PROPORTIONING OF CONCRETE MIXTURES EXAMPLE

How do we determine the proportions of ingredients to get concrete with desired properties?

The following example of a mix design is adapted from "*Design and Control of Concrete Mixtures*", *8th Edition, Cement Association of Canada.*

Conditions

Design a mix for concrete with f'_c = 35 MPa at 28 days using Type GU (10) cement and having a slump between 25mm and 75mm. Concrete is for use in a pavement exposed to moisture and de-icing salts in a severe freeze-thaw environment (C-2 Class of Exposure). (See **Table 10.2** of CAC Booklet)

Materials Available

Coarse aggregate: 28mm max. size (rounded gravel), oven-dry relative density = 2.68, absorption = 0.5%, oven-dry bulk density = 1600kg/m^3, and moisture content (MC) = 2%.

Fine aggregate: natural sand, oven-dry relative density = 2.64, absorption = 0.7%, moisture content (MC) = 6%, and fineness modulus = 2.80.

Solution:

Strength:
From **Table 12-1** it can be seen that the strength of 35MPa is greater than the maximum specified value of 32 MPa for C-2 exposure.
Table 12-11 gives required average strength $f'_{cr} = f'_c + 8.5 = 43.5$ MPa and air content is Category 1 (freezing & thawing)

Water/cement ratio:
Table 12-3 for f'_{cr} = 43.5 MPa w/c = 0.31
Value of 0.31 < 0.45 (max. for C-2 exposure in **Table 12-1**)

Air Content:
Table 12-1 requires air content category 1 for C-2 exposure.
Table 12-5 for air-entrained concrete with 28 mm coarse aggregate requires 4% to 7% air for air content category 1.

Water content:
Table 12-5 28 mm (max.) aggregate size with 75mm slump indicates 175 kg of water per 1m^3 of concrete. Since **Table 12-5** relates to crushed rock and we can reduce water content by about 25 kg for rounded gravel.

∴ water content = 175 - 25 = 150 kg/m^3

Further reduce by 10% and use water reducing admixture, i.e. use 135 kg/m^3

Cement content:
For w/c = 0.31 mass of cement = w/0.31 = 135/0.31 = 435 kg/m^3
Note that this is more than the minimum value of 335 kg/m^3 specified in the footnote to **Table 12-7** (severe exposure).

Coarse aggregate content:
For 28 mm aggregate and sand having a fineness modulus of 2.80
Table 12-4 gives volume of aggregate per unit volume of concrete = 0.67
∴ mass of coarse aggregate = 0.67 x 1600 = 1072 kg/m^3

Admixture content:
For 7% air content we typically require 0.5g of air-entraining agent per kg cement, giving $0.5 \times 10^{-3} \times 435 = 0.218$ kg Water reduction typically requires 3g of water reducing agent per kg cement, giving $3 \times 10^{-3} \times 435 = 1.305$ kg Note: The amounts of air entraining and water reducing admixtures required to obtain the desired effects will be specified by the manufacturers of the specific admixtures used.

Fine aggregate content:
To date we have the following volumes of ingredients for 1 m^3 of concrete:

Water = 135/ (1x1000) = 0.135 m^3
Cement = 435/ (3.15x1000) = 0.138 m^3
Air (7.5%) = 1x (7/100) = 0.070 m^3
Coarse agge. = 1072/2.68x1000 = 0.382 m^3

Total volume = 0.743 m^3
∴ volume of fine aggregate = 1 - 0.743 = 0.257 m^3 for 1 m^3 of concrete

giving quantity of fine aggregate = 0.257 x 2.64 x 1000 = 678 kg

First proportions
Hence, for 1 m^3 of concrete, we have:
water = 135 kg
cement = 435 kg
coarse aggregate = 1072 kg
fine aggregate = 678 kg
TOTAL = 2320 kg

Note that the mass of the air-entraining and water reducing admixtures (a total of 1.523 kg) is negligible.

We need to adjust the water content to account for absorption and moisture content of the aggregates.

Coarse aggregate (2% MC) 1072 x 1.02 = 1093 kg
Fine aggregate (6% MC) 678 x 1.06 = 719 kg

Note that absorbed water does not contribute to the mixing water.

Surface water from coarse aggregate = 2% - 0.5% = 1.5%
Surface water from fine aggregate = 6% - 0.7% = 5.3%

$\therefore$ required water = 135 - (0.015 x 1072) - (0.053 x 678) = 83 kg

Final proportions:
water (to be added) = 83 kg
cement = 435 kg
coarse aggregate = 1093 kg
fine aggregate = 719 kg

Should mix a trial batch in the laboratory to test the slump. Also make cylinders to test for strength at a particular age. Adjust the mix, if necessary.

The following Tables have been extracted from "Design and Control of Concrete Mixtures", 8th Edition, Cement Association of Canada.

Table 12-1 Requirements for C, F, N, A, and S Classes of Exposure (See Clauses 4.1.1.1.1, 4.1.1.3, 4.1.1.4, 4.1.1.5, 4.1.1.6.2, 4.1.1.10.1, 4.1.1.10.3, 4.1.2.1, 4.3.1.7.4.2.1, 8.7.3, 8.7.6.1, 8.13.3, and Tables 1 and 2, Annex L.)

Class of exposure*	Maximum water-to-cementing materials ratio†	Maximum specified compressive strenght (MPa) and age (d) at test†	Air content category as per Table 4	Curing type (see Table 20)			Chloride ion penetrability requirements and age at test‡
				Normal concrete	HVSCM 1	HVSCM 2	
C-XL	0.40	50 within 56 d	1 or 2§	3	3	3	<1000 coulombs within 56 d
C-1 or A-1	0.40	35 at 28 d	1 or 2§	2	3	2	<1500 coulombs within 56 d
C-2 or A-2	0.45	32 at 28 d	1	2	2	2	–
C-3 or A-3	0.50	30 at 28 d	2	1	2	2	–
C-4** - A-4	0.55	25 at 28 d	2	1	2	2	–
F-1	0.50	30 at 28 d	1	2	3	2	–
F-2	0.55	25 at 28 d	2††	1	2	2	–
N‡‡	As per the mix design for the strength required	For structural design	None	1	2	2	–
S-1	0.40	35 at 56 d	2	2	3	2	–
S-2	0.45	32 at 56 d	2	2	3	2	–
S-3	0.50	30 at 56	2	1	2	2	–

* See Table 1 for a description of classes of exposure.
† The minimum specified compressive strength may be adjusted to reflect proven relationships betweeen strength and the water-to-cementing materials ratio. The water-to-cementing materials ratio shall not be exceeded a given class of exposure.
‡ In accordance with ASTM C 1202, an age different from that indicated may be specified by the owner. Where calcium nitrite corrosion inhibitor is to be used, the same concrete mixture, without calcium nitrite, shall be prequalified to meet the requirements for the permeability index in Table. For field testing, the owner shall specify the type of specimen and location from which it is taken. If cores are required, the concrete cores shall be taken in accordance with Clause 6.1.2.3.3 of CSA S413.
§ Use air content category 1 for concrete exposed to freezing and thawing. Use air content category 2 for concrete not exposed to freezing and thawing.
**For class of exposure C-4, the requirement for air-entrainment should be waived when a steel trowelled finish is required. The addition of supplementary cementing materials may be used to provide reduced permability in the long term, if required.
††Interior ice rink slabs and freezer slabs with a steel trowelled finish have been found to perform satisfactorily without entained air.
‡‡See Clause 8.12 for concrete mixed for concrete floors.
Source: CSA Standard A23.1

Table 12-2 Additional requirements for concrete subjected to sulphate attack*

Class of exposure	Degree of exposure	Water-soluble sulphate (SO_4)† in soil sample, %	Sulphate (SO_4) in groundwater samples, mg/L ‡	Water soluble sulphate (SO_4) in recycled aggregate sample,%	Cementing materials to be used §††	Cementing requirements § Maximum expansion when tested using CSA A3004-C8, %	
						At 6 month	At 12 months††
S-1	Very severe	> 2.0	> 10,000	> 2.0	HS or HSb	0.05	0.10
S-2	Severe	0.20 – 2.0	1500 – 10,000	0.60 – 2.0	HS or HSb	0.05	0.10
S-3	Moderate	0.10 – 0.20	150 – 1500	0.20 – 0.60	MS, MSb LH, HS**, or HSb	0.10	

* For sea water exposure, see A23.1, Clause 4.1.1.5.
† In accordance with CSA A23.2-3B.
‡ In accordance with CSA A23.2-3B.
§ Where combinations of supplementary cementing materials and portland or blended hydrailic cements are to be used instead of the cementing materials listed, the performance requirements shall be used to demonstrate equivalent performance against sulphate explosure (see A23.1 Clauses 4.1.1.6.2, 4.2.1.1, and 4.2.1.3, and 4.2.1.4). Such combination shall not be designated as blended cements
** Type HS cement shall not be used in reinforced concrete exposed to both chlorides and sulphates. Refer to Clause 4.1.1.6.3.
†† If the expansion is greater than 0.05% at 6 months but less than 0.10% at 1 year, the cementing materials combination under test shall be considered to have passed.
Source: CSA Standard A23.1

Table 12-3 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.

Table 12-4 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.

Table 12-5 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 12-1 and 12-2 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.

Table 12-6 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.

Table 12-7 Minimum Requirements of Cementing Materials for Concrete Used in Flatwork

Nominal maximum size of aggregate, mm	Cementing materials, kg/m^3*
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/m^3 of cementing materials.
Adapted from ACI 302.

Table 12-11 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	$f'_c + 10.0$

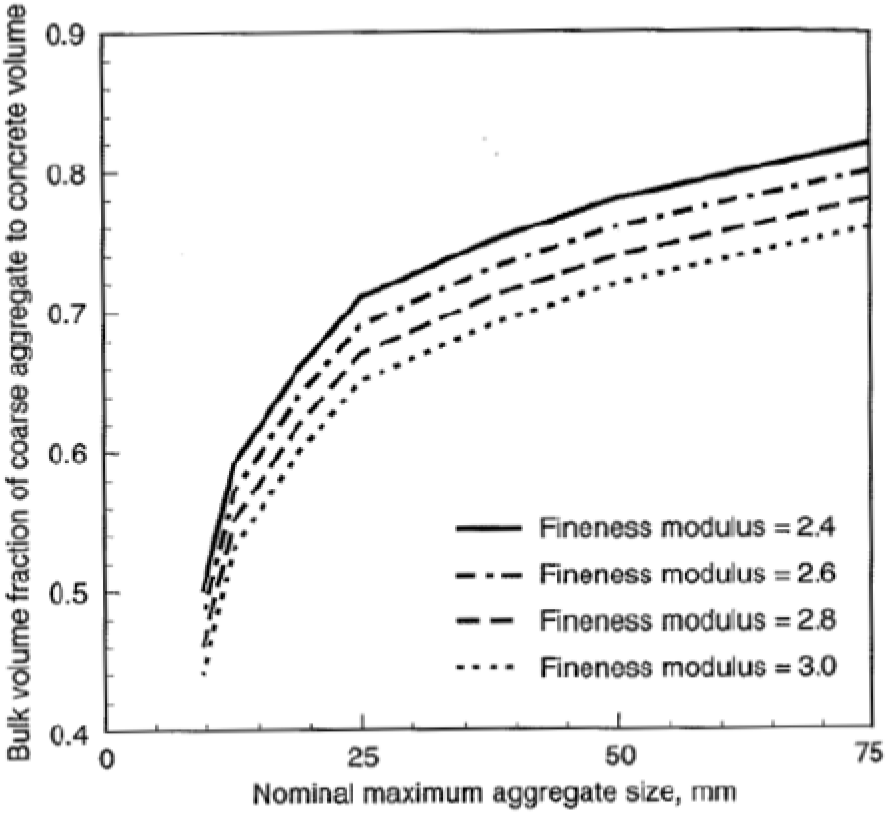
Adapted from ACI 318.

Table 10-2 Definitions of C, F, N, A and S Exposure Classes

C-XL	Structurally reinforced concrete exposed to chlorides or other severe environments with or without freezing and thawing condition, with higher durability perform ance expectations than the C-1, A-1, or S-1 classes.
C-1	Structurally reinforced concrete exposed to chlorides with or without freezing and thawing conditions. *Examples:* bridge decks, parking decks and ramps, portions of marine structures located in tidal and splash zone
C-2	Non-structurally reinforced (plain) concrete exposed to chlorides and freezing and thawing. *Examples:* garage floors, porches, steps, pavements, sidewalks, curbs and gutters
C-3	Continuously submerged concrete exposed to chlorides but not to freezing and thawing. *Examples:* underwater portions of marine structures
C-4	Non-structurally reinforced concrete exposed to chlorides but not to freezing and thawing. *Examples:* underground parking slabs on grade
F-1	Concrete exposed to freezing and thawing in a saturated condition but not to chlorides. *Examples:* pool decks, patios, tennis courts, freshwater pools, and fresh water control structures
F-2	Concrete in an unsaturated condition exposed to freezing and thawing but not to chlorides. *Examples:* exterior walls and columns
N	Concrete not exposed to chlorides nor to freezing and thawing. *Examples:* footings and interior slabs, walls and columns
A-1	Structurally reinforced concrete exposed to severe manure and/or silage gases, with or without freeze-thaw exposure. Concrete exposed to the vapour above municipal sewage or industrial effluent, where hydrogen sulphide gas might be generated. *Examples:* reinforced beams, slabs, and columns over manure pits and silos, canals, and pig slats and access holes, enclosed chambers, and pipes that are partially filled with effluents.
A-2	Structurally reinforced concrete exposed to moderate to severe manure and/or silage gases and liquids, with or without freeze-thaw exposure. *Examples:* reinforced walls in exterior manure tanks, silos and feed bunkers, and exterior slabs.
A-3	Structurally reinforced concrete exposed to moderate to severe manure and/or silage gases and liquids, with or without freeze-thaw exposure in a continuously submerged condition. Concrete continuously submerged in municipal or industrial effluents. *Examples:* interior gutter walls, beams, slabs, and columns; sewage pipes that are continuously full (e.g., forcemains); and submerged portions of sewage treatment structures.
A-4	Non-structurally reinforced concrete exposed to moderate manure and/or silage gases and liquids, without freeze-thaw exposure. *Examples:* interior slabs on grade.
S-1	Concrete subjected to very severe sulphate exposures
S-2	Concrete subjected to severe sulphate exposures
S-3	Concrete subjected to moderate sulphate exposures

Notes:
(1) "C" classes pertain to chloride exposure.
(2) "F" classes pertain to freezing and thawing exposure only.
(3) "N" class pertains to nonexposure to either chlorides or freezing and thawing.
(4) All classes of concrete exposed to sulphates shall comply with the minimum requirements of S class noted in CSA A23.1 Tables 2 and 3. In particular, Classes A-1 to A-4 in municipal sewage elements could be subjected to sulphate exposure.

Source: CSA Standard A23.1



Bulk volume of coarse aggregate per unit volume of concrete. Bulk volumes are based on aggregates in a dry-rodded condition as described in CSA A23.2-10A (ASTM C 29). For more workable concrete, such as may be required when placement is by pump, they may be reduced up to 10%.

Figure 12.3