EXHIBIT 6

General Guidelines for Concrete Mix Design

General Comments:

- This exhibit provides general guidelines and helpful hints so that teams understand what is required in the concrete mix design table and how it should be properly filled out.
- Under the categories of "Cementitious Materials," "Aggregates," "Fibers," and "Admixtures", provide the name of the constituents that are being used. **Commercial (trade) names should be used if it is clear what the product is.**
- Absorption and moisture content values (in percent) for the aggregates shall be provided (to the nearest 0.1%)
- Under the "Specific Gravity" column, provide the specific gravity (dimensionless) of the cementitious materials, aggregates, fibers, and water used in the concrete mix. **For aggregates, you will provide the Oven Dried (OD) and Saturated, Surface Dry (SSD) values**. Two or three decimal places are sufficient.
- The weight of the liquid admixtures shall be provided in lb/gal.

Notes:

1. The values provided in these tables are shown for MATHEMATICAL EXAMPLE purposes only.
2. Teams should not consider the mixture proportions shown to result in concrete with the needed fresh (slump, air content) and hardened (strength) characteristics required for the competition.
3. Values such as specific gravity are based on generalized numbers and should not be used for your design calculations (i.e., do not reference this document as the one you based your values on).

The following is a step-by-step example for reporting FINAL yielded concrete mixture proportions and checks to make sure that it is theoretically and mathematically correct. This means that the reported unit weight is measured, and the values provided consider relative yield, Ry.

Proposed Mixture Proportions

Type I/II Cement	400 lb¸ SG = 3.15
Fly Ash (Class C)	250 lb, SG = 2.93
Blast Furnace Slag	250 lb, SG = 2.85
Fibers, Nylon	5 lb, SG = 0.92
Fibers, PVA	3 lb, SG = 1.40
w/cm ratio	0.50
Expanded Shale, aggregate	600 lbs (dry), Abs = 13%, SG_{dry} = 1.55 (ASTM C330 compliant)
Pumice, aggregate	600 lbs (dry), Abs = 17%, SG_{dry} = 1.59 (ASTM C330 compliant)
Admixtures:	6 fl oz/cwt HRWR Admixture (47% solids by weight, 8.5 lb/gal) 20 fl oz/cwt Liquid Dye (50% solids by weight,10.0 lb/gal)
Design Unit Weight (wet)	99.55 lb/ft^3
Design Air Content	11.3%

ABSOLUTE VOLUME METHOD

The absolute volume of a given material is computed by dividing the mass of the material by its absolute density, which is the specific gravity (SG) times the density of water (62.4 lb/ft^3), as shown by:

$$\textit{Absolute Volume} = \textit{mass} / (SG \times 62.4)$$

Example : How much volume does 400 lbs of portland cement occupy given that SG = 3.15?

$$Volume_{cement} = Mass_{cement} / (SG_{cement} \times 62.4)$$

$$= 400 \ / \ (3.15 \times 62.4) = 2.04 \ ft^3$$

In a batch of concrete, the sum of the absolute volumes of cementitious materials, aggregate, fibers, water, solids from admixtures and air, gives the volume of concrete produced per batch. The above equation can be used to determine the volumes of the various constituents and populate the table.

Please note that there are several specific gravities reported for aggregate, depending on the condition that they are in, such as dry (SG_{OD}) and saturated, surface dry (SG_{SSD}). **The values are different** as one is obviously in the dry state and the other considers the water that is required to bring the aggregate to the SSD condition, and it can be shown that it is a function of absorption. For example, it can be shown that for the shale (SG_{SSD} = 1.55; A = 13%), the SG_{OD} is 1.75.

The volume that the aggregate occupies between the conditions, however, can be shown to be the same. That is, the volume of aggregate in the OD condition determined by taking the amount of aggregate in the OD condition divided by SG_{OD} is equal to the volume of aggregate in the SSD condition as determined by taking the amount of aggregate in the SSD condition divided by SG_{SSD}.

WATER

Based on the final w/cm ratio, the amount of water is simply computed using the total amount of cementitious material in the mixture

$$Water = w/cm \times cm$$

Example: How much water is needed for 900 lbs of cm using a w/cm of 0.50?

$$Water = w/cm \times cm$$

$$Water = 0.50 \times 900 \ lb = 450 \ lb$$

The water that is computed from the w/cm ratio is the water that is needed to hydrate the cementitious materials (cm). It is not used to condition the aggregate to the SSD condition.

The water (w) comes from three sources – water from the aggregate (if there is "free" water then the value of this is positive; if the aggregate is drier than the SSD condition, then the value is negative), water from the admixtures, and additional batch water, and is expressed as (or a rearrangement of this equation):

$$w_{batch} = w - \left(w_{free} + \sum w_{admx}\right)$$

Compute Free Water from Aggregates

With the values previously obtained for the aggregates, the total moisture content, free moisture content and the amount of moisture available, can be computed for each aggregate using the following three equations:

$$MC_{total} = \frac{W_{stk} - W_{od}}{W_{od}} \times 100\%$$

$$MC_{free} = MC_{total} - A$$

$$w_{free} = W_{OD} \times \left(\frac{MC_{free}}{100\%} \right)$$

Aggregate	W_{OD} (lb)	Abs (%)	W_{SSD} (lb)	MC_{total} (%)	MC_{free} (%)	w_{free} (lb)
Aggregate #1	600	13	678	8	-5	-30
Aggregate #2	550	17	643.50	12	-5	-27.5

Combined, the aggregates have -57.50 lb of free water

What does this mean? In this case it means that the aggregates are drier than the SSD condition. So, if you added the amount of water computed above (450 lbs to get your 0.5 w/cm ratio), the aggregate would want to soak up 57.5 lbs of it to get to the SSD condition. So, in the end, your w/cm ratio is no longer 0.5. However, we must deal with water from other sources as well. See below.

Compute Water from Admixtures

The water in the various admixtures can be found from the following equation:

Water in admixture = dosage x cwt of cm x water content x (1 gal/128 fl oz) x (lbs/gal of admixture)

From liquid dye

[20 fl oz/ cwt x 9.00 cwt] x [(100% – 50% solids)/100] x (1 gal/128 fl oz) x (10 lb/gal)= 7.03 lb

From HRWR

[6 fl oz/ cwt x 9.00 cwt] x [(100% – 47% solids)/100] x (1 gal/128 fl oz) x (8.5 lb/gal) = 1.90 lb

Total water from all the admixtures is then 8.93 lb.

Compute Batch Water

We have computed water from two of the three sources – the aggregate and the admixtures. Based on this example, we ended up having no "free" water from the aggregate (if fact, you were in a deficit).

Since we know the amount of water needed to hydrate the cm (450 lb) based on the w/cm ratio chosen, the batch water can be computed by:

$$w_{batch} = w - \left(w_{free} + \sum w_{admx}\right)$$

$$= 450 \text{ lbs} - (-57.5 + 8.93) = 498.57 \text{ lb}$$

The volume of water, to hydrate cm only, ($SG_{water} = 1$) is then

$$Volume_{water} = Mass_{water} / (62.4)$$

$$= 498.57 / 62.4 = 7.99 \text{ ft}^3$$

SOLIDS (from liquid admixtures)

Typically, the proportional volume of the solids included in the liquid admixture is so small in relation to the size of the batch that it can be neglected. The exclusion to this includes latex admixtures (which are prohibited) and dyes (both liquid and in powder form) which can have substantial volumes.

- **For the competition, only dye solids (in the liquid medium) are to be accounted for.**
- **Disregard the contribution of solids from other admixtures.**
- If you have a powdered admixture (i.e., it is not in a liquid medium), then use the absolute volume method as previously shown.

The solids content can be computed in a fashion like the water content from admixtures

Solids in admixture = dosage x cwt of cm x solid content x (1 gal/128 fl oz) x (lb/gal of admixture)

Based on the weight of the admixture (in lb/gal) and the percentages of water and solids within it, one can determine the SG of the solid particles (SG of water is taken as 1.0) as follows:

- If the liquid dye is 50% water by weight, the weight of water is 6 lb (0.50 x 12 lb)
- The weight of the solids is 6 lb (in a gal of admixture).
- The volume of water is then (6 / 62.4) to obtain 0.0962 ft^3.
- Solids volume is 0.0375 ft^3. Note: 1 gal = 0.13368 ft^3.
- The unit weight of solids is then 6 lb / 0.0375 ft^3 = 160 lb/ft^3 and therefore its SG is determined to be 2.56.

<u>From liquid dye</u>

[20 fl oz/ cwt x 9 cwt] x [(50% solids)/100] x (1 gal/128 fl oz) x (12 lb/gal) = 8.44 lb

<u>From HRWR</u>

[6 fl oz/ cwt x 9 cwt] x [(47% solids)/100] x (1 gal/128 fl oz) x (8.5 lb/gal) = 1.90 lb

DENSITIES, AIR CONTENT, SLUMP and RATIOS

Now that all the amounts have been determined, the respective volumes can be computed so that theoretical densities and air content can be found.

Mass of Concrete (M) – The mass of concrete is the sum of all masses of the constituents in the mixture – cm, fiber, aggregate, water and admixture solids:

$$M = Amount_{cm} + Amount_{fibers} + Amount_{aggregate} + Amount_{water} + Amount_{solids}$$
$$M = 900.00 + 8.0 + 1321.50 + 450 + 8.44 = \underline{2687.84\ lb}$$

Absolute Volume of Concrete (V) – The absolute volume of concrete is the sum of all the constituents in the mixture. This is based on zero air content. **This value has to be less than 27 ft^3 (1 yd^3):**

$$V = Volume_{cm} + Volume_{fibers} + Volume_{aggregate} + Volume_{water} + Volume_{solids}$$
$$V = 4.81 + 0.12 + 11.75 + 7.21 + 0.05 = \underline{23.941\ ft^3}$$

Theoretical Density (T) – is the density of concrete with no air in it and is the mass of concrete (M) divided by the absolute volume of concrete (V):

$$T = M / V$$
$$T = 2687.84\ lb / 23.91\ ft^3 = 112.27\ lb/ft^3$$

Measured, or Anticipated, Density (D) – the density of concrete obtained from cylinders, cubes, etc. in the plastic (wet) state (i.e., immediately after casting). 99.55 lb/ft^3

Air Content – The air content is computed by comparing the theoretical density (no air) to the measured density (D) or using the absolute volume methods:

Air content from theoretical density:

$$Air\ content = (T - D) / T \times 100$$
$$Air\ content = (112.27 - 99.55) / 112.27 \times 100 = 11.3\%$$

Air content from a absolute volume method:

$$Air\ content = (27 - V) / 27 \times 100$$
$$Air\ content = (27 - 23.941) / 27 \times 100 = 11.3\%\ (check)$$

The value of the air content should be checked using the absolute volume method (you should come up with the same answer. If you do not, then there is an error someplace).

Note: If the measured density is higher than the theoretical density, the result would be a negative air content. *This is not possible*.

Cement-Cementitious Materials Ratio

The c/cm ratio is a calculated value: 400 lb c / 900 lb cm = 0.444

Water-Cementitious Materials Ratio

The w/cm ratio is a calculated value: 450 lb / 900 lb cm = 0.50

Slump – measured value (in inches).

AGGREGATE PROPORTIONING

Aggregate - Concrete Ratio **(Volumetric)** – Per **EXHIBIT 5 – Technical Specifications for Concrete and Reinforcement**, "Regardless of source, the total aggregate volume shall be 30% (min.) of the total volume of any concrete mixture."

$$\textit{Aggregate Ratio (\%)} = V_{aggregate} / 27 \times 100\%$$

$$(11.75 / 27) \times 100\% = \underline{43.5\% > 30\% \text{ (OK!)}}$$