DO YOU REALLY KNOW ABOUT MOISTURE CORRECTIONS?

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Why Moisture Corrections Are Needed?

- Stockpile moisture conditions vary depending on storage conditions and the weather.
- Varying amounts of water coming from the aggregates must be accounted for if the intended amount of water is to be accurately achieved in the mix.

The Issue in Question

- Difference between industry practice (IP) and technically correct (TC) procedures for making moisture adjustments
- IP bases free water adjustments on saturated surface-dry (*ssd*) weights (masses), where TC is based on oven-dry (*od*) weights
- The difference in free water computation between the methods can be very tiny in some areas, but significantly different in others.

Why Should You Care?

- High quality concrete requires a high level of water control
- Especially in specialty concretes like SCC and HSC
- To have a full understanding of the subject
- To appreciate the pros and cons of the technically correct and the standard industry approaches to making moisture adjustments.

Aggregate Moisture States

- **Oven-dry** (*od*)– no moisture in the aggregates
- **Saturated surface dry** (*ssd*)– no surface moisture
- **Wet**– water on surface available to hydrate cement
- **Not fully saturated**– in between *od* and *ssd*
- Batch ticket weights (masses) are generally given for aggregates in the *ssd* condition.

Aggregate Moisture States (cont)

- Aggregates below *ssd* absorb water from the mix.
- Aggregates above *ssd* contribute water to the mix.
- Aggregates at *ssd* neither absorb nor contribute water to the mix.

Moisture Content
MC%

- ASTM C 566 Evaporable Moisture
- Heat weighed sample in oven or carefully in pan until there is no further moisture loss.
- Subtract the oven-dry mass , m_{od} , from the initial sample mass, m_i , (that's the water) divide by m_{od} then multiply by 100 for %.

$$MC\,\% = \frac{m_i - m_{od}}{m_{od}} \times 100$$

- Oven-dry state is repeatable

Free Moisture

- Free water is available to hydrate cement, therefore must be subtracted from the base water mass to maintain the required *w/cm*.
- It must also be added to the base aggregate mass. Otherwise the *ssd* aggregate mass will be short .
- The Free Moisture is the Total Moisture minus the Absorbed Moisture.

$$MC\%_{free} = MC\% - A\%$$

Mass of Free Water
Practical vs. Technical

- Difference between industry practice and technically correct procedures
- IP computes FWM based on *ssd* mass

$$mw_{free} = m_{ssd} \times MC\%_{free}$$

- TC computes FWM based on *od* mass

$$mw_{free} = m_{od} \times MC\%_{free}$$

The Consequence of the Difference

- IP overestimates the FWM
- by a little
- Significant under certain circumstances
- Demonstration requires a little Algebra

Saturated Surface-Dry
ssd

- Difference in methods results from IP's using *ssd* to compute the FWM
- *ssd* characterized by being completely saturated without free water
- A special moisture state

Absorption *A%*

- Absorption is the amount of moisture an aggregate will absorb before free moisture becomes available on the surface
- Moisture content when aggregate is at *ssd*
- *A%* is determined using ASTMs C 127 or C 128
- Looks just like oven-dry

Absorption $A\%$ (cont.)

- Subtract the *od* mass , m_{od} , from the *ssd* sample mass, m_{ssd} , divide the difference by $m_{od,}$ then multiply by 100 for %.

$$A\% = \frac{m_{ssd} - m_{od}}{m_{od}} \times 100$$

- Rearranging this equation the *ssd* mass can be expressed in terms of m_{od} and $A\%$.

$$\frac{A\%}{100} \times m_{od} + m_{od} = m_{ssd}$$

factoring out m_{od}

$$m_{ssd} = m_{od}\left(1 + \frac{A\%}{100}\right)$$

Algebraic Analysis of IP

- To examine the difference between IP and TC methods m_{ssd}, in terms of m_{od}, is substituted for technically correct m_{od} in the computation of FWM.

$$mw_{free} = m_{ssd} \times \frac{MC\%_{free}}{100}$$

$$mw_{free} = m_{od} \times (1 + \frac{A\%}{100}) \times \frac{MC\%_{free}}{100} = \left(m_{od} + m_{od} \frac{A\%}{100} \right) \times \frac{MC\%_{free}}{100}$$

$$= m_{od} \frac{MC\%_{free}}{100} + m_{od} \frac{A\%}{100} \frac{MC\%_{free}}{100}$$

What is in this result?

$$mw_{free} = m_{od}\frac{MC\%_{free}}{100} + m_{od}\frac{A\%}{100}\frac{MC\%_{free}}{100}$$

- The first term is the technically correct computation for the free water mass.
- The second term is the difference between IP and TC methods

Closer Look at the Second Term

$$+ m_{od} \frac{A\%}{100} \frac{MC\%_{free}}{100}$$

- Depends on three factors
- A small percentage multiplied by another small percentage– hundredths or thousandths of a percent
- This is why the difference between the methods come out small when demonstrated with typical values.

The Difference can be Significant

- Generally, the difference will be quite small and can, for various reasons, easily be neglected.
- However, with highly absorbent aggregates or aggregates at high moisture contents the difference could be consequential.

Impact on Mix Proportions

- Because FWM is high, water in the mix is low.
- Because FWM is high too much aggregate is weighed out.
- Effects are negligible with hard rock aggregates, but IP should be used with care when higher than average absorption materials are used

Advantages of Industry Practice

- Design and Batch Ticket weights are usually given in *ssd* terms
- Less computation, less possibility for mistake
- Differences are usually insignificant and within ASTM Tolerances
- Water is held back
  - Is that such a bad thing?

Guidance from ASTM Standards

- ASTM C 94 allows weighing tolerances ± 2% for aggregates, ± 1% for water
- ASTM C 1602 specifies that when w/c is increased 0.01, as can happen with high admixture dosages, it must be accounted
- Change the water content 1% or more you need to account for it.

Spreadsheet Analysis

- Within a range of Absorption and Total Moisture % , when would the difference between the methods exceed 1%?

Standard Industry Practice | S = 3200 (change me!) | SSD

Formula: W = S*(1 + M/100 - A/100)

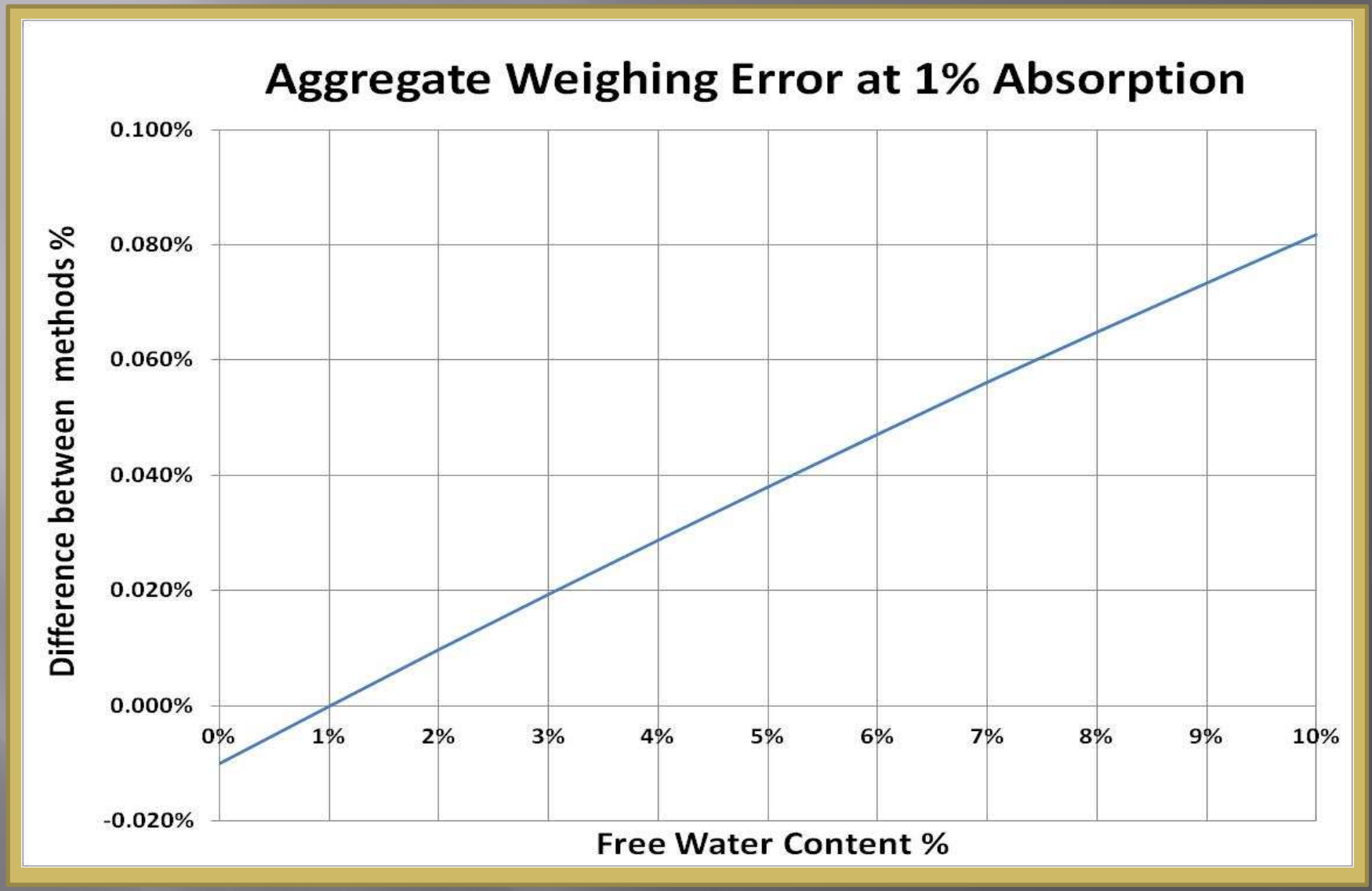
Total Moisture % \ Absorption [%]	0	1	2	3	4	5	6	7	8	9	10
0	3200	3168	3136	3104	3072	3040	3008	2976	2944	2912	2880
1	3232	3200	3168	3136	3104	3072	3040	3008	2976	2944	2912
2	3264	3232	3200	3168	3136	3104	3072	3040	3008	2976	2944
3	3296	3264	3232	3200	3168	3136	3104	3072	3040	3008	2976
4	3328	3296	3264	3232	3200	3168	3136	3104	3072	3040	3008
5	3360	3328	3296	3264	3232	3200	3168	3136	3104	3072	3040
6	3392	3360	3328	3296	3264	3232	3200	3168	3136	3104	3072
7	3424	3392	3360	3328	3296	3264	3232	3200	3168	3136	3104
8	3456	3424	3392	3360	3328	3296	3264	3232	3200	3168	3136
9	3488	3456	3424	3392	3360	3328	3296	3264	3232	3200	3168
10	3520	3488	3456	3424	3392	3360	3328	3296	3264	3232	3200

Theoretically Correct | S = 3200

Formula: W = S[100 + M] / [100 + A]

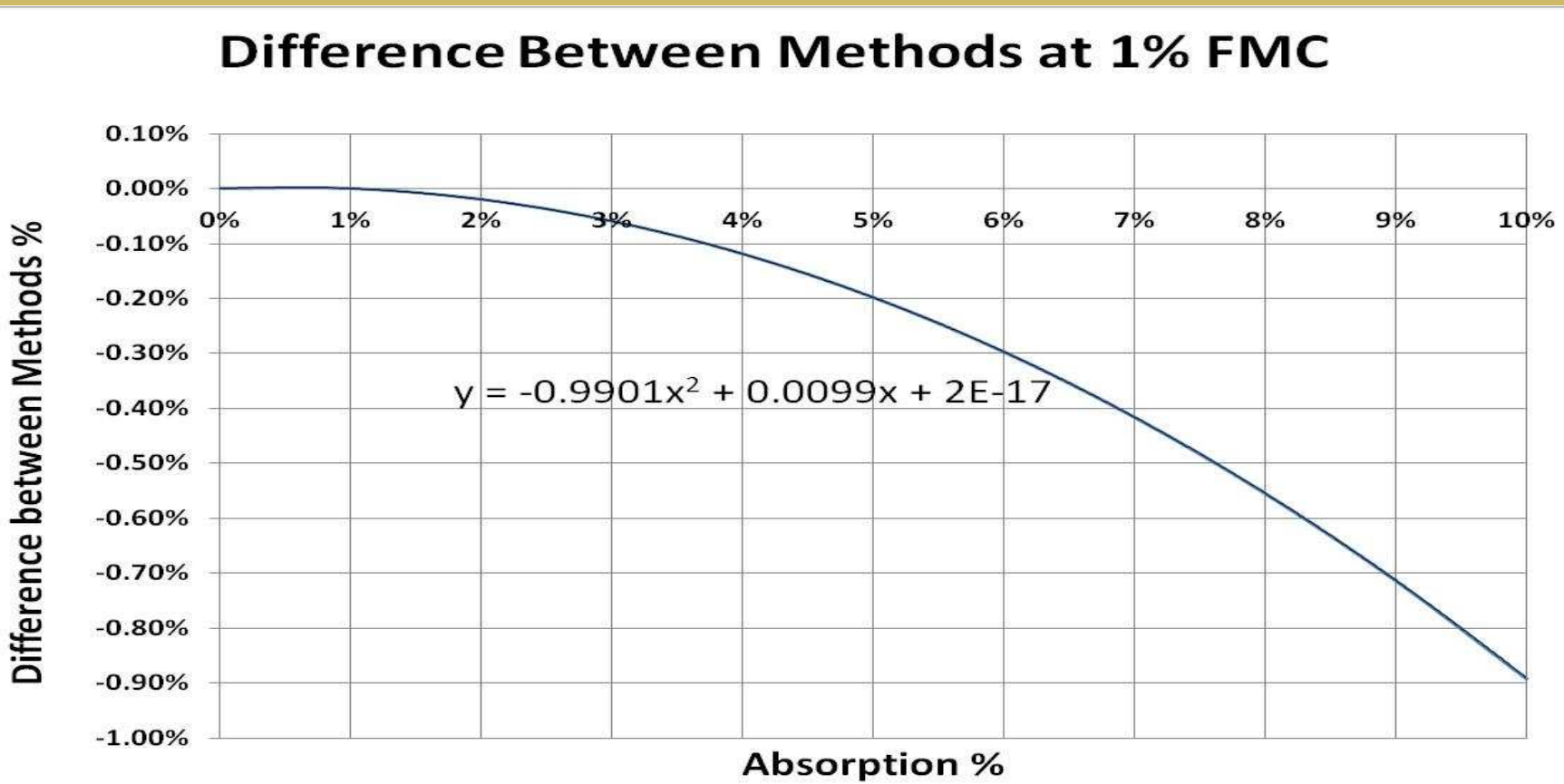
Total Moisture % \ Absorption [%]	0	1	2	3	4	5	6	7	8	9	10
0	3200	3168	3137	3107	3077	3048	3019	2991	2963	2936	2909
1	3232	3200	3169	3138	3108	3078	3049	3021	2993	2965	2938
2	3264	3232	3200	3169	3138	3109	3079	3050	3022	2994	2967
3	3296	3263	3231	3200	3169	3139	3109	3080	3052	3024	2996
4	3328	3295	3263	3231	3200	3170	3140	3110	3081	3053	3025
5	3360	3327	3294	3262	3231	3200	3170	3140	3111	3083	3055
6	3392	3358	3325	3293	3262	3230	3200	3170	3141	3112	3084
7	3424	3390	3357	3324	3292	3261	3230	3200	3170	3141	3113
8	3456	3422	3388	3355	3323	3291	3260	3230	3200	3171	3142
9	3488	3453	3420	3386	3354	3322	3291	3260	3230	3200	3171
10	3520	3485	3451	3417	3385	3352	3321	3290	3259	3229	3200

How Much Impact?



- Difference increases directly with increase in the FMC

How Much More Impact?



- Mostly, the difference between IP and TC increases as the negative of the square of absorption $-A\%^2$

Numerical Example

enough algebra

- Within a range of Absorption and Total Moisture %, when would the difference between the methods exceed 1%?
- 500 lb. cement mix, with the 3200 lb. *ssd* aggregate
- To move w/cm 0.01, a 5 lb. water change would be required.

cement	w/c	w
500	0.56	280
500	0.57	285
500	0.58	290

Free Water Computation Difference

Difference in free water mass between TC and IP methods

Total Moisture % \ Absorption [%]	0	1	2	3	4	5	6	7	8	9	10
0	0	3	-1	-3	-5	-8	-11	-15	-19	-24	-29
1	0	0	-1	-2	-4	-6	-9	-13	-17	-21	-26
2	0	0	0	-1	-2	-5	-7	-10	-14	-18	-23
3	0	1	1	0	-1	-3	-5	-8	-12	-16	-20
4	0	1	1	1	0	-2	-4	-6	-9	-13	-17
5	0	1	2	2	1	0	-2	-4	-7	-11	-15
6	0	2	3	3	2	2	0	-2	-5	-8	-12
7	0	2	3	4	4	3	2	0	-2	-5	-9
8	0	2	4	5	5	5	4	2	0	-3	-6
9	0	3	4	6	6	6	5	4	2	0	-3
10	0	3	5	7	7	8	7	6	5	3	0

- IP should not be used with high absorption aggregates, i.e. above 5%
- IP should be used carefully with aggregates at high moisture contents
- If IP is used under such conditions it should be used with understanding

Precedents For This Approach

1. Appendix X2 of both ASTM C 127 & C 128 express this same relationship (*ssd*=*od* x (*1*+*A*%)) in terms of *od* and *ssd* specific gravities (relative densities)
2. ACI E1-07 *Aggregates for Concrete* report from ACI Committee E-701 utilizes exactly the same approach (*od*=*ssd*/ (*1*+*A*%)) to making moisture adjustments as is proposed
3. PCA *Design and Control* makes adjustments based on *od* weights (masses)
4. *NRMCA instructional materials* make moisture adjustments based on *od* weights
5. From ACI 211.1-70 to -91 (reapproved 2009) has always utilized *od* weights for making moisture adjustments

Thank You for Your Attention

- Questions
- Comments