WHITE PAPER – Concrete Mixture Data Table

By Michael Carnivale, III, PE

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.

<u>Notes:</u>

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 supercede 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/yd^3 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):							
Cementitious Materials	Specific* Gravity	Amount (lb/yd^3)	Volume (ft^3)	Amount (lb)	Volume (ft^3)	Amount (lb/yd^3)	Volume (ft^3)
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/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. 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/yd^3.
- The "Volume" shall be provided in ft^3 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, ft^3* – the summation of all the absolute volume of ingredients (should total **27 ft^3**) (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 ft^3. For example, your team may decide to use 1 ft^3 of concrete each time during lab testing. (The batch size need not be 1 ft^3, 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 ft^3 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, ft^3* – 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/yd^3 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 yd^3 of concrete, therefore, would not be 400 lb. It could be more or less depending on the yield.

- Y*ield, ft*^{3} – is the summation of all the absolute volume of ingredients (should total **27 ft^3**)

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)
	200 fl oz/cwt Latex Admixture (45% solids by weight)

Determine the unit weight and air content of the concrete mixture [proportions are for 1 yd^3 (27 ft^3) 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:

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

<u>*Example*</u> – How much volume does 375 lbs of portland cement occupy knowing that $G_s = 3.15$?

<u>*Solution:*</u> $Volume_{cement} = Weight_{cement} / (G_{s(cement)} \times 62.4)$

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

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 MIX DESIGN						
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. ASTM C 150 Portand Cement Type III	3.15	375.0	1.908				
2. Fly Ash Class C	2.60	300.0	1.849				
3. Microsilica or Silica Fume	2.30	100.0	0.697				
Total of All Cementitious Materials:		775.0	4.454				
Fibers							
1. PVA Fibers	1.30	5.0	0.062				
2. Nylon Fibers	1.00	1.0	0.016				
Total of All Fibers:		6.0	0.078				
Aggregates							
1. Aggregate A Abs.: 10 % ; MC: 5%	0.80	300.0	6.010				
2. Aggregate B Abs.:7 % ; MC:0 %	0.50	200.0	6.410				
3. Aggregate C Abs.: 25 % ; MC: 25%	1.60	100.0	1.002				
Total of All Aggregates:		600.0	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 x cm

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

Solution: *Water = 0.37 x 775 lbs =* ***286.75 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 admixture = Dosage x Water content x (1 gal/128 fl oz) x (8.34 lbs water/1 gal)

<u>*Example*</u> – 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

<u>*Solution:*</u> 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 admixture = Dosage x Water content x (1 gal/128 fl oz) x (8.34 lbs water/1 gal)

[(200 fl oz/ cwt) x (775 pcy)/100] x [(100% – 45% solids)/100] x (1 gal/128 fl oz) x (8.34 lbs H_2O/1 gal) =

1550 fl oz (for 7.75 cwt) x 0.55 (% water in latex) x 8.34/128 = <u>**55.5 lbs water/cy of concrete**</u>

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 (21.1/775 = 0.027), so it will need to be included.

In our example, the water from the two admixtures is 76.7 lbs and is put into the table as shown below (Figure 4).

Water							
1. Total Batched Water^	1.00	279.0	4.471				
2. Water Added for Agg. Absorption	1.00	69.0	1.106				
3. Total Water from All Admixtures§	1.00	76.7	1.229				
Total Water:		355.7	4.594				
Solids Content of Latex Modifiers							
1.Latex Solids	1.04	45.4	0.698				
Total Latex Solids:		45.4	0.698				
Admixtures	% Solids	Amount (fl oz/cwt)	Water‡ in Admixture (lb/yd^3)				
1. Air Entraining (AEA) Wt./gal: 7.0 lb/gal	7.00	45.0	21.1				
2. Latex Wt./gal: 8.5 lb/gal	45.00	200.0	55.5				

Figure 4 – Populating the Table after Taking into Account Water

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

Water for aggregate absorption = Σ(Absorption x 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

*Water for Aggregate Absorption = (300 lbs)(10%) + (200 lbs)(7%) + (100 lbs)(25%) = 69 lbs***

Now, we already know that we needed 286.7 lbs of water to mix with the cementitious materials to achieve the 0.37 w/cm ratio. Given that

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

One can compute that the Total Water is 355.7 lbs (= 286.7 + 69.0).

The Total Batched Water is then computed by

Total Batched Water = Total Water - Water from Admixtures

Total Batched Water = 355.7 - 76.7 = 279.0 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 (286.7 lbs) will occupy is 4.594 cf (= 286.7/62.4). 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)

$$Volume_{\text{water}} = Volume_{\text{Total batched water}} - Volume_{\text{water for aggregate absorption}} + Volume_{\text{total water from all admixtures}}$$

$$= 4.471 - 1.106 + 1.229 = \underline{\mathbf{4.594\ cf}}$$

***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 lbs)(5%) + (200 lbs)(0%) + (100 lbs)(25%) = 40 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 76.7 lbs. The Total Batch Water is still 279 lbs. The only difference is that 10 lbs of the 279 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, there is 4.68 lbs water and 3.82 lbs solids. Therefore the soild/water ratio is 0.816. If 55.5 lbs of water is provided to the concrete mixture, then 0.816 x 55.5 = 45.4 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 = 0.48

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 = (279 – 69 + 76.7)/(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 + 286.7 + 69 + 45.4) /27 = ***66.0 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:

$$\textbf{Volume}_{concrete} = \textbf{Volume}_{cm} + \textbf{Volume}_{agg} + \textbf{Volume}_{water} + \textbf{Volume}_{fibers} + \textbf{Volume}_{adm} + \textbf{Volume}_{air}$$

$$Volume_{air} = 27 - (4.454 + 13.421 + 4.594 + 0.078 + 0.698) = 27 - 23.245 = 3.755 \text{ cf of air}$$

Air content = 3.755/27 x 100 = ***13.91 %***

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 x 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 + 286.7 + 69 + 45.4) / (4.454 + 13.421 + 4.594 + 0.078 + 0.698)
= 1782.1 / 23.245 = 76.7 pcf

then

Air content = (T – D)/T x 100

Air content = (76.7 – 66.0)/76.7 x 100 = ***13.91% check!***

WITH THE CALCULATIONS COMPLETED, THE TABLE FOR "AS DESIGN" is:

	Example Mixture Design						
Mixture ID:	**XYZ**	**Non-SSD Proportions as Designed**		**Actual Batched Proportions**		**Yielded Proportions**	
Batch Size (ft^3):	1.0						
Cementitious Materials	Specific* Gravity	Amount (lb/yd^3)	Volume (ft^3)	Amount (lb)	Volume (ft^3)	Amount (lb/yd^3)	Volume (ft^3)
1. ASTM C 150 Portand Cement Type III	3.15	375.0	1.908				
2. Fly Ash Class C	2.60	300.0	1.849				
3. Microsilica or Silica Fume	2.30	100.0	0.697				
Total of All Cementitious Materials:		775.0	4.454				
Fibers							
1. PVA Fibers	1.30	5.0	0.062				
2. Nylon Fibers	1.00	1.0	0.016				
Total of All Fibers:		6.0	0.078				
Aggregates							
1. Aggregate A Abs.: 10 % ; MC: 5%	0.80	300.0	6.010				
2. Aggregate B Abs.:7 % ; MC:0 %	0.50	200.0	6.410				
3. Aggregate C Abs.: 25 % ; MC: 25%	1.60	100.0	1.002				
Total of All Aggregates:		600.0	13.421				
Water							
1. Total Batched Water^	1.00	279.0	4.471				
2. Water Added for Agg. Absorption	1.00	69.0	1.106				
3. Total Water from All Admixtures§	1.00	76.7	1.229				
Total Water:		355.7	4.594				
Solids Content of Latex Modifiers							
1.Latex Solids	1.04	45.4	0.698				
Total Latex Solids:		45.4	0.698				
Admixtures	% Solids	Amount (fl oz/cwt)	Water‡ in Admixture (lb/yd^3)				
1. Air Entraining (AEA) Wt./gal: 7.0 lb/gal	7.00	45.0	21.1				
2. Latex Wt./gal: 8.5 lb/gal	45.00	200.0	55.5				
Cement-Cementitious Materials Ratio		0.48					
Water-Cementitious Materials Ratio (w/cm)		0.37					
Slump, Slump Flow, in. (Flow Table, %)		3 ± 1					
Design Air Content, %		13.91					
Density (Unit Weight), lb/ft^3		66.00					
Gravimetric Air Content, %							
Yield, ft^3		27.0					

Abs. = Absorption; MC = Batched moisture concrete;
^ Including water added for aggregate absorption;
** For aggregates, provide ASTM C 127 oven-dry bulk specific gravity.*
‡ *Water content of admixture.*
§ *If impact on w/cm is less than 0.01 enter zero.*

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 Mixture Design						
Mixture ID:	XYZ	**Non-SSD Proportions as Designed**		**Actual Batched Proportions**		**Yielded Proportions**	
Batch Size (ft³):	1.0						
Cementitious Materials	Specific Gravity	Amount (lb/yd³)	Volume (ft³)	Amount (lb)	Volume (ft³)	Amount (lb/yd³)	Volume (ft³)
1. ASTM C 150 Portand Cement Type III	3.15	375.0	1.908	13.9	0.071		
2. Fly Ash Class C	2.60	300.0	1.849	11.1	0.068		
3. Microsilica or Silica Fume	2.30	100.0	0.697	3.7	0.026		
Total of All Cementitious Materials:		775.0	4.454	28.7	0.165		
Fibers							
1. PVA Fibers	1.30	5.0	0.062	0.2	0.002		
2. Nylon Fibers	1.00	1.0	0.016	0.0	0.001		
Total of All Fibers:		6.0	0.078	0.2	0.003		
Aggregates							
1. Aggregate A Abs.: 10 %; MC: 5%	0.80	300.0	6.010	11.1	0.223		
2. Aggregate B Abs.:7 %; MC:0 %	0.50	200.0	6.410	7.4	0.237		
3. Aggregate C Abs.: 25 %; MC: 25%	1.60	100.0	1.002	3.7	0.037		
Total of All Aggregates:		600.0	13.421	22.2	0.497		
Water							
1. Total Batched Water^	1.00	279.0	4.471	10.3	0.166		
2. Water Added for Agg. Absorption	1.00	69.0	1.106	2.6	0.041		
3. Total Water from All Admixtures§	1.00	76.7	1.229	2.8	0.046		
Total Water:		355.7	4.594	13.2	0.170		
Solids Content of Latex Modifiers							
1.Latex Solids	1.04	45.4	0.698	1.7	0.026		
Total Latex Solids:		45.4	0.698	1.7	0.026		
Admixtures	% Solids	Amount (fl oz/cwt)	Water‡ in Admixture (lb/yd³)	Amount (fl oz)	Water‡ in Admixture (lb)		
1. Air Entraining (AEA) Wt./gal: 7.0 lb/gal	7.00	45.0	21.1	1.7	0.8		
2. Latex Wt./gal: 8.5 lb/gal	45.00	200.0	55.5	7.4	2.057		

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 (since there are 27 ft³ in 1 yd³).

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.

The values presented above are simply the "As Designed" divided 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.

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 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

Air content = (T – D)/T x 100

*Air content = (76.7 – 65.0)/76.7 x 100 = **15.25%***
(Excel spreadsheet has 15.22 but that is due to significant figures for unit weight)

The last piece of the puzzle is determining the yield (Y) of the batch. In our example, we were attempting to batch 1 ft^3 of concrete with a unit weight of 66 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 = Mass / (Density x 27)

*= 1782.1 / (65 x 27) = **1.015 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 ft^3 proportioning. In this example, it can be shown as 27.4 ft^3/ yd^3 (27 x 1.1015) or simply 27.4 ft^3. We generally report the yield as compared to the batch amount. Nowyou can populate the rest of the table for Actual Batched Proportions (Figure 8)

Cement-Cementitious Materials Ratio		0.48	0.48	
Water-Cementitious Materials Ratio (w/cm)		0.37	0.37	
Slump, Slump Flow, in. (Flow Table, %)		3 ± 1	3.75	
Design Air Content, %		13.91		
Density (Unit Weight), lb/ft^3		66.00	65.00	
Gravimetric Air Content, %			15.22	
Yield, ft^3		27.0	**1.015**	

Figure 7 – Populating Table Based on Laboratory Test Results

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

	Example Mixture Design						
Mixture ID:	**XYZ**	**Non-SSD Proportions as Designed**		**Actual Batched Proportions**		**Yielded Proportions**	
Batch Size (ft^3):	1.0						
Cementitious Materials	Specific* Gravity	Amount (lb/yd^3)	Volume (ft^3)	Amount (lb)	Volume (ft^3)	Amount (lb/yd^3)	Volume (ft^3)
1. ASTM C 150 Portand Cement Type III	3.15	375.0	1.908	13.9	0.071		
2. Fly Ash Class C	2.60	300.0	1.849	11.1	0.068		
3. Microsilica or Silica Fume	2.30	100.0	0.697	3.7	0.026		
Total of All Cementitious Materials:		775.0	4.454	28.7	0.165		
Fibers							
1. PVA Fibers	1.30	5.0	0.062	0.2	0.002		
2. Nylon Fibers	1.00	1.0	0.016	0.0	0.001		
Total of All Fibers:		6.0	0.078	0.2	0.003		
Aggregates							
1. Aggregate A Abs.: 10 % ; MC: 5%	0.80	300.0	6.010	11.1	0.223		
2. Aggregate B Abs.:7 % ; MC:0 %	0.50	200.0	6.410	7.4	0.237		
3. Aggregate C Abs.: 25 % ; MC: 25%	1.60	100.0	1.002	3.7	0.037		
Total of All Aggregates:		600.0	13.421	22.2	0.497		
Water							
1. Total Batched Water^	1.00	279.0	4.471	10.3	0.166		
2. Water Added for Agg. Absorption	1.00	69.0	1.106	2.6	0.041		
3. Total Water from All Admixtures §	1.00	76.7	1.229	2.8	0.046		
Total Water:		355.7	4.594	13.2	0.170		
Solids Content of Latex Modifiers							
1.Latex Solids	1.04	45.4	0.698	1.7	0.026		
Total Latex Solids:		45.4	0.698	1.7	0.026		
Admixtures	% Solids	Amount (fl oz/cwt)	Water‡ in Admixture (lb/yd^3)	Amount (fl oz)	Water‡ in Admixture (lb)		
1. Air Entraining (AEA) Wt./gal: 7.0 lb/gal	7.00	45.0	21.1	1.7	0.8		
2. Latex Wt./gal: 8.5 lb/gal	45.00	200.0	55.5	7.4	2.057		
Cement-Cementitious Materials Ratio		0.48		0.48			
Water-Cementitious Materials Ratio (w/cm)		0.37		0.37			
Slump, Slump Flow, in. (Flow Table, %)		3 ± 1		3.75			
Design Air Content, %		13.91					
Density (Unit Weight), lb/ft^3		66.00		65.00			
Gravimetric Air Content, %				15.22			
Yield, ft^3		27.0		**1.015**			

Abs. = Absorption; MC = Batched moisture concrete;

^ Including water added for aggregate absorption;

** For aggregates, provide ASTM C 127 oven-dry bulk specific gravity.*

‡ Water content of admixture.

§ If impact on w/cm is less than 0.01 enter zero.

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 ft^3 and the actual yield (Y) was 1.015 ft^3. Therefore the Ry is 1.015 (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:* $Yielded_{cement} = Design_{cement} / Ry$
>
> $= 375\ pcy / (1.015) = \mathbf{369.3\ pcy}$

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 ft^3 when done.

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

Mass of yielded constituents = 1755 lbs; Volume of yielded constituents = 22.891 cf

*Density of concrete = 1755 lbs / 27 cf = **65.0 pcf check!***
Theo. Density of concrete = 1755 lbs / 22.891 cf = 76.7 pcf

*Air content = [(76.7 – 65) / 76.7 x 100 = **15.25% check!** Or [(27 – 22.891) / 27[x 100= **15.22% check!***

NOW THE TABLE IS NOW COMPLETE!

	Example Mixture Design						
Mixture ID:	XYZ	Non-SSD Proportions as Designed		Actual Batched Proportions		Yielded Proportions	
Batch Size (ft^3):	1.0						
Cementitious Materials	Specific* Gravity	Amount (lb/yd^3)	Volume (ft^3)	Amount (lb)	Volume (ft^3)	Amount (lb/yd^3)	Volume (ft^3)
1. ASTM C 150 Portand Cement Type III	3.15	375.0	1.908	13.9	0.071	369.3	1.879
2. Fly Ash Class C	2.60	300.0	1.849	11.1	0.068	295.4	1.821
3. Microsilica or Silica Fume	2.30	100.0	0.697	3.7	0.026	98.5	0.686
Total of All Cementitious Materials:		775.0	4.454	28.7	0.165	763.2	4.386
Fibers							
1. PVA Fibers	1.30	5.0	0.062	0.2	0.002	4.9	0.061
2. Nylon Fibers	1.00	1.0	0.016	0.0	0.001	1.0	0.016
Total of All Fibers:		6.0	0.078	0.2	0.003	5.9	0.076
Aggregates							
1. Aggregate A Abs.: 10 % ; MC: 5%	0.80	300.0	6.010	11.1	0.223	295.4	5.918
2. Aggregate B Abs.:7 % ; MC:0 %	0.50	200.0	6.410	7.4	0.237	197.0	6.313
3. Aggregate C Abs.: 25 % ; MC: 25%	1.60	100.0	1.002	3.7	0.037	98.5	0.986
Total of All Aggregates:		600.0	13.421	22.2	0.497	590.9	13.217
Water							
1. Total Batched Water^	1.00	279.0	4.471	10.3	0.166	274.8	4.403
2. Water Added for Agg. Absorption	1.00	69.0	1.106	2.6	0.041	67.9	1.089
3. Total Water from All Admixtures§	1.00	76.7	1.229	2.8	0.046	75.5	1.210
Total Water:		355.7	4.594	13.2	0.170	350.3	4.524
Solids Content of Latex Modifiers							
1.Latex Solids	1.04	45.4	0.698	1.7	0.026	44.8	0.688
Total Latex Solids:		45.4	0.698	1.7	0.026	44.8	0.688
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. Air Entraining (AEA) Wt./gal: 7.0 lb/gal	7.00	45.0	21.1	1.7	0.8	44.3	20.8
2. Latex Wt./gal: 8.5 lb/gal	45.00	200.0	55.5	7.4	2.057	201.0	54.7
Cement-Cementitious Materials Ratio		0.48		0.48		0.48	
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, %		13.91					
Density (Unit Weight), lb/ft^3		66.00		65.00		65.00	
Gravimetric Air Content, %				15.22		15.22	
Yield, ft^3		27.0		**1.015**		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 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/yd^3** in any concrete mixture.

Our yielded portland cement is 369.3 lb/yd^3 which does not exceed the 400 lb/yd^3 limit – OK!

Our c/cm ratio is 0.48 (or 48%) 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 33.7% (590.9/1755) 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 15.22% which is above the minimum required content of 6.0% - OK!

Designation: C 138/C 138M – 01a

American Association State
Highway and Transportation Officials Standard
AASHTO No.: T121

Standard Test Method for Density (Unit Weight), Yield, and Air Content (Gravimetric) of Concrete[1]

This standard is issued under the fixed designation C 138/C 138M; the number immediately following the designation indicates the year of original adoption or, in the case of revision, the year of last revision. A number in parentheses indicates the year of last reapproval. A superscript epsilon (ε) indicates an editorial change since the last revision or reapproval.

This standard has been approved for use by agencies of the Department of Defense.

1. Scope *

1.1 This test method covers determination of the density (see Note 1) of freshly mixed concrete and gives formulas for calculating the yield, cement content, and air content of the concrete. Yield is defined as the volume of concrete produced from a mixture of known quantities of the component materials.

1.2 The values stated in either inch-pound or SI units shall be regarded separately as standard. The SI units are shown in brackets. The values stated might not be exact equivalents; therefore each system must be used independently of the other.

NOTE 1—Unit weight was the previous terminology used to describe the property determined by this test method, which is mass per unit volume.

1.3 The text of this test method references notes and footnotes that provide explanatory information. These notes and footnotes (excluding those in tables) shall not be considered as requirements of this test method.

2. Referenced Documents

2.1 *ASTM Standards:*

C 29/C 29M Test Method for Bulk Density (Unit Weight) and Voids in Aggregate[2]

C 150 Specification for Portland Cement[3]

C 172 Practice for Sampling Freshly Mixed Concrete[2]

C 188 Test Method for Density of Hydraulic Cement[3]

C 231 Test Method for Air Content of Freshly Mixed Concrete by the Pressure Method[2]

C 670 Practice for Preparing Precision and Bias Statements for Test Methods for Construction Materials[2]

3. Terminology

3.1 *Symbols*:

A = air content (percentage of voids) in the concrete

C = actual cement content, lb/yd^3 or kg/m^3

C_b = mass of cement in the batch, lb or kg

D = density (unit weight) of concrete, lb/ft^3 or kg/m^3

M = total mass of all materials batched, lb or kg (see Note 3)

M_c = mass of the measure filled with concrete, lb or kg

M_m = mass of the measure, lb or kg

R_y = relative yield

T = theoretical density of the concrete computed on an airfree basis, lb/ft^3 or kg/m^3 (see Note 2)

Y = yield, volume of concrete produced per batch, yd^3 or m^3

Y_d = volume of concrete which the batch was designed to produce, yd^3 or m^3

Y_f = volume of concrete produced per batch, ft^3

V = total absolute volume of the component ingredients in the batch, ft^3 or m^3

V_m = volume of the measure, ft^3 or m^3

NOTE 2—The theoretical density is, customarily, a laboratory determination, the value for which is assumed to remain constant for all batches made using identical component ingredients and proportions. It is calculated from the following equation:

$$T = M/V \quad (1)$$

The absolute volume of each ingredient in cubic feet is equal to the quotient of the mass of that ingredient divided by the product of its specific gravity times 62.4. The absolute volume of each ingredient in cubic metres is equal to the mass of the ingredient in kilograms divided by 1000 times its specific gravity. For the aggregate components, the bulk specific gravity and mass should be based on the saturated, surface-dry condition. For cement, the actual specific gravity should be determined by Test Method C 188. A value of 3.15 may be used for cements manufactured to meet the requirements of Specification C 150.

NOTE 3—The total mass of all materials batched is the sum of the masses of the cement, the fine aggregate in the condition used, the coarse aggregate in the condition used, the mixing water added to the batch, and any other solid or liquid materials used.

4. Apparatus

4.1 *Balance*—A balance or scale accurate to 0.1 lb [45 g] or to within 0.3 % of the test load, whichever is greater, at any point within the range of use. The range of use shall be

[1] This test method is under the jurisdiction of ASTM Committee C09 on Concrete and Concrete Aggregates and is the direct responsibility of Subcommittee C09.60 on Fresh Concrete Testing.

Current edition approved Mar. 10, 2001. Published May 2001. Originally published as C 138 – 38 T. Last previous edition C 138 – 01.

[2] *Annual Book of ASTM Standards*, Vol 04.02.

[3] *Annual Book of ASTM Standards*, Vol 04.01.

***A Summary of Changes section appears at the end of this standard.**

considered to extend from the mass of the measure empty to the mass of the measure plus its contents at 160 lb/ft^3 [2600 kg/m^3].

4.2 *Tamping Rod*—A round, straight steel rod, ⅝ in. [16 mm] in diameter and approximately 24 in. [600 mm] in length, having the tamping end rounded to a hemispherical tip the diameter of which is ⅝ in.

4.3 *Internal Vibrator*—Internal vibrators may have rigid or flexible shafts, preferably powered by electric motors. The frequency of vibration shall be 7000 vibrations per minute or greater while in use. The outside diameter or the side dimension of the vibrating element shall be at least 0.75 in. [19 mm] and not greater than 1.50 in. [38 mm]. The length of the shaft shall be at least 24 in. [600 mm].

4.4 *Measure*—A cylindrical container made of steel or other suitable metal (see Note 4). The minimum capacity of the measure shall conform to the requirements of Table 1 based on the nominal size of aggregate in the concrete to be tested. All measures, except for measuring bowls of air meters which are also used for Test Method C 138 tests, shall conform to the requirements of Test Method C 29/C 29M. When measuring bowls of air meters are used, they shall conform to the requirements of Test Method C 231, and shall be calibrated for volume as described in Test Method C 29/C 29M. The top rim of the air meter bowls shall be smooth and plane within 0.01 in. [0.3 mm] (see Note 5).

NOTE 4—The metal should not be readily subject to attack by cement paste. However, reactive materials such as aluminum alloys may be used in instances where as a consequence of an initial reaction, a surface film is rapidly formed which protects the metal against further corrosion.

NOTE 5—The top rim is satisfactorily plane if a 0.01-in. [0.3-mm] feeler gage cannot be inserted between the rim and a piece of ¼-in. [6-mm] or thicker plate glass laid over the top of the measure.

4.5 *Strike-Off Plate*—A flat rectangular metal plate at least ¼ in. [6 mm] thick or a glass or acrylic plate at least ½ in. [12 mm] thick with a length and width at least 2 in. [50 mm] greater than the diameter of the measure with which it is to be used. The edges of the plate shall be straight and smooth within a tolerance of 1⁄16 in. [2 mm].

4.6 *Mallet*—A mallet (with a rubber or rawhide head) having a mass of 1.25 ± 0.50 lb [600 ± 200 g] for use with measures of 0.5 ft^3 [14 L] or smaller, and a mallet having a mass of 2.25 ± 0.50 lb [1000 ± 200 g] for use with measures larger than 0.5 ft^3.

5. Sample

5.1 Obtain the sample of freshly mixed concrete in accordance with Practice C 172.

TABLE 1 Capacity of Measures

Nominal Maximum Size of Coarse Aggregate		Capacity of Measure[A]	
in.	mm	ft^3	L
1	25.0	0.2	6
1½	37.5	0.4	11
2	50	0.5	14
3	75	1.0	28
4½	112	2.5	70
6	150	3.5	100

[A] The indicated size of measure shall be used to test concrete containing aggregates of a nominal maximum size equal to or smaller than that listed. The actual volume of the measure shall be at least 95 % of the nominal volume listed.

6. Procedure

6.1 Base the selection of the method of consolidation on the slump, unless the method is stated in the specifications under which the work is being performed. The methods of consolidation are rodding and internal vibration. Rod concretes with a slump greater than 3 in. [75 mm]. Rod or vibrate concrete with a slump of 1 to 3 in. [25 to 75 mm]. Consolidate concretes with a slump less than 1 in. by vibration.

NOTE 6—Nonplastic concrete, such as is commonly used in the manufacture of pipe and unit masonry, is not covered by this test method.

6.2 *Rodding*—Place the concrete in the measure in three layers of approximately equal volume. Rod each layer with 25 strokes of the tamping rod when nominal 0.5-ft^3 [14-L] or smaller measures are used, 50 strokes when nominal 1-ft^3 [28-L] measures are used, and one stroke per 3 in.^{2} [20 cm^3] of surface for larger measures. Rod the bottom layer throughout its depth but the rod shall not forcibly strike the bottom of the measure. Distribute the strokes uniformly over the cross section of the measure and for the top two layers, penetrate about 1 in. [25 mm] into the underlying layer. After each layer is rodded, tap the sides of the measure 10 to 15 times with the appropriate mallet (see 4.6) using such force so as to close any voids left by the tamping rod and to release any large bubbles of air that may have been trapped. Add the final layer so as to avoid overfilling.

6.3 *Internal Vibration*—Fill and vibrate the measure in two approximately equal layers. Place all of the concrete for each layer in the measure before starting vibration of that layer. Insert the vibrator at three different points for each layer. In compacting the bottom layer, do not allow the vibrator to rest on or touch the bottom or sides of the measure. In compacting the final layer, the vibrator shall penetrate into the underlying layer approximately 1 in. [25 mm]. Take care that the vibrator is withdrawn in such a manner that no air pockets are left in the specimen. The duration of vibration required will depend upon the workability of the concrete and the effectiveness of the vibrator (see Note 7). Continue vibration only long enough to achieve proper consolidation of the concrete (see Note 8). Observe a constant duration of vibration for the particular kind of concrete, vibrator, and measure involved.

NOTE 7—Usually, sufficient vibration has been applied as soon as the surface of the concrete becomes relatively smooth.

NOTE 8—Overvibration may cause segregation and loss of appreciable quantities of intentionally entrained air.

6.4 On completion of consolidation the measure must not contain a substantial excess or deficiency of concrete. An excess of concrete protruding approximately ⅛ in. [3 mm] above the top of the mold is optimum. A small quantity of concrete may be added to correct a deficiency. If the measure contains a great excess of concrete at completion of consolidation, remove a representative portion of the excess concrete with a trowel or scoop immediately following completion of consolidation and before the measure is struck-off.

6.5 *Strike-Off*—After consolidation, strike-off the top surface of the concrete and finish it smoothly with the flat strike-off plate using great care to leave the measure just level full. The strike-off is best accomplished by pressing the strike-off plate on the top surface of the measure to cover about two thirds of the surface and withdrawing the plate with a sawing motion to finish only the area originally covered. Then place the plate on the top of the measure to cover the original two thirds of the surface and advance it with a vertical pressure and a sawing motion to cover the whole surface of the measure and continue to advance it until it slides completely off the measure. Several final strokes with the inclined edge of the plate will produce a smooth finished surface.

6.6 *Cleaning and Weighing*—After strike-off, clean all excess concrete from the exterior of the measure and determine the mass of the concrete and measure to an accuracy consistent with the requirements of 4.1.

7. Calculation

7.1 *Density (Unit Weight)*—Calculate the net mass of the concrete in pounds or kilograms by subtracting the mass of the measure, M_m, from the mass of the measure filled with concrete, M_c. Calculate the density, D, ft^3 or yd^3,by dividing the net mass of concrete by the volume of the measure, V_m as follows:

$$D = (M_c - M_m)/V_m \quad (2)$$

7.2 *Yield*—Calculate the yield as follows:

$$Y(\text{yd}^3) = M/(D \times 27) \quad (3)$$

or

$$Y(\text{m}^3) = M/D \quad (4)$$

7.3 *Relative Yield*—Relative yield is the ratio of the actual volume of concrete obtained to the volume as designed for the batch (see Note 9) calculated as follows:

$$R_y = Y/Y_d \quad (5)$$

NOTE 9—A value for R_y 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 practice, a ratio of yield in cubic feet per cubic yard of design concrete mixture is frequently used, for example, 27.3 ft^3/yd^3.

7.4 *Cement Content*—Calculate the actual cement content as follows:

$$C = C_b/Y \quad (6)$$

7.5 *Air Content*—Calculate the air content as follows:

$$A = [(T - D)/T] \times 100 \quad (7)$$

or

$$A = [(Y_f - V)/Y_f] \times 100 \text{ (inch-pound units)} \quad (8)$$

or

$$A = [(Y - V)/Y] \times 100 \text{ (SI units)} \quad (9)$$

8. Precision and Bias

8.1 The following estimates of precision for this test method are based on a collection of data from various locations by the National Ready Mixed Concrete Association.[4] The data represent concrete mixtures with slump ranging from 3 to 6 in. [75 to 150 mm] and density ranging from 115 to 155 lb/ft^3 [1842 to 2483 kg/m^3] and included air-entrained and non air-entrained concrete. The study was conducted using 0.25 ft^3 [7-L] and 0.5 ft^3 [14-L] measures.

8.1.1 *Single-Operator Precision*—The single operator standard deviation of density of freshly mixed concrete has been found to be 0.65 lb/ft^3 [10.4 kg/m^3] (1s). Therefore, results of two properly conducted by the same operator on the same sample of concrete should not differ by more than 1.85 lb/ft^3 [29.6 kg/m^3] (d2s).

8.1.2 *Multi-Operator Precision*—The multi-operator standard deviation of density of freshly mixed concrete has been found to be 0.82 lb/ft^3 [13.1 kg/m^3] (1s). Therefore, results of two properly conducted tests by the two operators on the same sample of concrete should not differ by more than 2.31 lb/ft^3 [37.0 kg/m^3] (d2s).

8.2 *Bias*—This test method has no bias since the density is defined only in terms of this test method.

9. Keywords

9.1 air content; cement content; concrete; relative yield; unit weight; yield

[4] Mullings, G. M., NRMCA/NAA Joint Research Lab Study "Series D 324 Accuracy of Concrete Density Test," Feb. 17, 2000.

SUMMARY OF CHANGES

This section identifies the location of changes to this test method that have been incorporated since the last issue.

(1) Designation was revised.
(2) Title was revised.
(3) Paragraphs 1.1 and 1.2 were revised.
(3) Note 1 and paragraph 1.3 were added. Subsequent notes were renumbered.
(4) Section 2 was updated.
(5) Section 3 was renamed "Terminology" and revised.
(6) Paragraphs 4.1-4.6 were revised.
(7) Paragraphs 6.1-6.6 were revised.
(8) Equations in Section 7 were revised.
(9) Paragraphs 7.1-7.5 were revised.
(10) Paragraph 8.1 was revised.