

WHITE PAPER – Concrete Mixture Data Table

By Michael Carnivale, III, PE

This revised version is published to correct two errors – (1) in the computation of water from admixtures and (2) the amount of admixture that is computed for the “Batched” proportions. The first error would result in subsequent changed to other values, however, the remaining calculations appear to be correct.

Over the last several years, I have been requested to review mixture design tables for the purpose of assisting judges in determining compliance with the Rules and Regulations of the ASCE National Concrete Canoe Competition™. During these reviews, I have noticed a number of issues ranging from very minor calculation errors (e.g., proper determination of w/cm ratio) to gross miscalculations (concrete densities many times greater than steel and negative air contents among others). Furthermore, I have seen values provided which have made the review of the tables very difficult for the judges (for instance, values such as “1.045E-04 lbs” shown as a weight). This “White Paper” has been prepared in the hope of providing some general guidelines and helpful hints so that concrete canoe teams have a better understanding on what is required in the table and how it should be filled out. To this end, I have provided a step-by-step example calculation showing mixture proportioning from the “As Designed” to the “Yielded” proportions. In addition, I have attached a copy of ASTM C 138/C 138 M “Standard Test Method for Density (Unit Weight), Yield and Air Content (Gravimetric) of Concrete” which is probably one of the most useful references you can have for this competition.

Notes:

1. The values provided in these tables are shown for MATHEMATICAL purposes only.
2. Teams should not consider the mixture proportions shown will actually result in a concrete with the needed fresh (slump, air content) and hardened (strength) characteristics needed 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 for which you based your values on).
4. This white paper does not supplement or supersede the Rules and Regulations
5. Some numbers shown may be off (second and third decimal place) due to the use of Excel spreadsheet (rounding).
6. Units such as lb/yd³ and pcy are used interchangeably.

The “TABLE”

Table 3.1 is broken down into three (3) major categories: **Oven-dry (Non-SSD) Proportions as Designed**, **Actual Batched Proportions** and **Yielded Proportions**. Each of these categories is then further broken down into “Amount” and “Volume.”

- Under the categories of “Cementitious Materials,” “Aggregates,” “Fibers,” and “Admixtures”, teams should provide the name of the particular constituents being used. Generic or commercial names may be used as long as it is clear what the product is.
- Absorption values and moisture contents (in percent) for the aggregates shall be provided. One or two decimal places are sufficient.
- Under the “Specific Gravity” column, provide the specific gravity (dimensionless) of the cementitious materials, aggregates (bulk dry specific gravity), fibers, and water used in the concrete mix. Two decimal places are sufficient. The specific gravity of portland cement is 3.15 and water is 1.0.
- The density of the admixtures shall be provided in lb/gal.
- “Air Content” is a typically a measured value (ASTM C 231), while the “Gravimetric Air Content” is a computed value (see ASTM C 138/ C 138 M).

On the following page is a blank copy of the mixture design table as shown in the Rules and Regulations and provided by the listserv (Figure 1). Teams can modify the table in terms of layout (color, font, etc.) and increase/decrease the number of rows needed (for example, if you have three aggregates, there is no need to have five lines). Teams must fill out all of the relevant data such as c/cm, air, slump, unit weight, air content and yield.

Mixture ID:		Non-SSD Proportions as Designed						Actual Batched Proportions		Yielded Proportions	
		Batch Size (ft ³):		Amount (lb/yd ³)	Volume (ft ³)	Amount (lb)	Volume (ft ³)	Amount (lb/yd ³)	Volume (ft ³)		
Cementitious Materials		Specific* Gravity									
1.											
2.											
3.											
4.											
Total of All Cementitious Materials:											
Fibers											
1.											
2.											
Total of All Fibers:											
Aggregates											
1.	Abs.: % ; MC: %										
2.	Abs.: % ; MC: %										
3.	Abs.: % ; MC: %										
4.	Abs.: % ; MC: %										
5.	Abs.: % ; MC: %										
Total of All Aggregates:											
Water											
1.	Total Batched Water [^]										
2.	Water Added for Agg. Absorption										
3.	Total Water from All Admixtures [§]										
Total Water:											
Solids Content of Latex Modifiers											
1.											
2.											
Total Latex Solids:											
Admixtures		% Solids	Amount (fl oz/cw t)	Water [‡] in Admixture (lb/yd ³)	Amount (fl oz)	Water [‡] in Admixture (lb)	Amount (fl oz/cw t)	Water [‡] in Admixture (lb/yd ³)			
1.	Wt./gal:										
2.	Wt./gal:										
3.	Wt./gal:										
4.	Wt./gal:										
5.	Wt./gal:										
Cement-Cementitious Materials Ratio											
Water-Cementitious Materials Ratio (w/cm)											
Slump, Slump Flow, in. (Flow Table, %)											
Design Air Content, %											
Density (Unit Weight), lb/ft ³											
Gravimetric Air Content, %											
Yield, ft ³											
Abs. = Absorption; MC = Batched moisture concrete;				‡ Water content of admixture.							
^ Including water added for aggregate absorption;				§ If impact on w/cm is less than 0.01 enter zero.							
* For aggregates, provide ASTM C 127 oven-dry bulk specific gravity.											

Figure 1 – Table 3.1, Concrete Mixture Proportion Table

Oven-Dry (Non-SSD) Proportions as Designed

This category indicates how the designer INTENDS on proportioning the concrete mixture. The proportioning may be based on previous mixtures (research and/or experience), ACI guides, recommendations from a supplier, etc. In this process, some parameters are assumed such as desired slump and air content. Basically, this is your starting point in the mixture proportioning process – determining what you think you need to make your concrete mix. **It is more of putting pen to paper rather than actually mixing materials.**

- The “Amount” of each ingredient shall be provided in lb/yd³.
- The “Volume” shall be provided in ft³ and is a measure of the absolute volume of each ingredient.
- The amount of admixtures shall be reported in fl oz/cwt (fluid ounces per 100 pounds of cementitious materials). Based on solids content, the amount of water contributed by each admixture used in the mixture can be determined and the “Total Water from All Admixtures” added to the table.
- Yield, ft³ – the summation of all the absolute volume of ingredients (should total 27 ft³) (Figure 2)

Density (Unit Weight), lb/ft ³				
Gravimetric Air Content, %				
Yield, ft ³		27.0		
Abs. = Absorption; MC = Batched moisture concrete;		* Water content of admixture.		
^ Including water added for aggregate absorption;		§ If impact on w/cm is less than 0.01 enter zero.		
* For aggregates, provide ASTM C 127 oven-dry bulk specific gravity.				

Figure 2 – Value of the Yield for the “As Designed” Proportions

Actual Batched Proportions

This category indicates what is actually batched in the laboratory and includes any deviations from proposed proportions or assumed amounts

- The “Batch Size” is measured in ft³. For example, your team may decide to use 1 ft³ of concrete each time during lab testing. (The batch size need not be 1 ft³, it is being used here for illustration purposes only.)
- The “Amount” of each ingredient in the batch shall be provided in lb.
- The “Volume” shall be provided in ft³ and is a measure of the absolute volume of each ingredient for the batching.
- During the actual mixing process, there may be some deviations from what was originally proportioned or assumed. For example, you may have determined that you needed 10 lb of water for your mix, but after adding some HRWR, you only needed to add 8 lb of water. Another example would be that you assumed an air content of 5%, but after adding air entrainment, you ended up measuring 8% air. There can be numerous other deviations, including, adding more cementitious materials than originally planned, adding an admixture that was not originally planned, etc.
- Yield, ft³ – is the mass of all of the ingredients used in the batch divided by the measured density of the concrete (see ASTM C 138/C 138 M). This value can be equal to, less than or greater than the assumed batch size.

Yielded Proportions

This category is to report the true amount of each ingredient of the concrete mixture, taking into account the actual batched amounts. It is the adjustment made to the “As Designed” proportions to account for the unit weight and air content obtained after batching in the laboratory.

- For example, you may have batched the equivalent of 400 lb/yd³ of cement. However, after mixing you determined that the concrete did not yield to your design volume for the batch. Your actual cement content for 1 yd³ of concrete, therefore, would not be 400 lb. It could be more or less depending on the yield.
- Yield, ft³ – is the summation of all the absolute volume of ingredients (should total 27 ft³)

The following is a step-by-step computation for designing a concrete mixture proportion (including determination of air content), the batching of concrete in the laboratory (including the determination of the yield) and the computation of the yielded proportions. This is followed by a check with the specifications as outlined in the rules and regulations for parameters such as c/cm, w/cm, and air content.

EXAMPLE EXAMPLE EXAMPLE EXAMPLE EXAMPLE EXAMPLE

Material	Non-SSD Amounts (per cy of concrete)
Type III Cement	375 lbs
Fly Ash (Class C)	300 lbs
Silica Fume	100 lbs
Fibers	PVA 5.0 lbs; Nylon 1.0 lbs
Aggregates:	A: 300 lbs (dry); Absorption 10%; Moist. Content 5%
	B: 200 lbs (dry); Absorption 7%; Moist. Content 0%
	C: 100 lbs (dry); Absorption 25%; Moist. Content 25%
w/cm ratio	0.37
Admixtures:	45 fl oz/cwt Air Entrainment (AE) Admixture (7% solids by weight, 7 lb/gal)
	200 fl oz/cwt Latex Admixture (45% solids by weight, 8.5 lb/gal)

Determine the unit weight and air content of the concrete mixture [proportions are for 1 yd³ (27 ft³) of concrete] and fill out the table for the “Non-SSD Proportions as Designed”

Absolute Volume Method

The absolute volume of a given material is computed by dividing the mass of the material by the absolute density, which is the specific gravity (G_s) times the density of water (62.4 pcf) as shown by:

$$Absolute\ Volume = mass / (G_s \times 62.4)$$

Example – How much volume does 375 lbs of portland cement occupy knowing that G_s = 3.15?

Solution:

$$Volume_{cement} = Weight_{cement} / (G_{s(cement)} \times 62.4)$$

$$= 375 / (3.15 \times 62.4) = 1.908\ cy\ (say\ \underline{1.91\ cy})$$

In a batch of concrete, the sum of the absolute volumes of cementitious materials, aggregate, fibers, water, and air, gives the volume of concrete produced per batch. The above equation can be used to determine the volumes and populate the table as shown on the following page (Figure 3).

EXAMPLE MIXURE DESIGN (Revised)							
Mixture ID:	XYZ	Non-SSD Proportions as Designed		Actual Batched Proportions		Yielded Proportions	
Batch Size (ft ³):							
Cementitious Materials	Specific* Gravity	Amount (lb/yd ³)	Volume (ft ³)	Amount (lb)	Volume (ft ³)	Amount (lb/yd ³)	Volume (ft ³)
1. Portland Cement, Type III (ASTM C 150)	3.15	375.00	1.908				
2. Class C Fly Ash	2.60	300.00	1.849				
3. Microsilica (Silica Fume)	2.30	100.00	0.697				
Total of All Cementitious Materials:		775.00	4.454				
Fibers							
1. PVA Fibers	1.30	5.00	0.062				
2. Nylon Fibers	1.00	1.00	0.016				
Total of All Fibers:		6.00	0.078				
Aggregates							
1. Aggregate A Abs.: 10% ; MC: 5%	0.80	300.00	6.010				
2. Aggregate B Abs.: 7% ; MC: 0%	0.50	200.00	6.410				
3. Aggregate C Abs.: 25 % ; MC: 25%	1.60	100.00	1.002				
Total of All Aggregates:		600.00	13.421				
Water							

Figure 3 – Populating the Table after Calculating the Absolute Volumes

Water

Based on a w/cm ratio, the amount of water anticipated can be simply computed using the total amount of cementitious material in the mixture

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

Example – How much water is needed for 775 lbs of cm using a w/cm of 0.37

Solution: $Water = 0.37 \times 775 \text{ lbs} = 286.75 \text{ lbs}$

In the mixture design table, teams are to account for the “Total Water” that is to be included in the concrete. This “Total Water” is a combination of water that is used to account for aggregate absorption, water from the admixtures and batched water. There is a note that the “Total Batched Water” includes the water added for aggregate absorption. It is important to note that the water used for aggregate absorption is not available to hydrate the cementitious materials, therefore, it is not used in the determination of the w/cm ratio. Also, while the weight (mass) of the water added for aggregate absorption will be used in the determination of the unit weight of concrete, the volume of the water added for aggregate absorption is not included in the unit weight determination (the aggregate volume includes the pore spaces for water and is already accounted for).

In general, the “Total Water” is

$$Total\ Water = Total\ Batched\ Water + Water\ from\ Admixtures$$

and is equivalent to

$$Total\ Water = Water\ for\ cm\ hydration + Water\ for\ Aggregate\ Absorption$$

Let’s compute the water that will be in the admixtures based on known weights and solid contents using 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)

Example – Based on a dosage of 200 fl oz/cwt for a latex admixture, what is the amount of water added per cy of concrete, if the percent solids of the admixture is 45% by weight? Assume a gal of latex weighs 8.5 lbs. *Note:* 1 gal = 0.13368 cf

Solution: If the latex is 55% water by weight, the weight of water is 4.68 lbs (0.55 x 8.5 lbs) and the weight of the solids is 3.82 lbs. Given that the G_s of water is 1, the unit weight of water is 62.4 pcf, the volume of water can be determined by dividing the weight by the unit weight (4.68/62.4) to obtain 0.07492 cf (we are going to 5 significant figures given that we used that many in the conversation of gal to cf). Therefore the remaining volume is solids (0.13368 – 0.07492 = 0.05876 cf). The unit weight of solids is then 3.82 lbs/0.05876 cf = 65.10 pcf and therefore its G_s is determined to be 1.043.

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

$[(200 \text{ fl oz/ cwt}) \times (775 \text{ pcy})/100] \times [(100\% - 45\% \text{ solids})/100] \times (1 \text{ gal}/128 \text{ fl oz}) \times (8.5 \text{ lbs} / 1 \text{ gal}) =$

$1550 \text{ fl oz (for 7.75 cwt)} \times 0.55 (\% \text{ water in latex}) \times 8.5/128 = \underline{\underline{56.6 \text{ lbs water/cy of concrete}}}$

The above equation can be applied to the other admixtures that are to be used to determine the amount of water being contributed and the table can be populated as shown below (Figure 4).

You will notice that the water for the AEA is in blue (supposedly blocked out and not needed to be filled in). The note for the table is that if the contribution for an admixture has an effect on the w/cm of 0.01 or less, then it does not need to be included. However, using an example where we “spiked” the concrete with AEA, you will notice if you run the equation that it can have an effect (17.0/775 = 0.022), so it will need to be included.

In our example, the water from the two admixtures is 74.35 lbs and is put into the table as shown below (Figure 4).

Water								
1. Total Batched Water [^]	1.00	281.40	4.510					
2. Water Added for Agg. Absorption	1.00	69.00	1.106					
3. Total Water from All Admixtures [§]	1.00	74.35	1.191					
Total Water:		355.75	4.595					
Solids Content of Admixtures								
1. Latex Solids	1.04	46.32	0.712					
2. AEA Solids	0.27	1.34	0.080					
Total Solids:		47.65	0.792					
Admixtures		% Solids	Amount (fl oz/cwt)	Water [†] in Admixture (lb/yd ³)	Amount (fl oz)	Water [†] in Admixture (lb)	Amount (fl oz/cwt)	Water [†] in Admixture (lb/yd ³)
1. Latex	Wt./gal: lb/gal	45.00	200.00	56.6				
2. Air Entraining (AEA)	Wt./gal: lb/gal	7.00	45.00	17.7				

Figure 4 – Populating the Table after Taking into Account Water

Let's compute the water that will be absorbed by the aggregate:

$$\text{Water for aggregate absorption} = \Sigma(\text{Absorption} \times \text{Amount of Aggregate})$$

Based on the values provided in the table (and the absorption values can be obtained through testing following ASTM procedures or perhaps provided by the aggregate supplier), the sum of the water absorbed can be calculated and added to the table. In our example

$$\text{Water for Aggregate Absorption} = (300 \text{ lbs})(10\%) + (200 \text{ lbs})(7\%) + (100 \text{ lbs})(25\%) = 69 \text{ lbs}^{**}$$

Now, we already know that we needed 286.75 lbs of water to mix with the cementitious materials to achieve the 0.37 w/cm ratio. Given that

$$\text{Total Water} = \text{Water for cm hydration} + \text{Water for Aggregate Absorption}$$

One can compute that the Total Water is 355.75 lbs (= 286.75 + 69.0).

The Total Batched Water is then computed by

$$\text{Total Batched Water} = \text{Total Water} - \text{Water from Admixtures}$$

$$\text{Total Batched Water} = 355.75 - 74.35 = 281.4 \text{ lbs}$$

The tricky part is that while the weight of water in the concrete mixture is 355.7 lbs, the volume that it occupies has to take into account the volume of aggregate. The water needed for cm hydration (286.75 lbs) will occupy is 4.595 cf (= 286.75/62.4). Since the volume of aggregate includes the pore space for water, the volume of water is computed from the values in the table (Figure 4)

$$\begin{aligned} \text{Volume}_{\text{water}} &= \text{Volume}_{\text{Total batched water}} - \text{Volume}_{\text{water for aggregate absorption}} + \text{Volume}_{\text{total water from all admixtures}} \\ &= 4.510 - 1.106 + 1.191 = \underline{4.595 \text{ cf}} \end{aligned}$$

***Note: The calculation for the amount of water needed for aggregate absorption resulted in 69 lbs of water. This value includes the amount of water already in the aggregates (i.e., the batched moisture content). Based on the values in the example there is already 40 lbs of water in the aggregate*

$$(300 \text{ lbs})(5\%) + (200 \text{ lbs})(0\%) + (100 \text{ lbs})(25\%) = 40 \text{ lbs}$$

This means that only an additional 29 lbs of water is needed to bring the aggregates to the saturated-surface dry (SSD) condition. So what happens if you are batching aggregate at moisture content above the SSD condition? In our example, we know that 69 lbs is needed absorption. Assume that the batched moisture content resulted in 79 lbs of water and that each of the batched moisture contents is greater than the absorption value. Nothing really changes. The Water for Aggregate Absorption is still 69 lbs. The Water from the Admixtures is still 74.35 lbs. The Total Batch Water is still 281.4 lbs. The only difference is that 10 lbs of the 281.4 lbs needed will come from the aggregate itself and not from the spigot, garden hose, etc. that you get the rest of the water from.

Latex Solids

The solids content of the latex can be computed in a fashion similar to that used in the computation of the water contributed by the admixture. For ease, one can use proportionality. In the above example, we already determined that for every gal of latex used, it is 55% water to 45% solids. Therefore the solid/water ratio is (45/55 = 0.818). If 56.6 lbs of water is provided to the concrete mixture, then 0.818 x 56.6 = 46.32 pcy of solids are added to the mixture.

In addition, we have already computed the G_s of latex solids to be 1.043. Again, using the absolute volume method, we can determine the volume that the latex solids will occupy in the concrete mixture.

Now that we have determined the amount of mass and volumes for the cementitious materials, fibers, aggregate, water and admixtures, we can populate the remainder of the table (Figure 5).

Cement-Cementitious Materials Ratio

The c/cm ratio is a calculated value: 375 lbs c / 775 lbs cm = **0.484**

Water-Cementitious Materials Ratio – The w/cm ratio was assumed and used to determine the amount of water needed based on cm content (in this example, it was 0.37). This can be double checked as:

$$(Total\ Batched\ Water - Water\ Added\ for\ Agg.\ Absorption + Water\ from\ Admixtures) / (total\ cm)$$

$$w/cm = (281.4 - 69 + 74.35)/(775) = **0.37\ check!**$$

Slump – Slump is an assumed value (perhaps based on experience or other design guidance that you have). Generally, you would provide a range of acceptable slump rather than just a hard number. In our example, we are going with a slump of **3 ± 1 inch**.

Unit Weight of Concrete – The unit weight (density, D) of concrete is the wet or plastic weight of the concrete and is determined simply by dividing the weight of the constituents by 27. When accounting for the water, include the water needed to hydrate the cement and the water for aggregate absorption.

$$Unit\ Weight = (775 + 6 + 600 + 355.75 + 47.65) / 27 = **66.1\ pcf**$$

Design Air Content – We still use the absolute volume method to determine the air content of the concrete mixture and it is fairly simple to calculate. Given that you are proportioning 1 cy (27 cf) of concrete and you have the absolute volumes of the cementitious materials, water, fibers, aggregate and admixtures, you can determine the air content using one of the following two (2) equations:

$$Volume_{concrete} = Volume_{cm} + Volume_{agg} + Volume_{water} + Volume_{fibers} + Volume_{adm} + Volume_{air}$$

$$Volume_{air} = 27 - (4.454 + 13.421 + 4.595 + 0.078 + 0.792) = 27 - 23.340 = 3.660\ cf\ of\ air$$

$$Air\ content = 3.660/27 \times 100 = **13.56\ %**$$

Another way to compute the air content is by ASTM C138, where it is a comparison of the theoretical density (T) of the concrete (no air) to the density of concrete with air (D):

$$Air\ content = (T - D)/T \times 100$$

The theoretical density is determined by taking the weight of the constituents and dividing it by the volume that those constituents take up (no air volume is included, therefore the volume has to be less than 27 cf). In our example we have:

$$T = (775 + 6 + 600 + 355.75 + 47.65) / (4.454 + 13.421 + 4.594 + 0.078 + 0.792) \\ = 1784.4 / 23.340 = 76.45\ pcf$$

then

$$Air\ content = (T - D)/T \times 100$$

$$Air\ content = (76.45 - 66.1)/76.45 \times 100 = **13.54\ %\ check!**$$

WITH THE CALCULATIONS COMPLETED, THE TABLE FOR “AS DESIGN” is:

EXAMPLE MIXTURE DESIGN (Revised)							
Mixture ID:	XYZ	Non-SSD Proportions as Designed		Actual Batched Proportions		Yielded Proportions	
Batch Size (ft ³):							
Cementitious Materials	Specific* Gravity	Amount (lb/yd ³)	Volume (ft ³)	Amount (lb)	Volume (ft ³)	Amount (lb/yd ³)	Volume (ft ³)
1. Portland Cement, Type III (ASTM C 150)	3.15	375.00	1.908				
2. Class C Fly Ash	2.60	300.00	1.849				
3. Microsilica (Silica Fume)	2.30	100.00	0.697				
Total of All Cementitious Materials:		775.00	4.454				
Fibers							
1. PVA Fibers	1.30	5.00	0.062				
2. Nylon Fibers	1.00	1.00	0.016				
Total of All Fibers:		6.00	0.078				
Aggregates							
1. Aggregate A Abs.: 10% ; MC: 5%	0.80	300.00	6.010				
2. Aggregate B Abs.: 7% ; MC: 0%	0.50	200.00	6.410				
3. Aggregate C Abs.: 25 % ; MC: 25%	1.60	100.00	1.002				
Total of All Aggregates:		600.00	13.421				
Water							
1. Total Batched Water [^]	1.00	281.40	4.510				
2. Water Added for Agg. Absorption	1.00	69.00	1.106				
3. Total Water from All Admixtures [§]	1.00	74.35	1.191				
Total Water:		355.75	4.595				
Solids Content of Admixtures							
1. Latex Solids	1.04	46.32	0.712				
2. AEA Solids	0.27	1.34	0.080				
Total Solids:		47.65	0.792				
Admixtures	% Solids	Amount (fl oz/cwt)	Water [†] in Admixture (lb/yd ³)	Amount (fl oz)	Water [†] in Admixture (lb)	Amount (fl oz/cwt)	Water [†] in Admixture (lb/yd ³)
1. Latex Wt./gal: lb/gal	45.00	200.00	56.6				
2. Air Entraining (AEA) Wt./gal: lb/gal	7.00	45.00	17.7				
Cement-Cementitious Materials Ratio			0.484				
Water-Cementitious Materials Ratio (w/cm)			0.37				
Slump, Slump Flow, in. (Flow Table, %)			3 +/- 1				
Design Air Content, %			13.56				
Density (Unit Weight), lb/ft ³			66.09				
Gravimetric Air Content, %							
Yield, ft ³			27.0				

Figure 5 – Non-SSD Proportions (As Designed) Populated

Now that the Non-SSD Proportions as designed has been completed, it is now time to actually batch the proportions in the laboratory so that specimens can be made to determine the true unit weight, air content, workability and compressive/tensile strengths, etc.

Determine the batched proportions for a 1 ft³ batch of concrete, based on the Non-SSD proportions.

		EXAMPLE MIXURE DESIGN (Revised)						
Mixture ID:	XYZ	Non-SSD Proportions as Designed		Actual Batched Proportions		Yielded Proportions		
Batch Size (ft ³):	1.00							
Cementitious Materials	Specific* Gravity	Amount (lb/yd ³)	Volume (ft ³)	Amount (lb)	Volume (ft ³)	Amount (lb/yd ³)	Volume (ft ³)	
1. Portland Cement, Type III (ASTM C 150)	3.15	375.00	1.908	13.9	0.071			
2. Class C Fly Ash	2.60	300.00	1.849	11.1	0.068			
3. Microsilica (Silica Fume)	2.30	100.00	0.697	3.7	0.026			
Total of All Cementitious Materials:		775.00	4.454	28.7	0.165			
Fibers								
1. PVA Fibers	1.30	5.00	0.062	0.2	0.002			
2. Nylon Fibers	1.00	1.00	0.016	0.0	0.001			
Total of All Fibers:		6.00	0.078	0.2	0.003			
Aggregates								
1. Aggregate A Abs.: 10% ; MC: 5%	0.80	300.00	6.010	11.1	0.223			
2. Aggregate B Abs.: 7% ; MC: 0%	0.50	200.00	6.410	7.4	0.237			
3. Aggregate C Abs.: 25 % ; MC: 25%	1.60	100.00	1.002	3.7	0.037			
Total of All Aggregates:		600.00	13.421	22.2	0.497			
Water								
1. Total Batched Water [^]	1.00	281.40	4.510	10.4	0.167			
2. Water Added for Agg. Absorption	1.00	69.00	1.106	2.6	0.041			
3. Total Water from All Admixtures [§]	1.00	74.35	1.191	2.8	0.044			
Total Water:		355.75	4.595	13.2	0.170			
Solids Content of Admixtures								
1. Latex Solids	1.04	46.32	0.712	1.7	0.026			
2. AEA Solids	0.27	1.34	0.080	0.0	0.003			
Total Solids:		47.65	0.792	1.8	0.029			
Admixtures		% Solids	Amount (fl oz/cwt)	Water [†] in Admixture (lb/yd ³)	Amount (fl oz)	Water [†] in Admixture (lb)	Amount (fl oz/cwt)	Water [†] in Admixture (lb/yd ³)
1. Latex Wt./gal: lb/gal	45.00	200.00	56.6	57.4	2.1			
2. Air Entraining (AEA) Wt./gal: lb/gal	7.00	45.00	17.7	12.9	0.7			

Figure 6 – Actual Batched Proportions Populated (based on an assumed 1 ft³ batch size)

The above table (Figure 6) is based on batching 1.0 ft³ and is computed simply by dividing the amounts by 27. It should be noted that when you are actually batching, you may end up adding or subtracting materials from the design (e.g., you added more cm or did not add all of the water). In that case, you amend the table to indicate what you actually batched. While any batch size can be used, it would be recommended that values such as 0.5, 1.0, etc. be used. From a practical standpoint, one would make a batch from which various cylinders, plates, slump test, etc. would be made. I have seen awkward values such as 0.0245 ft³ used as batch sizes (these are perhaps the volumes of cylinders or cubes that are used), but you really would not batch such a small amount.

Under “Admixtures”, the Amount is given as *fl oz* which is different than the dosage which is given in *fl oz/cwt* [fluid ounces for every hundred pounds (hundredweight; cwt) of cementitious material]. In our example, we have 775 pcy or 7.75 cwt. Therefore, our dosage of 200 fl oz//cwt of latex would result in

$$200 \text{ fl oz/cwt} \times 7.75 \text{ cwt} = 1550 \text{ fl oz of latex (for a cubic yard of concrete)}$$

Given a batch size of 1 cubic foot, **57.4 fl oz** (1550/27) is added to the batch.

Now comes the part where some teams have trouble.....

Once you have made your mixtures in the laboratory, you will determine (measure) the plastic (wet) unit weight of the concrete. The plastic unit weight is when you make your QC test cylinders; not after they harden, not after they dry out. That value should be reported in the table. In our example, we determined a unit weight of 65.0 pcf for our concrete mixture and are reporting a slump of 3.75 inches (Figure 7). Given that we did not change the amount of cm or water in our mixture, the c/cm and w/cm will remain the same as designed.

You will notice that the “as batched” unit weight (65 pcf) is less than the “as designed” unit weight (66.1 pcf). In some cases it may be higher, but generally, it will not be exact. Since there is a difference (and in this example the mass or weights of the constituents did not change), there MUST be a change in the amount of air in the mixture.

One can simply compute the “as batched” air content with

$$\text{Air content} = (T - D)/T \times 100$$

$$\text{Air content} = (76.45 - 65.0)/76.45 \times 100 = \underline{\underline{14.98\% \text{ (say 15\%)}}}$$

The last piece of the puzzle is determining the yield (Y) of the batch. In our example, we were attempting to batch 1 ft³ of concrete with a unit weight of 66.1 pcf. However, we ended up with a 65 pcf concrete mixture. Since we had 66 lbs of materials and ended up with a density of 65 pcf, we ended up making a volume of concrete slightly larger than we anticipated. Conversely, had we ended up with a batched density of say 67 pcf, we would have ended up with a volume less than what was anticipated.

Yield (Y) is computed as

$$Y = \text{Mass} / (\text{Density} \times 27)$$

$$= 1784.4 / (65 \times 27) = \underline{\underline{1.017 \text{ cf}}}$$

This value is compared to the batch amount (what you thought you would yield). As shown in ASTM C 138, the yield can be shown in comparison to the 27 ft³ proportioning. In this example, it can be shown as 27.46 ft³/yd³ (27 x 1.017) or simply 27.46 ft³. We generally report the yield as compared to the batch amount. Now you can populate the rest of the table for Actual Batched Proportions (Figure 8)

Cement-Cementitious Materials Ratio	0.484	0.484	
Water-Cementitious Materials Ratio (w/cm)	0.37	0.37	
Slump, Slump Flow, in. (Flow Table, %)	3 +/- 1	3.75	
Design Air Content, %	13.56		
Density (Unit Weight), lb/ft ³	66.09	65.00	
Gravimetric Air Content, %		14.98	
Yield, ft ³	27.0	1.017	

Figure 7 – Populating Table Based on Laboratory Test Results

WITH THE CALCULATIONS COMPLETED, THE TABLE IS NOW 2/3 COMPLETE:

EXAMPLE MIXURE DESIGN (Revised)							
Mixture ID:	XYZ	Non-SSD Proportions as Designed		Actual Batched Proportions		Yielded Proportions	
Batch Size (ft ³):	1.00						
Cementitious Materials	Specific* Gravity	Amount (lb/yd ³)	Volume (ft ³)	Amount (lb)	Volume (ft ³)	Amount (lb/yd ³)	Volume (ft ³)
1. Portland Cement, Type III (ASTM C 150)	3.15	375.00	1.908	13.9	0.071		
2. Class C Fly Ash	2.60	300.00	1.849	11.1	0.068		
3. Microsilica (Silica Fume)	2.30	100.00	0.697	3.7	0.026		
Total of All Cementitious Materials:		775.00	4.454	28.7	0.165		
Fibers							
1. PVA Fibers	1.30	5.00	0.062	0.2	0.002		
2. Nylon Fibers	1.00	1.00	0.016	0.0	0.001		
Total of All Fibers:		6.00	0.078	0.2	0.003		
Aggregates							
1. Aggregate A Abs.: 10% ; MC: 5%	0.80	300.00	6.010	11.1	0.223		
2. Aggregate B Abs.: 7% ; MC: 0%	0.50	200.00	6.410	7.4	0.237		
3. Aggregate C Abs.: 25 % ; MC: 25%	1.60	100.00	1.002	3.7	0.037		
Total of All Aggregates:		600.00	13.421	22.2	0.497		
Water							
1. Total Batched Water [^]	1.00	281.40	4.510	10.4	0.167		
2. Water Added for Agg. Absorption	1.00	69.00	1.106	2.6	0.041		
3. Total Water from All Admixtures [§]	1.00	74.35	1.191	2.8	0.044		
Total Water:		355.75	4.595	13.2	0.170		
Solids Content of Admixtures							
1. Latex Solids	1.04	46.32	0.712	1.7	0.026		
2. AEA Solids	0.27	1.34	0.080	0.0	0.003		
Total Solids:		47.65	0.792	1.8	0.029		
Admixtures	% Solids	Amount (fl oz/cwt)	Water [†] in Admixture (lb/yd ³)	Amount (fl oz)	Water [†] in Admixture (lb)	Amount (fl oz/cwt)	Water [†] in Admixture (lb/yd ³)
1. Latex Wt./gal: lb/gal	45.00	200.00	56.6	57.4	2.1		
2. Air Entraining (AEA) Wt./gal: lb/gal	7.00	45.00	17.7	12.9	0.7		
Cement-Cementitious Materials Ratio			0.484		0.484		
Water-Cementitious Materials Ratio (w/cm)			0.37		0.37		
Slump, Slump Flow, in. (Flow Table, %)			3 +/- 1		3.75		
Design Air Content, %			13.56				
Density (Unit Weight), lb/ft ³			66.09		65.00		
Gravimetric Air Content, %					14.98		
Yield, ft ³			27.0		1.017		

Figure 8 – Non-SSD and Actual Batched Proportions

The last portion of this exercise is to take the information obtained during the batching process and to go back to the design proportions (Non –SSD) and adjust them. The end result will be the Yielded Proportions.

Relative Yield

Relative yield (Ry) is the ratio of the actual volume of concrete obtained to the volume as designed for the batch calculated as follows:

$$Ry = Y/Yd$$

A value for Ry greater than 1.00 indicates an excess of concrete being produced whereas a value less than this indicates the batch to be “short” of its designed volume.

In our example, the design yield (Yd) is 1 ft³ and the actual yield (Y) was 1.017 ft³. Therefore the Ry is 1.017 (we had an excess of concrete)

Yielded Proportions

We now adjust the “As Designed” proportions so that when all is said and done they will result in a concrete with the unit weight and air content obtained during the batching process. This is simply done by dividing the “As Designed” proportions by the value of the relative yield.

Example – Based on an “As Designed” proportion of 375 lbs of portland cement and a relative yield of 1.015, what is the “Yielded Proportion” of portland cement for the example mixture?

Solution:

$$\begin{aligned} \text{Yielded}_{\text{cement}} &= \text{Design}_{\text{cement}} / Ry \\ &= 375 \text{ pcy} / (1.017) = \mathbf{368.8 \text{ pcy}} \end{aligned}$$

This adjustment is then applied to all of the constituents used in the concrete mixture (Figure 9).

Final Values and Calculations

The density, air content and slump of the yielded proportions should match those in the actual batched proportions (we are adjusting the values of the design proportions so that they match up with the batched proportions). The c/cm and w/cm ratios will stay the same (in this example). The yield must be 27 ft³ when done.

Checks (see table on next page for values, Figure 9):

$$\text{Mass of yielded constituents} = 1755 \text{ lbs}; \text{ Volume of yielded constituents} = 22.955 \text{ cf}$$

$$\begin{aligned} \text{Density of concrete} &= 1755 \text{ lbs} / 27 \text{ cf} = \mathbf{65.0 \text{ pcf check!}} \\ \text{Theo. Density of concrete} &= 1755 \text{ lbs} / 22.955 \text{ cf} = 76.45 \text{ pcf} \end{aligned}$$

$$\text{Air content} = [(76.45 - 65) / 76.45 \times 100 = \mathbf{14.98\% \text{ check!}} \quad \text{Or} \quad [(27 - 22.955) / 27] \times 100 = \mathbf{14.98\% \text{ check!}}$$

NOW THE TABLE IS NOW COMPLETE!

EXAMPLE MIXTURE DESIGN (Revised)							
Mixture ID:	XYZ	Non-SSD Proportions as Designed		Actual Batched Proportions		Yielded Proportions	
Batch Size (ft ³):	1.00						
Cementitious Materials	Specific* Gravity	Amount (lb/yd ³)	Volume (ft ³)	Amount (lb)	Volume (ft ³)	Amount (lb/yd ³)	Volume (ft ³)
1. Portland Cement, Type III (ASTM C 150)	3.15	375.00	1.908	13.9	0.071	368.8	1.876
2. Class C Fly Ash	2.60	300.00	1.849	11.1	0.068	295.1	1.819
3. Microsilica (Silica Fume)	2.30	100.00	0.697	3.7	0.026	98.4	0.685
Total of All Cementitious Materials:		775.00	4.454	28.7	0.165	762.2	4.380
Fibers							
1. PVA Fibers	1.30	5.00	0.062	0.2	0.002	4.9	0.061
2. Nylon Fibers	1.00	1.00	0.016	0.0	0.001	1.0	0.016
Total of All Fibers:		6.00	0.078	0.2	0.003	5.9	0.076
Aggregates							
1. Aggregate A Abs.: 10% ; MC: 5%	0.80	300.00	6.010	11.1	0.223	295.1	5.911
2. Aggregate B Abs.: 7% ; MC: 0%	0.50	200.00	6.410	7.4	0.237	196.7	6.305
3. Aggregate C Abs.: 25 % ; MC: 25%	1.60	100.00	1.002	3.7	0.037	98.4	0.985
Total of All Aggregates:		600.00	13.421	22.2	0.497	590.1	13.200
Water							
1. Total Batched Water [^]	1.00	281.40	4.510	10.4	0.167	276.8	4.435
2. Water Added for Agg. Absorption	1.00	69.00	1.106	2.6	0.041	67.9	1.088
3. Total Water from All Admixtures [§]	1.00	74.35	1.191	2.8	0.044	73.1	1.172
Total Water:		355.75	4.595	13.2	0.170	349.9	4.520
Solids Content of Admixtures							
1. Latex Solids	1.04	46.32	0.712	1.7	0.026	45.6	0.700
2. AEA Solids	0.27	1.34	0.080	0.0	0.003	1.3	0.079
Total Solids:		47.65	0.792	1.8	0.029	46.9	0.778
Admixtures							
	% Solids	Amount (fl oz/cwt)	Water [†] in Admixture (lb/yd ³)	Amount (fl oz)	Water [†] in Admixture (lb)	Amount (fl oz/cwt)	Water [†] in Admixture (lb/yd ³)
1. Latex Wt./gal: lb/gal	45.00	200.00	56.6	57.4	2.1	196.7	55.7
2. Air Entraining (AEA) Wt./gal: lb/gal	7.00	45.00	17.7	12.9	0.7	44.3	17.4
Cement-Cementitious Materials Ratio		0.484		0.484		0.484	
Water-Cementitious Materials Ratio (w/cm)		0.37		0.37		0.37	
Slump, Slump Flow, in. (Flow Table, %)		3 +/- 1		3.75		3.75	
Design Air Content, %		13.56					
Density (Unit Weight), lb/ft ³		66.09		65.00		65.00	
Gravimetric Air Content, %				14.98		14.98	
Yield, ft ³		27.0		1.017		27.0	

Figure 9 – Completed Table 3.1

With the Yielded Proportions completed, teams should ensure that the values are in compliance with the rules and regulations.

3.3 REQUIREMENTS

3.3.1 Mass of Cementitious Materials

A maximum of **50%** (by mass) of the cementitious materials used in any concrete mixture can consist of hydraulic cement meeting the requirements of Section 3.2.1.1. In addition, the total amount of hydraulic cement meeting the requirements of Section 3.2.1.1 shall not exceed **400 lb/yd³** in any concrete mixture.

Our yielded portland cement is 368.8 lb/yd³ which does not exceed the 400 lb/yd³ limit – OK!

Our c/cm ratio is 0.484 (or 48.4%) which is under the maximum of 50% - OK!

3.3.2 Aggregate Proportioning

The aggregate(s) selected shall constitute a minimum of **15%** of the total weight of any concrete mixture. This weight percentage shall be based on a comparison of the total weight of all aggregates in the oven-dry condition, to the total weight of the concrete (based on yielded proportions). The composite gradation of the aggregates selected shall have no more than **5%** (by weight) passing the No. 100 sieve (0.15 mm). The amount of recycled aggregate must comprise a minimum of **50%** of the total amount of aggregate by weight. The total amount of aggregate used in concrete mixtures may vary from one mix to another; however, each mixture must contain aggregate (Section 3.2.2) in it to be in accordance with the rules and regulations.

Our aggregate proportioning is 33.6% (590.1/1755) which is above the minimum requirement of 15% – OK!

The gradation and recycled content are beyond the scope of this white paper, but are important to determine compliance with the Rules and Regulations. In our example, we are assuming that the requirements were met.

3.3.3 Allowable Water-to-Cementitious Materials Ratio

The maximum allowable water-cementitious materials ratio (w/cm) for any concrete mixture is **0.40**.

Our w/cm ratio is 0.37 which is under the maximum of 0.40 – OK!

3.3.4 Minimum Air Content

The minimum required air content for any concrete mixture is **6.0%**, determined gravimetrically (ASTM C 138).

Our air content is 14.98% (say 15%) which is above the minimum required content of 6.0% - OK!