CONCRETE MIX DESIGN

Specify the mix proportions of a concrete to be used in a bridge deck in the province of Ontario. A compressive strength f'_c of 30 MPa at 28 days is specified. No statistical data on previous mixes are available. The available ingredients are as follows:

Cement:	Relative density = 3.15
Coarse aggregate:	20-mm nominal maximum size
	Oven-dry relative density = 2.60
	Absorption capacity = 0.5%
	Bulk density = 1600 kg/m^3
	Aggregate is in SSD condition
Fine aggregate:	Oven-dry relative density = 2.60
	Absorption capacity = 0.7%
	FM = 2.80
	Aggregate is in SSD condition

1. Specify slump (Table 9-6)

- For structural concrete, the maximum slump that is allowed is 100 mm

2. Identify strength requirement

- The exposure class for a bridge deck in Ontario is: C-1
- If the concrete was to be exposed to a sulphate environment, Table 9-2 should be checked to identify the level of exposure to sulphates (this is not the case here.)
- According to Table 9-1, the minimum strength requirement for a concrete in C-1 exposure condition is 35 MPa. Since this minimum strength requirement is greater than what it was specified, the value used for f'_c becomes now 35 MPa.
- Since there is no statistical data available on previous mixes, the average strength required for proportioning is (see Table 9-11):

$$f'_{cr} = f'_c + 8.5 = \underline{43.5 \text{ MPa}}$$

3. Identify water-to-cementing materials ratio requirement

- From a durability requirement, the maximum *w/c* allowed for a concrete exposed to a C-1 environment is 0.40 (see Table 9-1.)
- From a strength requirement, the recommended *w/c* for a f'_{cr} of 43.5 MPa is 0.31 (this value is interpolated from those in Table 9-3 as follows: [(45-43.5)x(0.34-0.30)/(45-40)]+0.30=0.31..... *yeahhhh I was right* ☺!!!!).

- Since the lower *w/c* governs, the mix must be designed for *w/c* = 0.31.

4. Determine the amount of air content

- From Table 9-1, the category for air content for a C-1 exposure condition is Category 1, since the concrete is likely to be exposed to freezing and thawing.
- For a 20-mm nominal maximum aggregate size and an air content category 1, the recommended range for entrained air is 5-8% (see Table 9-5). The mix proportions will therefore be designed for the maximum allowable of 8%.

5. Determine the amount of mixing water

- For a 20-mm nominal maximum aggregate size and a slump of 100 mm, the recommended amount of mixing water for an air-entrained concrete is 184 kg/m^3 of concrete (see Table 9-5).

6. Determine the amount of cement

- $\text{mass of cement} = \dfrac{\text{mass of water}}{w/c} = \dfrac{184}{0.31} = 593 \text{ kg/m}^3 \text{ of concrete}$
- The requirement that concrete exposed to deicers should contain at least 335 kg/m^3 of cementing materials is satisfied by the previous value (see Table 9-7).

7. Determine the amount of coarse aggregates

- The bulk volume of dry-rodded coarse aggregate per unit volume of concrete for a 20-mm nominal maximum aggregate size and a fineness modulus of 2.80 is 0.62 (see Table 9-4).
- $\text{mass of coarse agg.} = 1600 \times 0.62 = 992 \text{ kg/m}^3 \text{ of concrete}$ (oven-dry mass)

8. Determine the amount of fine aggregates

- Let's calculate first the absolute volume of the known ingredients:

volume of water	$= \dfrac{184}{1.0 \times 1000}$	$= 0.184 \text{ m}^3$
volume of cement	$= \dfrac{593}{3.15 \times 1000}$	$= 0.188 \text{ m}^3$
volume of coarse agg.	$= \dfrac{992}{2.60 \times 1000}$	$= 0.381 \text{ m}^3$
volume of air	$= 8\%$	$= 0.08 \text{ m}^3$
Total volume of know ingredients		0.833 m^3

- Calculate the absolute volume of the fine aggregates by subtracting the previous value from 1 m^3.

- volume of fine agg. $= 1.0 - 0.833 = 0.167$ m^3
- mass of fine agg. $= 0.167 \times 2.60 \times 1000 =$ <u>434 kg/m^3 of concrete</u> (oven-dry mass)

9. <u>Adjust for aggregate moisture</u>

- So far the mixture has the following proportions:

Water	184 kg
Cement	593 kg
Coarse agg. (dry)	992 kg
Fine agg. (dry)	434 kg

- Since the aggregates are in the SSD condition and the above quantities are based on oven-dry conditions, their weight must be adjusted for the presence of water in them.

  mass of coarse agg. (0.5% MC) $= 992 \times 1.005 =$ <u>997 kg/m^3 of concrete</u>

  mass of fine agg. (0.7% MC) $= 434 \times 1.007 =$ <u>437 kg/m^3 of concrete</u>

  The revised batch quantities for 1 m^3 of concrete are:

Water	184 kg
Cement	593 kg
Coarse agg. (0.5%)	997 kg
Fine agg. (0.7%)	437 kg
	2211 kg

  The density of the concrete (2211 kg/m^3) is within normal range.

- Let's assume that the coarse and fine aggregates were to be provided at 2% and 6% MC, respectively. Since both of them are on the wet side, besides adjusting the weight of the aggregates for their level of moisture content, the weight of water to be added needs to be adjusted too. There is going to be water contributed to the mix by both the coarse and fine aggregates.

  mass of coarse agg. (2% MC) $= 992 \times 1.02 =$ <u>1012 kg/m^3 of concrete</u>

  mass of fine agg. (6% MC) $= 434 \times 1.06 =$ <u>460 kg/m^3 of concrete</u>

  mass of water $= 184 - \underbrace{\left[992 \times (0.02 - 0.005)\right]}_{\substack{\text{surface moisture} \\ \text{contributed by coarse agg.}}} - \underbrace{\left[434 \times (0.06 - 0.007)\right]}_{\substack{\text{surface moisture} \\ \text{contributed by fine agg.}}} =$ <u>146 kg/m^3 of concrete</u>

The revised batch quantities for 1 m^3 of concrete are:

Water	146 kg
Cement	593 kg
Coarse agg. (2%)	1012 kg
Fine agg. (6%)	460 kg

TABLES USED FOR CONCRETE MIX DESIGN (CSA A23.1)

The following tables are those of chapter 9 of "Design and Control of Concrete Mixtures" published by the Cement Association of Canada.

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.

Table 9-2. 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	Minimum specified 56-day compressive strength, MPa†	Maximum water-to-cementing materials ratio‡	Air content category▲	Cementing materials to be used**††
S-1	Very severe	Over 2.0	Over 10,000	35	0.40	2	50
S-2	Severe	0.20 – 2.0	1500 – 10,000	32	0.45	2	50
S-3	Moderate	0.10 – 0.20	150 – 1500	30	0.50	2	20E‡‡, 40, or 50E

* For seawater exposure refer to CSA A23.1, Clause 15.
† Where supplementary cementing materials are used, the owner may specify other test ages.
‡ The owner shall specify the minimum 28-day compressive strength.
** When combinations of portland cement and supplementary cementing materials are used, they shall have been proven, to the satisfaction of the owner, to produce concrete resistant to the exposure conditions under consideration.
▲ For steel-troweled interior slabs on grade, subject to sulphate attack but not freeze thaw, air entrainment is not required.
†† Cementing material combinations with equivalent performance may be used. (Refer to CSA A23.1, Clauses 3.2, 3.3, and 3.4).
‡‡ Type 20E cement with moderate sulphate resistance (Refer to CSA A23.1, Clause 3.1.2).

Note: Type 50E cement shall not be used in reinforced concrete exposed to both chlorides and sulphates. Refer to CSA A 23.1, Clause 15.4.
See CSA Test Methods A23.2-2B and A23.2-3B for test methods to determine sulphate ion content.

Source: CSA Standard A23.1

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.

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.

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.

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.

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.

Table 9-8. Cementing Materials Requirements for Concrete Exposed to Deicing Chemicals

Cementing materials*	Maximum percent of total cementing materials by mass**
Fly ash and natural pozzolans	25
Slag	50
Silica fume	10
Total of fly ash, slag, silica fume and natural pozzolans	50†
Total of natural pozzolans and silica fume	35†

* Includes portion of supplementary cementing materials in blended cements.

** Total cementing materials include the summation of portland cements, blended cements, fly ash, slag, silica fume and other pozzolans.

† Silica fume should not constitute more than 10% of total cementing materials and fly ash or other pozzolans shall not constitute more than 25% of cementing materials.

Adapted from ACI 318.

Table 9-9. Maximum Chloride-Ion Content for Corrosion Protection

Type of member	Maximum water-soluble chloride ion (Cl^-) in concrete, percent by mass of cementing material
Prestressed concrete	0.06
Reinforced concrete exposed to a moist environment or chlorides or both	0.15
Reinforced concrete exposed to neither a moist environment nor chlorides	1.00

Source: CSA Standard A23.1

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

* Interpolate for intermediate numbers of tests.
** Modified standard deviation to be used to determine required average strength, f'_{cr}.
Adapted from ACI 318.

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.