CIVL 3137
Homework 6 Solution

1. (45 pts) Design a non-air-entrained concrete mix that will have a slump of 3-4" and a design strength ($f'_c$) of 4300 psi using the ***absolute volume method***. Assume the following aggregate properties:

| Natural Sand | Gravel w/ some crushed particles |
| --- | --- |
| Fineness modulus = 2.90 | NMAS = ¾" |
| Absorption = 1.25% | Absorption = 0.95% |
| Bulk relative density = 2.55 | Bulk relative density = 2.66 |
| Dry-rodded unit weight = 106 $lb/ft^3$ | Dry-rodded unit weight = 99 $lb/ft^3$ |

Don't forget to adjust the water content for the shape of the coarse aggregate. Also, make sure you add enough extra water to your mix design the make the aggregate SSD (but you don't know the moisture content of the aggregate yet, so ignore the last two parts of Step 10). Do all calculations based on a cubic yard of concrete.

Step 1: The slump has been specified (3" to 4").

Step 2: The NMAS has been specified (NMAS = ¾").

Step 3: From the table, for 3-4" slump and ¾" NMAS, $W_w$ = 340 $lb/yd^3$, Air = 2.0%

Step 4: For gravel w/ some crushed particles, subtract 35 $lb/yd^3$: $W_w$ = 340 – 35 = 305 $lb/yd^3$

Step 5: Design strength ($f'_c$) has been specified ($f'_c$ = 4300 psi).

Required cylinder strength ($f'_{cr}$) = 4300 + 1200 = 5500 psi (to provide a factor of safety)

Step 6: Interpolating in the table between 5000 and 6000 psi: w/c ratio = (0.41+0.48)/2 = 0.445

Step 7: $W_c$ = 305/0.445 = 685 $lb/yd^3$

Step 8: Interpolating in the table between FM = 2.8 and FM = 3.0, $b/b_o$ = (0.60+0.62)/2 = 0.61

$V_{bulk} = 0.61 \times 27\ ft^3/yd^3 = 16.47\ ft^3/yd^3$

$W_g = \gamma_g \times V_{bulk} = 99\ lb/ft^3 \times 16.47\ ft^3/yd^3 = 1631\ lb/yd^3$

Step 9: $V_w = W_w/RD_B/\gamma_w = 305/1.00/62.4 = 4.89\ ft^3/yd^3$ (we'll need this for Problem 2)

$V_c = W_c/RD_B/\gamma_w = 685/3.15/62.4 = 3.48\ ft^3/yd^3$ (we'll need this for Problem 2)

$V_g = W_g/RD_B/\gamma_w = 1631/2.66/62.4 = 9.83\ ft^3/yd^3$

$V_{air} = (0.02)\ 27\ ft^3/yd^3 = 0.54\ ft^3/yd^3$ (we'll need this for Problem 2)

$V_s = 27\ ft^3/yd^3 - V_w - V_c - V_g - V_{air} = 27 - 4.89 - 3.48 - 9.83 - 0.54 = 8.26\ ft^3/yd^3$

$W_s = V_s \times RD_B \times \gamma_w = 8.26\ ft^3/yd^3 \times 2.55 \times 62.4 = 1314\ lb/yd^3$

Step 10: Add enough water to ensure the aggregate is SSD

$W_w = 305 + 1630\ (0.0095) + 1314\ (0.0125) = 337\ lb/yd^3$

Note that this doesn't change the w/cm ratio of the concrete! You're adding water to saturate the aggregate so it doesn't suck water out of the cement paste. The amount of water available to hydrate the cement is still 305 lb so the w/cm ratio is still 0.445 as you calculated in Step 6.

2. (5 pts) Calculate the volume (in $ft^3$) of the cement paste (cement + water + air) for the mix you designed in Problem 1. Do NOT include the water added to make the aggregate SSD; that water is not part of the cement paste, it's part of the aggregate.

$V_{paste} = V_w + V_c + V_{air} = 4.89 + 3.48 + 0.54 = 8.91\ ft^3/yd^3$

3. (15 pts) If the coarse aggregate in Problem 1 had a 1½" NMAS instead of a ¾" NMAS, what would be the volume of the cement paste (cement + water + air)? How much more or less is this volume as a percentage of the volume in Problem 1? Note that you don't need to determine the amount of gravel and sand in the mix; just the amounts of cement, water, and air (Steps 3-7).

Step 3: From the table, for 3-4" slump and 1½" NMAS, $W_w = 300\ lb/yd^3$, Air = 1.0%

Step 4: For gravel w/ some crushed particles, subtract 35 $lb/yd^3$: $W_w = 300 – 35 = 265\ lb/yd^3$

Step 5: Required cylinder strength ($f'_{cr}$) is the same as before (5500 psi)

Step 6: w/c ratio is the same as before (0.445)

Step 7: $W_c = 265/0.445 = 596\ lb/yd^3$

Now we just need to calculate the volume of the water, cement, and air:

$V_w = 265/1.00/62.4 = 4.25\ ft^3/yd^3$

$V_c = 596/3.15/62.4 = 3.03\ ft^3/yd^3$

$V_{air} = (0.01)\ 27\ ft^3/yd^3 = 0.27\ ft^3/yd^3$

$V_{paste} = V_w + V_c + V_{air} = 4.25 + 3.03 + 0.27 = 7.55\ ft^3/yd^3$

This is 15% less cement paste volume due to the lower surface area of the larger aggregate.

4. (10 pts) Redesign the mix in Problem 1 using the ***estimated weight method***. Don't bother to repeat Steps 1-8 (they won't change); just redo Steps 9 and 10.

Step 9: From the table, Estimated Weight ($W_T$) = $27\ ft^3/yd^3 \times 146.5\ lb/ft^3 = 3956\ lb/yd^3$

$W_s = W_T – W_w – W_c – W_g = 3956 – 305 – 685 – 1630 = 1336\ lb/yd^3$

Step 10: Add enough water to ensure the aggregate is SSD:

$W_w = 305 + 1630\ (0.0095) + 1336\ (0.0125) = 337\ lb/yd^3$

5. (10 pts) if the moisture content of the sand stockpile is 4.5% and the moisture content of the gravel stockpile is 1.3%, how much cement, water, and moist aggregate will be needed to make a 1-$yd^3$ batch of the concrete in Problem 1.

$W_c = 685\ lb/yd^3$ (this doesn't change)

Moist $W_s = 1314 \times 1.045 = 1373\ lb/yd^3$ (there is 59 $lb/yd^3$ of water in the aggregate)

Moist $W_g = 1631 \times 1.013 = 1653\ lb/yd^3$ (there is 22 $lb/yd^3$ of water in the aggregate)

New $W_w = 337 – (1373–1314) – (1653–1631) = 256\ lb/yd^3$ (81 $lb/yd^3$ less than before)

Remember, the new weight of water doesn't change the w/cm ratio. You've added water to make the aggregate SSD (which doesn't change the amount of water available to hydrate the cement) and you've subtracted water because Mother Nature has provided some of the mixing water for you by raining on the stockpiles. The w/cm ratio is still 0.445 as you determined in Problem 1.

6. (15 pts) If the coarse aggregate in Problem 1 was crushed stone (i.e., angular aggregate) instead of gravel with some crushed particles (i.e., mostly rounded aggregate), what would be the volume of the cement paste (cement + water + air)? How much more or less is this volume as a percentage of the volume in Problem 1? Note that you don't need to determine the amount of gravel and sand in the mix; just the amounts of cement, water, and air (Steps 3-7).

Step 3: From the table, for 3-4" slump and ¾" NMAS, $W_w$ = 340 lb/yd$^3$, Air = 2.0%

Step 4: For crushed stone, you don't need to adjust the water, so $W_w$ = 340 lb/yd$^3$

Step 5: Required cylinder strength ($f'_{cr}$) is the same as before (5500 psi)

Step 6: w/c ratio is the same as before (0.445)

Step 7: $W_c$ = 340/0.445 = 764 lb/yd$^3$

Now we just need to calculate the volume of the water, cement, and air:

$V_w = 340/62.4 = 5.45\ ft^3/yd^3$

$V_c = 596/3.15/62.4 = 3.89\ ft^3/yd^3$

$V_{air} = (0.02)\ 27\ ft^3/yd^3 = 0.54\ ft^3/yd^3$

$V_{paste} = V_w + V_c + V_{air} = 5.45 + 3.89 + 0.54 = 9.88\ ft^3/yd^3$

This is 8% more cement paste volume due to the higher surface area of the angular stone.