GIVEN
- Bridge deck in Ontario f'c (28 days) = 30 MPa - EXPOSURE CLASS
- Cement
- BSG = 3.15
- Coarse aggregate
- 20-mm nominal maximum size BSG=2.60
- AC=0.5% - the link between Oven Dry and Surface Saturated Dry
- BSG(OD) - 2.60 - given at over dry - M/(V x density of water) = bulk specific gravity
- Bulk density = 1600 kg/m3 - dry rodded density, therefore its volume will decrease in cement
- Aggregate is in SSD condition

DRY RODDED - a dry compact measurement of a substances density that will change once in cement given by a ratio in a lower table, Decrease in volume is caused by the space between each dry aggregrate

Fine aggregate BSG=2.60
- AC=0.7%
- FM = 2.80
- Aggregate is in SSD condition

Take Slump = a maximum of 100
Exposure Class = C1, therefore Max W/C ratio = 0.4 & minimum specific 28 day strength = 35 MPa & also a category 1 air content

From table 9-11: F'c = 35, within the table of 21 - 35 therefore add 8.5 MPa to our F'c
therefore new strength requirement = 35 + 8.5 = 43.5MPa

on Table 9-3, our MPa input is 43.5 therefore our W/C ratio will be equal to 0.31 which is under the Class C1 requirement.

On Table 9-5, following our aggregate size and slump measurement, we have air entrained concrete so therefore in category 1 we would take a 5 - 8% air content ratio, always taking the higher value, our value is 8% in comparison to the water(kg per m^3 of concrete)

mass of cement = 184/0.31 = 593kg/m^3 of concrete (used the W/C ratio to solve, 184 amount of water from table 9-5)

Coarse aggregate: table 9-4, nominal size = 20mm, M = 1600(density) x 0.62(ratio from table) = 992kg/m^3 of concrete

CONVERT ALL VALUES INTO VOLUME (using V = m/(S.G. x denisty H20))

Vol water = 184/1x1000 = 0.184m^3
Vol cement = 593/(3.15 x 1000) = 0.188M^3
Vol Coarse Agg = 992/(2.6 x 1000) = 0.381m^3
Vol air = 8% = 0.08m^3 total = 0.833m^3

Vol Fine Agg = 1 - total volume = 1 - 0.833 = 0.167m^3

mass Fine Agg = 0.167 x 2.60 x 1000 (volume x S.G. x density water)
= 434 kg/m^3 of concrete

water = 184kg, cement = 593kg, CA = 992kg, FA = 434kg, Air = 8kg

Concrete Mix Design

Design of Concrete Mixtures

- Select suitable ingredients
- Determine relative quantities ("proportioning")
  - economy
  - workability
  - strength & durability
  - Appearance

Mix Characteristics

- Strength
- Water-cementing materials ratio
- Aggregate size and volume
- Air content
- Slump and workability
- Water content
- Cementing materials content and type
- Admixtures

Mix Design Procedure

1. Required information
2. Choice of slump
3. Maximum aggregate size
4. Water/cement ratio
5. Estimation of mixing water & air content
6. Calculation of cement content
7. Estimation of coarse aggregate content
8. Estimation of fine aggregate content
9. Adjustment for moisture in the aggregate
10. Trial batch

(1) Required (given) Information

- Bridge deck in Ontario
- f'_c (28 days) = 30 MPa
- Cement
  - SG = 3.15
- Coarse aggregate
  - 20-mm nominal maximum size
  - BSG = 2.60
  - AC = 0.5%
  - Bulk density = 1600 kg/m^3
  - Aggregate is in SSD condition

(1) Required Information (cont'd)

- Fine aggregate
  - BSG = 2.60
  - AC = 0.7%
  - FM = 2.80
  - Aggregate is in SSD condition

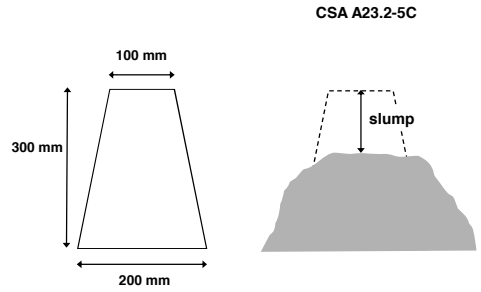
Mix Design Procedure

1. Required information
2. Choice of slump
3. Maximum aggregate size
4. Water/cement ratio
5. Estimation of mixing water & air content
6. Calculation of cement content
7. Estimation of coarse aggregate content
8. Estimation of fine aggregate content
9. Adjustment for moisture in the aggregate
10. Trial batch

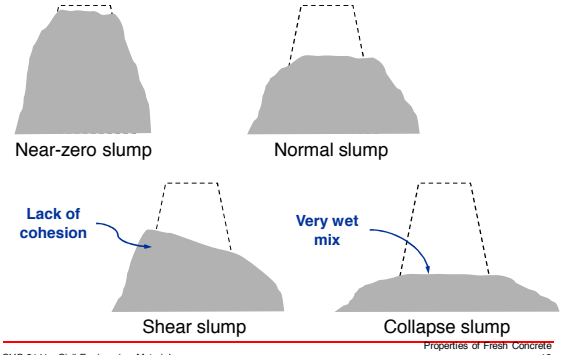
Mix Design Procedure

1. Required information
2. Choice of slump
3. Maximum aggregate size
4. Water/cement ratio
5. Estimation of mixing water & air content
6. Calculation of cement content
7. Estimation of coarse aggregate content
8. Estimation of fine aggregate content
9. Adjustment for moisture in the aggregate
10. Trial batch

Slump



Types of Slump



Slump test

(2) Choice of Slump

Table 9-6. Recommended Slumps for Various Types of Construction

Concrete construction	Slump, mm	
	Maximum*	Minimum
Reinforced foundation walls and footings	75	25
Plain footings, caissons, and substructure walls	75	25
Beams and reinforced walls	100	25
Building columns	100	25
Pavements and slabs	75	25
Mass concrete	75	25

*May be increased 25 mm for consolidation by hand methods, such as rodding and spading.
Plasticizers can safely provide higher slumps.
Adapted from ACI 211.1.

(From "Design and Control of Concrete Mixtures" by Cement Association of Canada)

Mix Design Procedure

1. Required information
2. Choice of slump
3. Maximum aggregate size
4. Water/cement ratio
5. Estimation of mixing water & air content
6. Calculation of cement content
7. Estimation of coarse aggregate content
8. Estimation of fine aggregate content
9. Adjustment for moisture in the aggregate
10. Trial batch

(3) Maximum Aggregate Size

- ≤ 1/5 min. dimension between forms
- ≤ 3/4 min. clear spacing between bars or between bars & forms
- ≤ 1/3 slab depth
- Here given to 20 mm

Mix Design Procedure

1. Required information
2. Choice of slump
3. Maximum aggregate size
4. Water/cement ratio
5. Estimation of mixing water & air content
6. Calculation of cement content
7. Estimation of coarse aggregate content
8. Estimation of fine aggregate content
9. Adjustment for moisture in the aggregate
10. Trial batch

(4) Water-to-Cement Ratio

- Strength
- Durability

Exposure Classes

CSA A23.1

chloride	C-1	Structurally r.c. exposed to Cl w/ or w/o freezing & thawing (bridge decks, parking decks & ramps, …)
chloride	C-2	Non-structurally r.c. (plain) exposed to Cl & freezing & thawing (garage floors, sidewalks, steps, curbs, …)
chloride	C-3	Submerged concrete exposed to Cl but not freezing & thawing (underwater portions of marine structures)
chloride	C-4	Non-structurally r.c. exposed to Cl but not freezing & thawing (underground parking slabs on grade)
freeze thaw	F-1	Saturated concrete exposed to freezing & thawing but not to Cl (pool decks, patios, freshwater control structures, …)
freeze thaw	F-2	Unsaturated concrete exposed to freezing & thawing but not to Cl (exterior walls & columns)
	N	Concrete not exposed to Cl nor to freezing & thawing (footings & interior slabs, walls & columns)

W/C & Strength Requirements

Table 9-1. Maximum Water-Cementing Materials Ratios and Minimum Design Strengths for Various Exposure Conditions*

Requirements for specifying concrete	Requirements for concrete		
Class of Exposure*	Maximum water-to-cementing materials ratio	Minimum, specified 28-day compressive strength, MPa	Air content category
C-1	0.40	35	**
C-2	0.45	32	1
C-3	0.50	30	2
C-4	0.55	25	2
F-1	0.50	30	1***
F-2	0.55	25	2***
N	For structural design	For structural design	

* See Table 8-2 or this Chapter for a description of classes of exposure.
** Use Category 1 for concrete exposed to freezing and thawing.
Use Category 2 for concrete not exposed to freezing and thawing.
*** Interior ice rink slabs and freezer slabs with a steel-troweled finish have been found to perform satisfactorily without entrained air.
Source: CSA Standard A23.1.

(From "Design and Control of Concrete Mixtures" by Cement Association of Canada)

Strength Requirements

- P.248 of Mamlouk's book
- CSA A23.1 Required Strength When Data Are Available to Establish a Standard Deviation

Required Avg. Compressive Strength

Specified compressive strength, f'_c MPa	Required average compressive strength, f'_{cr}, MPa
≤ 35	$f'_{cr} = f'_c + 1.34s$ $f'_{cr} = f'_c + 2.33s - 3.45$ Use larger value
Over 35	$f'_{cr} = f'_c + 1.34s$ $f'_{cr} = 0.90f'_c + 2.33s$ Use larger value

f'_{cr} = required avg. compressive strength (MPa)

f'_c = specified compressive strength (MPa)

S = standard deviation (MPa)

Adjusted Standard Deviation

Table 9-10. Modification Factor for Standard Deviation When Less Than 30 Tests Are Available

Number of tests*	Modification factor for standard deviation**
Less than 15	Use Table 9-11
15	1.16
20	1.08
25	1.03
30 or more	1.00

(From "Design and Control of Concrete Mixtures" by Cement Association of Canada)

When Statistical Data Not Available

Table 9-11. Required Average Compressive Strength When Data Are Not Available to Establish a Standard Deviation

Specified compressive strength, f'_c, MPa	Required average compressive strength, f'_{cr}, MPa
Less than 21	$f'_c + 7.0$
21 to 35	$f'_c + 8.5$
Over 35	$f'_c + 10.0$

Adapted from ACI 318.

(From "Design and Control of Concrete Mixtures" by Cement Association of Canada)

Water-to-Cementing Materials Ratio

Table 9-3. Relationship Between Water to Cementing Materials Ratio and Compressive Strength of Concrete

Compressive strength at 28 days, MPa	Water-cementing materials ratio by mass	
	Non-air-entrained concrete	Air-entrained concrete
45	0.38	0.30
40	0.42	0.34
35	0.47	0.39
30	0.54	0.45
25	0.61	0.52
20	0.69	0.60
15	0.79	0.70

Strength is based on cylinders moist-cured 28 days in accordance with CSA A23.2-3C (ASTM C 31). Relationship assumes nominal maximum size aggregate of about 20 to 28 mm.
Adapted from ACI 211.1 and ACI 211.3.

(From "Design and Control of Concrete Mixtures" by Cement Association of Canada)

Mix Design Procedure

1. Required information
2. Choice of slump
3. Maximum aggregate size
4. Water/cement ratio
5. Estimation of mixing water & air content
6. Calculation of cement content
7. Estimation of coarse aggregate content
8. Estimation of fine aggregate content
9. Adjustment for moisture in the aggregate
10. Trial batch

Water & Air Content Requirements

Table 9-1. Maximum Water-Cementing Materials Ratios and Minimum Design Strengths for Various Exposure Conditions*

Requirements for specifying concrete	Requirements for concrete		
Class of Exposure*	Maximum water-to-cementing materials ratio	Minimum, specified 28-day compressive strength, MPa	Air content category
C-1	0.40	35	**
C-2	0.45	32	
C-3	0.50	30	2
C-4	0.55	25	2
F-1	0.50	30	1***
F-2	0.55	25	2***
N	For structural design	For structural design	

* See Table 8-2 or this Chapter for a description of classes of exposure.
** Use Category 1 for concrete exposed to freezing and thawing.
Use Category 2 for concrete not exposed to freezing and thawing.
*** Interior ice rink slabs and freezer slabs with a steel-troweled finish have been found to perform satisfactorily without entrained air.
Source: CSA Standard A23.1.

(From "Design and Control of Concrete Mixtures" by Cement Association of Canada)

Water & Air Content Requirements

Table 9-5. Approximate Mixing Water and Air Content Requirements for Different Slumps and Nominal Maximum Sizes of Aggregate

Slump, mm	Water, kilograms per cubic metre of concrete, for indicated sizes of aggregate*							
	10 mm	14 mm	20 mm	28 mm	40 mm	56 mm**	80 mm**	150 mm**
	Non-air-entrained concrete							
25 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	—
Approximate amount of entrapped air in non-air-entrained concrete, percent	3	2.5	2	1.5	1	0.5	0.3	0.2
	Air-entrained concrete							
25 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	—
CSA A23.1 Recommended total air content percent†								
Category 1	6 to 9	5 to 8		4 to 7		—	—	—
Category 2	5 to 8	4 to 7		3 to 6		—	—	—

* These quantities of mixing water are for use in computing cementing material contents for trial batches. They are maximums for reasonably well-shaped angular coarse aggregates graded within limits of accepted specifications.
** The slump values for concrete containing aggregates larger than 40 mm are based on slump tests made after removal of particles larger than 40 mm by wet screening.
† See Tables 9-1 and 9-2 for class of exposure and corresponding air content category.
Adapted from CSA Standard A23.1, ACI 211.1, and ACI 318. Hover (1995) presents this information in graphical form.
(From "Design and Control of Concrete Mixtures" by Cement Association of Canada)

Mix Design Procedure

1. Required information
2. Choice of slump
3. Maximum aggregate size
4. Water/cement ratio
5. Estimation of mixing water & air content
6. Calculation of cement content
7. Estimation of coarse aggregate content
8. Estimation of fine aggregate content
9. Adjustment for moisture in the aggregate
10. Trial batch

Minimum Cement Content

Table 9-7. Minimum Requirements of Cementing Materials for Concrete Used in Flatwork

Nominal maximum size of aggregate, mm	Cementing materials, kg/m³*
40	280
28	310
20	320
14	350
10	360

* Cementing materials quantities may need to be greater for severe exposure. For example, for deicer exposures, concrete should contain at least 335 kg/m³ of cementing materials.
Adapted from ACI 302.

(From "Design and Control of Concrete Mixtures" by Cement Association of Canada)

Mix Design Procedure

1. Required information
2. Choice of slump
3. Maximum aggregate size
4. Water/cement ratio
5. Estimation of mixing water & air content
6. Calculation of cement content
7. Estimation of coarse aggregate content
8. Estimation of fine aggregate content
9. Adjustment for moisture in the aggregate
10. Trial batch

Bulk Volume of Coarse Aggregate

Table 9-4. Bulk Volume of Coarse Aggregate Per Unit Volume of Concrete

Nominal maximum size of aggregate, mm	Bulk volume of dry-rodded coarse aggregate per unit volume of concrete for different fineness moduli of fine aggregate*			
	2.40	2.60	2.80	3.00
10	0.50	0.48	0.46	0.44
14	0.59	0.57	0.55	0.53
20	0.66	0.64	0.62	0.60
28	0.71	0.69	0.67	0.65
40	0.75	0.73	0.71	0.69
56	0.78	0.76	0.74	0.72
80	0.82	0.80	0.78	0.76
150	0.87	0.85	0.83	0.81

*Bulk volumes are based on aggregates in dry-rodded condition as described in CSA A23.2-10A (ASTM C 29). Adapted from ACI 211.1.

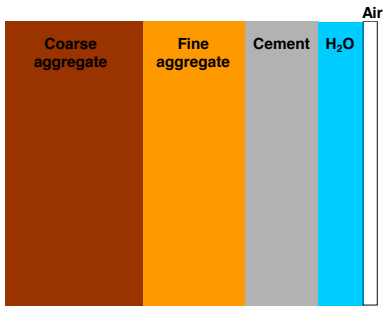
(From "Design and Control of Concrete Mixtures" by Cement Association of Canada)

University of Ottawa

Mix Design Procedure

1. Required information
2. Choice of slump
3. Maximum aggregate size
4. Water/cement ratio
5. Estimation of mixing water & air content
6. Calculation of cement content
7. Estimation of coarse aggregate content
8. Estimation of fine aggregate content
9. Adjustment for moisture in the aggregate
10. Trial batch

Absolute Volume Method

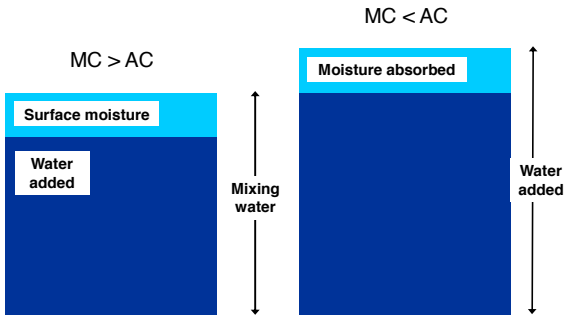


1 m^3 of concrete

Mix Design Procedure

1. Required information
2. Choice of slump
3. Maximum aggregate size
4. Water/cement ratio
5. Estimation of mixing water & air content
6. Calculation of cement content
7. Estimation of coarse aggregate content
8. Estimation of fine aggregate content
9. Adjustment for moisture in the aggregate
10. Trial batch

Aggregate Moisture



Mix Design Procedure

1. Required information
2. Choice of slump
3. Maximum aggregate size
4. Water/cement ratio
5. Estimation of mixing water & air content
6. Calculation of cement content
7. Estimation of coarse aggregate content
8. Estimation of fine aggregate content
9. Adjustment for moisture in the aggregate
10. Trial batch

Example I