tr>
<tr><td colspan="2">Workability</td><td colspan="6">75 mm</td></tr>
<tr><td colspan="2">Exposure environment</td><td colspan="6">moderate</td></tr>
<tr><td colspan="2">Method of concrete placing</td><td colspan="6">pumpable</td></tr>
<tr><td colspan="2">Degree of supervision</td><td colspan="6">Intermittent supervision</td></tr>
<tr><td rowspan="2">Chemical admixture type conforming to IS 9103</td><td>Type</td><td colspan="6">High range water reducing admixture – HRWR @ 2% of Cement wt</td></tr>
<tr><td>Specific gravity</td><td colspan="6">1.145</td></tr>
</table>

Step 2: Calculate Target mean strength of Concrete

$f'_{ck} = f_{ck} + 1.65\ s$

Target strength = 25 + 1.65 *5 = 33.25 N/mm^2

s= 4 from Table1 of IS 10262-2009; Add 1N/mm^2 as supervision is intermittent

Step 3: Decide Water to Cement proportion

From IS 456, for moderate exposure condition and Reinforced concrete (Plain/), Maximum permissible water-cement ratio is 0.5. Consider 0.45 as water-cement ratio. It is less than 0.50.

Step 4: Determination of Water quantity

From Table 2 of IS 10262-2009, highest water quantity = 186 litre for angular coarse and saturated surface dry aggregate and for a slump of 25 to 50 mm without any admixtures.

a). slump is 75 mm. Hence increase water quantity by 3%.Water quantity = 186 *1.03 = 192 litre
b). Reduce water quantity by approximately 10 kg for sub-angular aggregates, water quantity = 192-10 = 182 litre
c). Lower water quantity by 25 percent for High range water reducing admixture. = 182*0.75 = 137 litre
d). Saturated surface dry (SSD) condition is assumed for aggregates.

Step 5: Determination of Cement Quantity
Cement quantity in kg/m^3 = 137/0.45 = 304 kg. It is more than minimum cement quantity of 300 kg

Step 6: Fractions of Coarse and Fine aggregate quantity by volume
From Table 3 of IS 10262-2009 volume of coarse aggregate is 0.60 corresponding to 20 mm size aggregate and zone of fine aggregate I for a water-cement ratio of 0.50
a) Modify the proportion of volume of coarse aggregate at the rate of 0.01 decrease/increase (-/+) for every increase/decrease (±) of 0.05 change in W/C ratio.
For 0.45 W/C ratio Volume of CA = 0.60+(0.01*0.05/0.05) =0.61
b) Reduce the volume CA by 10 percent for pumpable concrete, Volume of CA = 0.61*0.9 = 0.55
Fraction of volume of fine aggregate quantity = I – 0.55=0.45

Step 7: Determination of quantities of ingredients
The mix calculations per unit volume of concrete shall be as follows:
a) Volume of concrete = 1 m^3
b) Volume of cement m^3 = (304 * 1) /(3.15 *1000) = 0.097 m^3
c) Volume of water m^3 = (137 * 1) /(1 *1000) = 0.137 m^3
d) Volume of chemical admixture (super plasticizer) (@ 2.0 percent by mass of cementitious material)

Mass of admixture kg = 304 *0.02 = 6.08 kg
Volume m^3 = (6.08 * 1) /(1.145 *1000) = 0.005 m^3

e) Volume of aggregates (coarse + fine) = [a- (b +c +d)] = 1- (0.097+0.137+0.005) = 0.761 m^3
f) Mass of coarse aggregate kg = volume of aggregates calculated in step e x fraction of coarse aggregate calculated as in step 6 x Specific gravity of coarse aggregate x 1000 = 0.761*0.55*2.67*1000 = 1118 kg
g) Mass of fine aggregate kg = volume of aggregates calculated in step e x fraction of fine aggregate calculated as in step 6 x Specific gravity of fine aggregate x 1000 = 0.761*0.45*2.6*1000 = 890 kg
h) Adjustment of for free moisture quantity on fine aggregate.
a) Reduce water quantity based on the free (surface) moisture quantity 2% for fine aggregates = 890*0.02 = 18 kg or litre
Hence water quantity = 137-18 = 119 litre
b) Increase fine aggregate based on the free (surface) moisture quantity 2% for fine aggregates.
Hence fine aggregate quantity = 890+18 = 908 kg

Trial 1: Quantities for Mix as calculated above
Cement = 304 kg/m^3
Water = 119 kg/m^3 or litre / m^3
Fine aggregate = 908 kg/m^3
Gravel = 1118 kg/m^3
Chemical admixture = 6.08 kg/m^3
Water to cement fraction = 0.45
Concrete should be free from segregation and bleeding. Check the slump.

Trial 2: In case mismatch of slump, adjust the water quantity and dosage of admixture till the specified slump is achieved. Re estimate the mix proportions based on the revised water quantity. Check for durability requirements.

Trial 3 and Trial 4: Conduct with a variation of ±10 percent of water-cement ratio to Trial 2 W-C ratio.

Example 2: Design M25 concrete using fly ash and as per the data given below.

Step 1: Collect all the required project specifications and test data as shown below

Item		**Data**					
Concrete	Grade designation	M25					
	Type of Concrete	Reinforced Cement Concrete					
Cement	Type of Cement	Grade 53 conforming to IS 12269					
	Lowest cement quantity	300					
	Highest cement quantity	450 kg/m^3					
	Specific gravity	3.15					
Mineral admixture	Type	Fly ash Conforming to IS 3812 (Part I)					
	Specific gravity	2.2					
Aggregate	Maximum nominal size	20					
	Type and Shape of aggregate	Crushed granite and Sub angular					
		Gravel					Fine aggregate
	Specific gravity	2.67					2.6
	Water absorption	0.5%					nil
	Free (surface) moisture	nil					2%
	Sieve analysis gradation	IS Sieve size mm	Analysis of Coarse Aggregate Fraction			Remarks	Conforming to Zone I IS 383
			I	II	Combined (55% of I + 45% of II)	Conforming to IS 383	
		20	100	100	100		
		10	10	50	28		
		4.75		10	4.5		
		2.36					
Highest water-cement ratio		0.50					
Workability		75 mm					
Exposure Environment		moderate					
Method of concrete placing		pumpable					
Degree of supervision		Intermittent supervision					
Chemical admixture type conforming to IS 9103	**Type**	High range water reducing admixture - HRWR					
	Specific gravity	1.145					

Step 2: Calculate Target mean strength of Concrete

$f'_{ck} = f_{ck} + 1.65\ s$
Target strength = 25 + 1.65 *5 = 33.25 N/mm^2
s= 4 from Table1 of IS 10262-2009; Add 1N/mm^2 as supervision is intermittent

Step 3: Decide Water to Cement fraction
From IS 456, for moderate exposure condition and Reinforced concrete, Maximum permissible water to cement fraction is 0.5. Consider 0.45 as water to cement fraction. It is less than 0.50.

Step 4: Determination of Water quantity

From Table 2 of IS 10262-2009, highest water quantity = 186 litre for angular coarse and saturated surface dry aggregate and for a slump of 25 to 50 mm without any admixtures.
a). slump is 75 mm. Hence rise water quantity by 3%. Water quantity = 186 *1.03 = 192 litres
b). Decrease water quantity by approximately 10 kg for sub-angular aggregates, water quantity = 192-10 = 182 litres
c). Lower water quantity by 25 percent for High range water reducing admixture. = 182*0.75 = 137 litres
d). Saturated surface dry (SSD) condition is assumed for aggregates.

Step 5: Determination of Cementitious (cement + fly ash) material Quantity

Cementitious (cement + fly ash) material quantity in kg/m^3 = 137/0.45 = 304 kg. It is more than prescribed lowest cement quantity of 300 kg

Fly ash proportion and quantity

Based on previous experience and trials, higher cementitious quantity can be used.
Assume a 12% hike in cementitious material quantity
The revised cementitious quantity = 304*1.12 = 340 kg/m^3
and modified water to cement fraction= 137/340 = 0.40
Consider percentage of fly ash in cementitious quantity as 28% based on project requirement and quality of materials.
Fly ash quantity = 340 * 0.28 = 95 kg/m^3
Cement (OPC) quantity = 340 – 95 = 245 kg/m^3

Step 6: Fractions of Coarse and Fine aggregate quantity by volume
From Table 3 of IS 10262-2009 volume of gravel is 0.60 corresponding to 20 mm size aggregate and zone I of fine aggregate for a water to cement fraction of 0.50
a) Modify the proportion of volume of gravel at the rate of 0.01 decrease/increase (-/+) for every increase/decrease (±) of 0.05 change in W/C fraction.
For 0.40 W/C fraction, Volume of CA = 0.60+(0.01*0.1/0.05) =0.60+0.02=0.62
b) Lower the volume CA by 10% for pumpable concrete, Volume of CA = 0.62*0.9 = 0.56
Fraction of volume of fine aggregate quantity = 1 – 0.56=0.44

Step 7: Determination of quantities of ingredients

The mix calculations per unit volume of concrete shall be as follows:
a) Volume of concrete = 1 m^3
b) Volume of cement m^3 = (245 * 1) /(3.15 *1000) = 0.078 m^3
c) Volume of fly ash m^3 = (95 * 1) /(2.2*1000) = 0.043 m^3
d) Volume of water m^3 = (137 * 1) /(1 *1000) = 0.137 m^3
e) Volume of chemical admixture (superplasticizer) (@ 2.0 percent by mass of cementitious material)

Mass of admixture kg = 340 *0.02 = 6.8 kg
Volume m^3 = (6.8 * 1) /(1.145 *1000) = 0.006 m^3

f) Volume of aggregates (coarse + fine) = [a- (b +c +d+e)] = 1- (0.078+0.043+0.137+0.006) = 0.736 m^3
g) Mass of gravel, kg = volume of aggregates calculated in step e x fraction of coarse aggregate calculated as in step 6 x Specific gravity of coarse aggregate x 1000 = 0.736*0.56*2.67*1000 = 1100 kg
h) Mass of fine aggregate kg = volume of aggregates calculated in step e x fraction of fine aggregate calculated as in step 6 x Specific gravity of fine aggregate x 1000 = 0.736*0.44*2.6*1000 = 842 kg
i) Adjustment of for free moisture quantity on fine aggregate.
a) Lower water quantity based on the free (surface) moisture quantity 2% for fine aggregates = 842*0.02 = 17 kg or litres
Hence water quantity = 137-17 = 120 litres
b) Increase fine aggregate based on the free (surface) moisture quantity 2% for fine aggregates.
Hence fine aggregate quantity = 842+17 = 859 kg

Trial 1: Quantities for Mix as calculated above

Cement = 245 kg/m^3
Fly ash = 95 kg/m^3
Water = 120 kg/m^3 or litres / m^3
Fine aggregate = 859 kg/m^3
Gravel = 1100 kg/m^3
Chemical admixture = 6.8 kg/m^3
Water-cement ratio = 0.40
Concrete should be free from segregation and bleeding. Check the slump.

Trial 2: In case mismatch of slump, adjust the water quantity and dosage of admixture till the specified slump is achieved. Re estimate the mix proportions based on the revised water quantity. Check for durability requirements.

Trial 3 and Trial 4: Conduct with a variation of ±10 percent of water-cement ratio to Trial 2 W-C ratio.

Note: Final strength**,** Water-cement ratio and Slump properties of concrete need to be consistent with stipulations of IS 456 and project specifications.

REFERENCES

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