CVG 2141 – CIVIL ENGINEERING MATERIALS

Mid Term Examination — Dr. B. Martín-Pérez
October 24th, 2002

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

QUESTION 1: (10 marks)

A cylindrical rod with a length of 380 mm and a diameter of 10 mm is to be subjected to a tensile load of 30 kN. The rod must not experience plastic deformation or an increase in length of more than 0.9 mm when the load is applied. Which of the four materials listed below are possible candidates? Justify your answer.

Material	Elastic Modulus (GPa)	Yield strength (MPa)
Copper	110	248
Aluminum alloy	70	255
Steel	200	448
Brass alloy	101	345

SOLUTION:

In choosing the material from the list provided, there are two requirements that must be fulfilled:

1. The rod must not experience plastic deformation, i.e., it must not yield. Upon the application of a tensile load of 30 kN, the stress in the rod is:

   $$\sigma = \frac{P}{A} = \frac{30\times10^3}{\pi\times\frac{10^2}{4}} = \underline{382\text{ MPa}}$$

   The only material that does not yield at that stress level is steel. However, one must still ensure that the second requirement is met.

2. The rod must not experience an increase in length of more than 0.9 mm when the load is applied. The strain and change of deformation corresponding to a stress of 382 MPa are:

   $$\sigma = E\varepsilon \quad\Rightarrow\quad \varepsilon = \frac{\sigma}{E} = \frac{382}{200\times10^3} = \underline{1.91\times10^{-3}}$$

$$\varepsilon = \frac{\Delta L}{L} \quad \Rightarrow \quad \Delta L = \varepsilon \times L = 1.91 \times 10^{-3} \times 380 = \underline{0.73 \text{ mm}}$$

A rod made out of steel indeed does not deform more than 0.9 mm when subjected to the tensile load of 30 kN. Steel is therefore the only material to fulfill both requirements.

QUESTION 2: (20 marks)

Using the information given, determine the proportions of cement, water, fine aggregate, and coarse aggregate for a concrete subjected to a mild sulphate environment and exposed to de-icing chemicals. The concrete is to be used in an underground parking slab on grade and the 28 day specified compressive strength is to be 20 MPa. The maximum aggregate size is 14 mm, the dry rodded density of coarse aggregate is 1600 kg/m^3, the specific gravity of both coarse and fine aggregates is 2.65, the absorption capacity of the fine aggregate is 0.7%, and the absorption capacity of the coarse aggregate is 0.5%. All aggregates are saturated surface dry.

Sieve analysis of the fine aggregate is as follows:

Sieve (mm)	5	2.5	1.75	0.630	0.315	0.160
Percentage of individual fraction passing	97	87	82	82	75	82

SOLUTION:

1. Fineness modulus

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

Sieve (mm)	5	2.5	1.75	0.630	0.315	0.160
Percentage of individual fraction passing	97	87	82	82	75	82
Percentage of individual fraction retained	3	13	18	18	25	18
Cumulative percentage of individual fraction retained	3	16	34	52	77	95
						277

$$\text{FM} = \frac{277}{100} = \underline{2.77}$$

2. Strength

- From Table 8-2, the exposure class for an underground parking slab on grade is C-4 (minimum 28 day compressive strength of 25 MPa, $w/c \leq 0.55$, air content category 2). Since the concrete is also to be exposed to a moderate sulphate environment, Table 9-2 identifies the level of exposure to sulphates as S-3 (minimum 56 day compressive strength of 30 MPa, $w/c \leq 0.50$, air entrainment not required).
- According to Table 9-1, the minimum strength requirement for a concrete in C-4 exposure condition is 25 MPa. Since this minimum strength requirement is greater than what it was specified, the value used for f'_c becomes now 25 MPa.
- Since there is no statistical data available on previous mixes, the average strength required for proportioning is (see Table 9-11):

$$f'_{cr} = f'_c + 8.5 = \underline{33.5 \text{ MPa}}$$

3. Water-to-cementing materials ratio

- From a durability requirement, the maximum *w/c* allowed for a concrete exposed to a C-4 environment is 0.55 (see Table 9-1), and the maximum *w/c* allowed for a concrete exposed to an S-3 environment is 0.50 (see Table 9-2). Therefore, the value of 0.50 governs from a durability point of view.
- From a strength requirement, the recommended *w/c* for a concrete with f'_{cr} of 33.5 MPa and air-entrained (category 2) is 0.41 (this value is interpolated from those in Table 9-3). Since the lower *w/c* governs, the mix must be designed for $w/c = 0.41$.

4. Air content

- From Table 9-1, the category for air content for a C-4 exposure condition is Category 2.
- For a 14-mm nominal maximum aggregate size and an air content category 2, the recommended range for entrained air is 4-7% (see Table 9-5). The mix proportions will therefore be designed for the maximum allowable of 7%.

5. Slump

- For an underground parking slab on grade, the maximum slump that is allowed is 75 mm (see Table 9-6.)

6. Amount of mixing water

- For a 14-mm nominal maximum aggregate size and a slump of 75 mm, the recommended amount of mixing water for an air-entrained concrete is 193 kg/m^3 of concrete (see Table 9-5).

7. Amount of cement

- $\text{mass of cement} = \dfrac{\text{mass of water}}{w/c} = \dfrac{193}{0.41} = \underline{471\ \text{kg/m}^3\ \text{of concrete}}$
- The requirement that concrete to be used in flatwork should contain at least 350 kg/m^3 of cementing materials for a 14-mm nominal maximum size of aggregate is satisfied by the previous value (see Table 9-7).

8. Amount of coarse aggregates

- The bulk volume of dry-rodded coarse aggregate per unit volume of concrete for a 14-mm nominal maximum aggregate size and a fineness modulus of 2.77 is 0.55 (interpolated from values of Table 9-4).
- $\text{mass of coarse agg.} = 1600 \times 0.55 = \underline{880\ \text{kg/m}^3\ \text{of concrete}}$ (oven-dry mass)

9. Determine the amount of fine aggregates

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

$$\begin{array}{lll} \text{volume of water} & = \dfrac{193}{1.0\times1000} & = 0.193\ \text{m}^3 \\ \text{volume of cement} & = \dfrac{471}{3.15\times1000} & = 0.149\ \text{m}^3 \\ \text{volume of coarse agg.} & = \dfrac{880}{2.65\times1000} & = 0.332\ \text{m}^3 \\ \text{volume of air} & = 7\% & = 0.07\ \text{m}^3 \\ \hline \text{Total volume of know ingredients} & & 0.744\ \text{m}^3 \end{array}$$

- $\text{volume of fine agg.} = 1.0 - 0.744 = 0.256\ \text{m}^3$
- $\text{mass of fine agg.} = 0.256 \times 2.65 \times 1000 = \underline{678\ \text{kg/m}^3\ \text{of concrete}}$ (oven-dry mass)

10. Adjust for aggregate moisture

- So far the mixture has the following proportions:

Water	193 kg
Cement	471 kg
Coarse agg. (dry)	880 kg
Fine agg. (dry)	678 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.

  $\text{mass of coarse agg. (0.5\% MC)} = 880 \times 1.005 = \underline{884\ \text{kg/m}^3\ \text{of concrete}}$

mass of fine agg. (0.7% MC) $= 678 \times 1.007 =$ <u>683 kg/m^3 of concrete</u>

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

Water	193 kg
Cement	471 kg
Coarse agg. (0.5%)	884 kg
Fine agg. (0.7%)	683 kg
	2231 kg

The density of the concrete (2231 kg/m^3) is within normal range.

QUESTION 3: (10 marks)

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

(a) How to improve freeze-thaw resistance

Freeze-thaw resistance in concrete can be improved by reducing the w/c (thus reducing the porosity of the concrete) and purposely entraining air in the concrete mix. Entrained air guarantees empty spaces in the concrete within which the compressed water from the capillary pores can move and freeze.

(b) Use of retarding admixtures

A retarding admixture is added to the concrete to delay its setting and hardening, and thus slowing down hydration. It is used in hot climates or when ambient temperatures are greater than 32^{o}C (the rate of hydration, and hardening, is higher at higher temperatures, making it difficult to place and finish the concrete). Retarding admixtures are also used in those applications that require keeping the concrete workable during the entire placing period.

(c) Alkali-aggregate reaction

Alkali-aggregate reaction is a chemical reaction between the active minerals in some aggregates and the alkalis in the hydrated Portland cement. The products of the reaction form on the exterior the aggregate particles, creating a hydraulic pressure around the particle that eventually cracks the concrete. There are two types of alkali-aggregate reaction: alkali-silica reaction and alkali-carbonate reaction. Alkali-silica reaction is of more concern than alkali-carbonate reaction because of the occurrence of aggregates containing reactive silica minerals is more common.

For alkali-aggregate reaction to occur there is a need of: (1) alkali-reactive components in the aggregates; (2) high-alkali content in the cement; and, (3) moisture. Therefore, the best way to minimize the risk for the reaction to occur is to use: (1) non-reactive aggregates; (2) low-alkali cement (<0.6%); and, (3) mineral admixtures.

(d) Hydration

Hydration is the chemical reaction between the cement compounds and water. The reaction is accompanied by a release of heat, known as the heat of hydration. It can be considered to be formed of two stages: setting and hardening. Setting is the period by which noticeable stiffening of the paste commences, usually within a few hours of mixing. The final set is when the past begins to harden and can sustain some loads. Hardening is the development of strength over an extended period of time, i.e., the net outcome of hydration.

(e) Types of Portland cement manufactured in Canada and their uses

There are five types of Portland cement manufactured in Canada:

- Type 10, Normal Portland cement. This is a cement used for general purposes.
- Type 20, Moderate Portland cement. This cement is used when precaution against moderate sulphate attack is important, as it is the case of structural elements exposed to soil or ground water where the sulphate ions content is high but not severe. It must be used with a low *w/c* and low permeability.
- Type 30, High-early strength Portland cement. This cement is used when the forms need to be removed immediately or when the concrete structure needs to be in service right away.
- Type 40, Low-heat of hydration Portland cement. It is used when the rate and amount of heat of hydration must be minimized, as it is the case for massive concrete structures.
- Type 50, Sulphate-resistant Portland cement. This cement is used for applications exposed to a severe sulphate action. As in Type 20, it must be used with a low *w/c* and low permeability.