Université d'Ottawa · University of Ottawa

Faculté de génie — Génie Civil
Faculty of Engineering — Civil Engineering

CVG 2141 – CIVIL ENGINEERING MATERIALS

Mid Term Examination — Dr. B. Martín-Pérez
October 26th, 2004

Closed book exam
Calculators permitted
Time allowed: 1 hour & 20 minutes

QUESTION 1: (20 marks)

Using the information given, determine the proportions of cement, water, fine aggregate, and coarse aggregate for a concrete subjected to frequent freezing and thawing in a saturated condition. The concrete is to be used for a retaining wall in Ottawa and the specified 28-day compressive strength is 20 MPa. The maximum aggregate size is 20 mm, the dry rodded density of coarse aggregate is 1600 kg/m^3, the specific gravity of both coarse and fine aggregates is 2.60, the absorption capacity of the fine aggregate is 0.7%, and the absorption capacity of the coarse aggregate is 0.5%. The moisture content of the fine and coarse aggregates to be used is respectively 0.7% and 0.2%.

Sieve analysis of the fine aggregate is as follows:

Sieve (mm)	5	2.5	1.25	0.630	0.315	0.160	pan
Percentage of individual fraction retained	2	10	15	20	29	21	3

SOLUTION:

1. Fineness modulus

The fineness modulus of the fine aggregate is calculated as follows:

Sieve (mm)	5	2.5	1.25	0.630	0.315	0.160
Percentage of individual fraction retained	2	10	15	20	29	21
Cumulative percentage of individual fraction retained	2	12	27	47	76	97
						261

$$\text{FM} = \frac{261}{100} = \underline{2.61}$$

2. Slump

- For a retaining wall, the maximum slump that is allowed is 75 mm (see Table 9-6.)

3. Strength

- As specified in the problem statement, the wall is to be exposed to frequent freezing and thawing in a saturated condition. From Table 8-2, the exposure class for this environment is F-1.
- According to Table 9-1, the minimum 28-day compressive strength is 30 MPa, the maximum *w/c* is 0.50, and the air content category is 1. Since the minimum strength requirement is greater than what it was specified (20 MPa), the value used for f'_c becomes now 30 MPa.
- Since there is no statistical data available on previous mixes, the average strength required for proportioning is (see Table 9-11):

$$f'_{cr} = f'_c + 8.5 = \underline{38.5\ \text{MPa}}$$

4. Water-to-cementing materials ratio

- From a durability requirement, the maximum *w/c* allowed for a concrete exposed to an F-1 environment is 0.50 (see Table 9-1).
- From a strength requirement, the recommended *w/c* for a concrete with f'_{cr} of 38.5 MPa and entrained air (category 1) is 0.35 (this value is interpolated from those in Table 9-3). Since the lower *w/c* governs, the mix must be designed for *w/c* = 0.35.

5. Air content

- From Table 9-1, the category for air content for an F-1 exposure condition is Category 1.
- 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%.

6. Amount of mixing water

- For a 20-mm nominal maximum aggregate size and a slump of 75 mm, the recommended amount of mixing water for an air-entrained concrete is 184 kg/m^3 of concrete (see Table 9-5).

7. Amount of cement

- $$\text{mass of cement} = \frac{\text{mass of water}}{w/c} = \frac{184}{0.35} = \underline{526\ \text{kg/m}^3\ \text{of concrete}}$$

8. 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 2.61 is 0.64 (see Table 9-4).
- mass of coarse agg. $= 1600 \times 0.64 = \underline{1024\ \text{kg/m}^3\ \text{of concrete}}$ (oven-dry mass)

9. Determine the amount of fine aggregates

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

$$\begin{aligned} &\text{volume of water} && = \frac{184}{1.0 \times 1000} && = 0.184\ \text{m}^3 \\ &\text{volume of cement} && = \frac{526}{3.15 \times 1000} && = 0.167\ \text{m}^3 \\ &\text{volume of coarse agg.} && = \frac{1024}{2.60 \times 1000} && = 0.394\ \text{m}^3 \\ &\text{volume of air} && = 8\% && = 0.08\ \text{m}^3 \end{aligned}$$

Total volume of know ingredients $0.825\ \text{m}^3$

- volume of fine agg. $= 1.0 - 0.825 = 0.175\ \text{m}^3$
- mass of fine agg. $= 0.175 \times 2.60 \times 1000 = \underline{455\ \text{kg/m}^3\ \text{of concrete}}$ (oven-dry mass)

10. Adjust for aggregate moisture

- So far the mixture has the following proportions:

Water	184 kg
Cement	526 kg
Coarse agg. (dry)	1024 kg
Fine agg. (dry)	455 kg

- Since the fine aggregate is in the SSD condition (the moisture content is equal to the absorption capacity, i.e., 0.7%) and the above quantity is based on oven-dry conditions, its weight must be adjusted for the presence of water in it.

  mass of fine agg. (0.7% MC) $= 455 \times 1.007 = \underline{458\ \text{kg/m}^3\ \text{of concrete}}$

- The coarse aggregate is actually on the dry side (its moisture content is lower than its absorption capacity, i.e., 0.2% < 0.5%). The above quantity for the coarse aggregate is based on oven-dry conditions, thus its weight still has to be adjusted for the presence of some water in it. However, it will also absorb water until its moisture content reaches that corresponding to SSD conditions. It is for this reason that the mixing water needs to be increased to compensate for the loss of water absorbed by the coarse aggregates.

$\text{mass of coarse agg. (0.2\% MC)} = 1024 \times 1.002 = \underline{1026 \text{ kg/m}^3 \text{ of concrete}}$

$\text{mass of water} = 184 + (1024 \times 0.003) = \underline{187 \text{ kg/m}^3 \text{ of concrete}}$

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

Water	187 kg
Cement	526 kg
Coarse agg. (0.5%)	1026 kg
Fine agg. (0.7%)	458 kg
	2197 kg

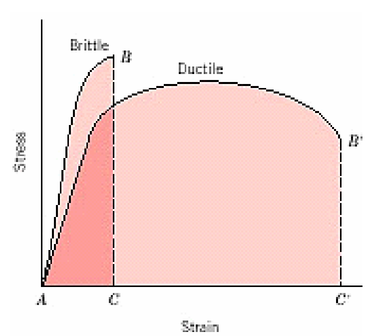
The density of the concrete (2197 kg/m^3) is within normal range.

QUESTION 2: (20 marks)

Write a short description (4-6 lines) on each of the following. Use a sketch if appropriate.

(a) Brittle and ductile materials

Brittle materials exhibit little or no yielding at all before failure. On the other hand, ductile materials undergo large strains (well into the plastic range) before failure.



(b) The role of C_3S and C_2S in the hydration of Portland cement

The calcium silicates form calcium-silicate-hydrate, C-S-H, and calcium hydroxide, $Ca(OH)_2$, when combined with water. C-S-H is what makes the hydrated cement paste strong, thus the hydration of both C_3S and C_2S is very important for strength development of the cement paste. C_3S hydrates more rapidly than C_2S contributing to early strength gain of the cement paste, whereas the hydration of both C_3S and C_2S contribute equally to ultimate strength.

(c) Use of Type 50 cement

Type 50 cement is a sulphate-resistant Portland cement. It is used for applications where the concrete is exposed to severe sulphate action. Its sulphate resistance is provided by limiting the amount of C_3A to no more than 3.5%. For it to be effective, it must be used in conjunction with a low *w/c* and a low permeability concrete.

(d) Why gypsum is added in the manufacture of Portland cement

Gypsum is added to the manufacture of cement to retard the setting time of cement (i.e., to prevent flash set) by controlling the hydration of C_3A. The reaction rate of C_3A with water is very high; however, the resulting hydration products do not contribute to the strength development of the cement paste. The presence of gypsum (a source of sulphate ions) slows down the early rate of hydration of C_3A.

(e) Use of superplasticizers

Superplasticizers, also called high-range water-reducing admixtures, are added to the concrete mix to improve the workability, reduce the water-to-cement ratio by reducing the amount of mixing water, and/or to increase the strength of concrete, eliminate segregation, and reduce plastic shrinkage cracks.

(f) Similarities and differences between creep and shrinkage of concrete

Creep and shrinkage are both time-dependent deformations that occur in concrete; creep is due to sustained loading, while shrinkage is due to loss of moisture. When a concrete member is allowed to creep or shrink freely no stresses are induced; however, if the deformation either from creep or shrinkage is controlled or restrained, tensile stresses develop in the concrete, and these can cause cracking if the concrete tensile strength is exceeded.

(g) Methods to reduce corrosion of reinforcing steel in concrete

Strategies to combat corrosion of reinforcing steel involve restricting the availability of oxygen and moisture at the cathodes and preventing electron flow from the anode to the cathode. This can be achieved by:

(1) reducing the permeability of concrete: low *w/c*, proper curing, use of mineral admixtures, increasing the concrete cover.

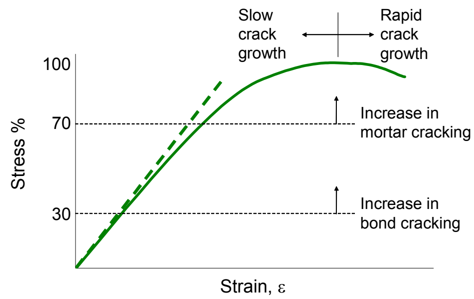
(2) using protective membranes on the concrete: concrete overlays, surface treatments with water-repellent materials, sealers.

(3) using protective coatings on the reinforcing steel: epoxy-coated, galvanized, stainless-steel.

(4) suppressing the electrochemical process: corrosion inhibiting admixtures, cathodic protection.

(h) Why concrete exhibits non-linear behaviour when subjected to compressive loads

Concrete exhibits non-linear behaviour under compression because of cracking. At low compressive stresses, around 30% of f'_c, microcracking starts to originate at the interface between the aggregates and the mortar. As the stress level increases, these cracks grow leading to further cracking of the mortar at around 70% of f'_c. After reaching the compressive strength f'_c, crack growth accelerates until failure.



(i) A brass alloy has a yield strength of 280 MPa, a tensile strength of 390 MPa, and an elastic modulus of 105 GPa. A cylindrical specimen of this alloy 12.7 mm in diameter and 250 mm long is stressed in tension and found to elongate 7.6 mm. Can you calculate the magnitude of the load necessary to produce this change in length? If not, explain why.

$$\varepsilon = \frac{\Delta L}{L} = \frac{7.6}{250} = 0.0304 \text{ mm/mm}$$

$$\sigma = E\varepsilon = 105 \times 10^3 \times 0.0304 = 3192 \text{ MPa} >> \sigma_y$$

The stress calculated using Hooke's law, which assumes elastic behaviour, is much higher than the yield strength. This means that the material is already experiencing plastic deformation, and we CANNOT use the theory of elasticity to calculate the load necessary to produce such deformation.