

Carleton University
Department of Civil and Environmental Engineering
Civil Engineering Materials (CIVE 2700)
ASSIGNMENT # 2

Issued November 18, 2018 Due Date: Dec. 03, 2018 at 6:00 pm

Drop off location: Filing cabinet near the entrance to the Civil and Environmental Engineering office. The cabinet located to the right of room 3424 ME.

Question (1)

A project specifies a concrete strength of 24.1 MPa. Materials engineers will design the mix for a strength higher than that to account for variables.

- a. Calculate the required average compressive strength of the mix design if the mixing plant has a standard deviation of $s=3.8$ MPa
- b. Using the ACI code equation, estimate what would be the modulus of elasticity of this concrete at the required compressive strength.

a.

$$\begin{aligned}f'_{cr} &= f'_c + 2.33s - 3.45 && (\text{since } s > 3.45 \text{ MPa}) \\ &= 24.1 + 2.33 \times 3.8 - 3.45 \\ &= 29.5 \text{ MPa}\end{aligned}$$

b.

$$\begin{aligned}E_c &= 4731\sqrt{f'_{cr}} && (f'_{cr} \text{ in MPa}) \\ &= 4731\sqrt{29.5} \\ &= 25696 \text{ MPa} \\ &= 25.7 \text{ GPa}\end{aligned}$$

Question (2)

Using the following data for an unreinforced PCC Pavement slab:

- Design strength $f'_c = 27.6$ MPa
- Slab thickness = 300 mm
- Standard deviation f'_c of obtained from 20 samples = 1.4 MPa
- Ignore any exposure requirement
- Use air entrained concrete
- Fineness modulus of fine aggregate = 2.6
- Maximum aggregate = 50 mm and nominal maximum aggregate = 37.5 mm
- Bulk oven-dry specific gravity of coarse aggregate = 2.6
- Oven-dry rodded density of coarse = 2002 kg/m³

find the following:

- a. Required compressive strength
- b. w/c ratio
- c. Coarse aggregate amount (kg/m³)
- d. If the w/c ratio is 10% reduced, will the quantity of coarse aggregate increase, decrease or remain the same? Explain your answer.

a.

$$\begin{aligned} f'_{cr} &= f'_c + 1.34s && \text{(since } s < 3.45 \text{ MPa)} \\ &= 27.6 + 1.34 \times 1.4 \times 1.08 && \text{(for 20 samples the multiplication factor is 1.08)} \\ &= 29.6 \text{ MPa} \end{aligned}$$

b.

$$w/c \text{ ratio} = 0.46 \quad \text{(from Table 12-3 for air-entrained concrete)}$$

c.

$$\begin{aligned} \text{Maximum aggregate size} &= \frac{1}{3} \text{ slab thickness} \\ &= 100 \text{ mm} (> 50 \text{ mm, the maximum aggregate size}) \end{aligned}$$

Hence the aggregate size is satisfactory

$$\text{Coarse aggregate factor} = 0.72 \quad \text{(from Table 12-4 for 2.6 FM and 37.5 mm}$$

Nominal maximum aggregate size)

$$\begin{aligned} \text{Weight of coarse aggregate} &= 0.721 \times 2002 \\ &= 1443 \text{ kg/m}^3 \end{aligned}$$

d. The quantity of coarse aggregate will be the same since it is not affected by w/c ratio

Question (3)

Design the concrete mix according to the following conditions.

Design Environment

- Pavement slab, Bozeman, Montana (cold climate)
- Required design strength = 30 MPa
- Slab thickness = 300 mm.
- Statistical data indicate a standard deviation of compressive strength of 2.5MPa is expected (10 samples).
- Only air entrainer is allowed.

Available Materials

- Air entrainer: Manufacture specification is 7 ml/1% air/100 kg cement.
- Coarse aggregate:
 - 50 mm nominal maximum size, crushed stone
 - Bulk oven-dry specific gravity = 2.573, Absorption = 0.1%
 - Oven-dry rodded density = 1923 kg/m³
 - Moisture content = 1%
- Fine aggregate: Natural sand
 - Bulk oven-dry specific gravity = 2.54, Absorption = 0.2%
 - Moisture content 3.67%
- Fineness modulus = 2.68

1. Required strength

$$\begin{aligned} f'_{cr} &= f'_c + 8.5 && \text{(since the number of samples is less than 15)} \\ &= 30 + 8.5 \\ &= 38.5 \text{ MPa} \end{aligned}$$

2. w/c ratio

$$w/c \text{ ratio} = 0.353 \quad (\text{from Table 7.1 for air-entrained concrete})$$

3. Coarse Aggregate requirement

$$\begin{aligned} \text{Maximum aggregate size} &= \frac{1}{3} \text{ slab thickness} \\ &= 100 \text{ mm} (> 75 \text{ mm}, 3 \text{ in.}, \text{ the maximum aggregate size,} \\ &\text{the sieve size bigger than the nominal maximum aggregate size}) \end{aligned}$$

Hence the aggregate size is satisfactory

$$\text{Coarse aggregate factor} = 0.752 \quad (\text{from Table 7.5 for 2.68 FM and 50 mm}$$

Nominal maximum aggregate size)

$$\begin{aligned} \text{Weight of coarse aggregate} &= 0.752 \times 1923 \\ &= 1446 \text{ kg/m}^3 \end{aligned}$$

4. Air content for severe exposure conditions

$$\text{Target air content} = 5\% \quad (\text{from table 7.6})$$

$$\text{Job specification} = 4 - 7\%. \quad (-1\% \text{ to } +2\% \text{ from the target to be delivered})$$

Take **6%** as the design value

5. Slump requirement

$$\text{For slabs and pavements} = 25 - 75 \text{ mm} \quad (\text{from table 7.7})$$

Take **50 mm** as the design value

6. Required water content

$$\text{Water requirement} = 142 \text{ kg/m}^3 \quad (\text{From table 7.8 for 50 mm nominal aggregate size, air-entrained, and 50 mm slump})$$

$$\begin{aligned} \text{7. Required Cement content} &= \frac{142}{0.353} \\ &= 402 \text{ kg/m}^3 \end{aligned}$$

Minimum cement content for severe exposure is $335 \text{ kg/m}^3 (< 402 \text{ kg/m}^3)$. Hence use **402 kg/m³**.

8. Admixture – air entrainer

$$\begin{aligned} \text{Requirement} &= 7 \times \frac{6\%}{1\%} \times \frac{402}{100} \\ &= 169 \text{ ml/m}^3 \end{aligned}$$

9. Fine aggregate requirement

$$\begin{aligned} \text{Volume of water} &= \frac{142}{1000} \\ &= 0.142 \text{ m}^3 \end{aligned}$$

$$\begin{aligned} \text{Volume of cement} &= \frac{402}{1000 \times 3.15} \quad (\text{SG of cement is 3.15}) \\ &= 0.128 \text{ m}^3 \end{aligned}$$

$$\begin{aligned}
\text{Volume of air} &= 0.06 \text{ m}^3 && (6\% \text{ air}) \\
\text{Volume of CA} &= \frac{1446}{1000 \times 2.573} && (\text{SG of CA is } 2.573) \\
&= 0.562 \text{ m}^3 \\
\text{Volume of FA} &= 1 - (0.142 + 0.128 + 0.06 + 0.562) \\
&= 0.108 \text{ m}^3 \\
\text{FA weight} &= 0.108 \times 2.54 \times 1000 \\
&= 274 \text{ kg/m}^3
\end{aligned}$$

10. Moisture correction

Coarse aggregates

$$\begin{aligned}
\text{Required weight with moisture} &= 1446 \times 1.01 && (1\% \text{ total moisture}) \\
&= 1460 \text{ kg/m}^3
\end{aligned}$$

Fine aggregates

$$\begin{aligned}
\text{Required weight with moisture} &= 274 \times 1.0367 && (3.67\% \text{ total moisture}) \\
&= 284 \text{ kg/m}^3
\end{aligned}$$

$$\begin{aligned}
\text{Reduction in water content} &= 1446 \times (1\% - 0.1\%) + 274 \times (3.67\% - 0.2\%) \\
&= 22.5 \text{ kg/m}^3
\end{aligned}$$

$$\begin{aligned}
\text{Water content} &= 142 - 22.5 \\
&= 119.5 \text{ kg/m}^3
\end{aligned}$$

Summary (after moisture adjustment)

Material	Content per 1m ³ of concrete
Cement	402 kg
Water	119.5 kg (or l)
Coarse Aggregate	1460 kg
Fine Aggregate	284 kg
Admixture	169 ml

Question (4)

The design of a concrete mix requires 1173 kg/m³ of gravel in dry condition, 582 kg/m³ of sand in dry condition, and 157 kg/m³ of free water. The gravel available at the job site has a moisture content of 0.8% and absorption of 1.5%, and the available sand has a moisture content of 1.1% and absorption of 1.3%. What are the masses of gravel, sand, and water per cubic meter that should be used at the job site?

Gravel

$$\begin{aligned}
\text{Required weight with moisture} &= 1173 \times 1.008 && (1\% \text{ total moisture}) \\
&= 1182 \text{ kg/m}^3
\end{aligned}$$

Sand

$$\begin{aligned}
\text{Required weight with moisture} &= 582 \times 1.011 && (3.67\% \text{ total moisture}) \\
&= 588 \text{ kg/m}^3
\end{aligned}$$

Since the absorption of the aggregate are higher than the moisture content we need to add more water to achieve SSD condition

$$\begin{aligned}\text{Increase in water content} &= 1173 \times (1.5\% - 0.8\%) + 582 \times (1.3\% - 1.1\%) \\ &= 9.4 \text{ kg/m}^3 \\ \text{Water content} &= 157 + 9.4 \\ &= 166.4 \text{ kg/m}^3\end{aligned}$$

Question (5)

Design the concrete mix according to the following conditions:

Design Environment

- Building frame
- Required design strength 27.6 MPa
- Minimum dimension = 150 mm
- Minimum space between rebar = 40 mm
- Minimum cover over rebar = 40 mm
- Statistical data indicate a standard deviation of compressive strength of 2.1 MPa is expected (more than 30 samples).
- Only air entrainer is allowed.

Available Materials

- Air entrainer: Manufacture specification 6.3 ml/1% air/100 kg cement.
- Coarse aggregate: 19 mm nominal maximum size, river gravel (rounded)
 - Bulk oven-dry specific gravity = 2.55, Absorption = 0.3%
 - Oven-dry rodded density = 1761 kg/m³
 - Moisture content = 2.5%
- Fine aggregate: Natural sand
 - Bulk oven-dry specific gravity = 2.659, Absorption = 0.5%
 - Moisture content = 2%
 - Fineness modulus = 2.47

1. Required strength

$$\begin{aligned}f'_{cr} &= f'_c + 1.34s \\ &= 27.6 + 1.34 \times 2.1 \\ &= 30.4 \text{ MPa}\end{aligned}$$

2. w/c ratio

$$\text{w/c ratio} = 0.45 \quad (\text{from Table 7.1 for air-entrained concrete})$$

3. Coarse Aggregate requirement

Maximum aggregate size = 25 mm (19 mm nominal aggregate size)

Requirement

Allowable maximum	
Minimum dimension	$\frac{1}{5} \times 150 = 30 \text{ mm}$
Clear space between rebar	$\frac{3}{4} \times 40 = 30 \text{ mm}$
Cover space	$\frac{3}{4} \times 40 = 30 \text{ mm}$

Maximum coarse aggregate size of 25 mm (< 30 mm) satisfies all these conditions.

Coarse aggregate factor = 0.653 (from Table 7.5 for 2.47 FM and 19 mm Nominal maximum aggregate size)

$$\begin{aligned}\text{Weight of coarse aggregate} &= 0.653 \times 1761 \\ &= 1150 \text{ kg/m}^3\end{aligned}$$

4. Air content for mild exposure conditions

Target air content = 3.5% (from table 7.6)

Job specification 2.5 – 5.5%. (–1% to +2% from the target to be delivered)

Take 3.5% as the design value

5. Slump requirement

For building frame = 25 – 100 mm (from table 7.7)

Take 50 mm as the design value (building frame is beams and columns)

6. Required water content

Water requirement = 168 kg/m³ (From table 7.8 for 19 mm nominal aggregate size, air-entrained, and 50 mm slump)

Reduction due to rounded gravel = 27 kg/m³

$$\begin{aligned}\text{Net water requirement} &= 168 - 27 \\ &= 141 \text{ kg/m}^3\end{aligned}$$

7. Required Cement content = $\frac{141}{0.45}$

$$= 313 \text{ kg/m}^3$$

Mild exposure to be used in beams and columns (no flat work). Hence, the cement requirement is satisfactory.

8. Admixture – air entrainer

$$\begin{aligned}\text{Requirement} &= 6.3 \times \frac{3.5\%}{1\%} \times \frac{313}{100} \\ &= 69 \text{ ml/m}^3\end{aligned}$$

9. Fine aggregate requirement

$$\begin{aligned}\text{Volume of water} &= \frac{141}{1000} \\ &= 0.141 \text{ m}^3 \\ \text{Volume of cement} &= \frac{313}{1000 \times 3.15} \quad (\text{SG of cement is } 3.15) \\ &= 0.100 \text{ m}^3 \\ \text{Volume of air} &= 0.035 \text{ m}^3 \quad (6\% \text{ air}) \\ \text{Volume of CA} &= \frac{1150}{1000 \times 2.55} \quad (\text{SG of CA is } 2.573) \\ &= 0.451 \text{ m}^3 \\ \text{Volume of FA} &= 1 - (0.141 + 0.100 + 0.035 + 0.451) \\ &= 0.273 \text{ m}^3 \\ \text{FA weight} &= 0.273 \times 2.659 \times 1000 \\ &= 726 \text{ kg/m}^3\end{aligned}$$

10. Moisture correction

Coarse aggregates

$$\begin{aligned}\text{Required weight with moisture} &= 1150 \times 1.025 \quad (2.5\% \text{ total moisture}) \\ &= 1179 \text{ kg/m}^3\end{aligned}$$

Fine aggregates

$$\begin{aligned}\text{Required weight with moisture} &= 726 \times 1.02 \quad (2\% \text{ total moisture}) \\ &= 740 \text{ kg/m}^3\end{aligned}$$

$$\begin{aligned}\text{Reduction in water content} &= 1150 \times (2.5\% - 0.3\%) + 726 \times (2\% - 0.5\%) \\ &= 36 \text{ kg/m}^3\end{aligned}$$

$$\begin{aligned}\text{Water content} &= 141 - 36 \\ &= 105 \text{ kg/m}^3\end{aligned}$$

Summary (after moisture adjustment)

Material	Content per 1m ³ of concrete
Cement	313 kg
Water	105 kg
Coarse Aggregate	1179 kg
Fine Aggregate	740 kg
Admixture	69 ml