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Mix design programming for normal concrete using cubic equation

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ABSTRACT

A computer programming requires inputs and processes to produce output, good data processing requires a formula, in programming when using tables is very inefficient, so an approach is needed in this case the existing table tables are converted into formulas, making it easier to process programming. Mix Design for normal concrete, in general, always use tables that have SNI (ACI), the tables are modified with Polynomial Regression to be equations, tables in SNI (ACI) that are transformed into equations. The equation produced, using polynomial regression, with a value of $R^2 \approx 1$. The equation to find weight of mixing water (Ww) = y1j, y2j, with main variable aggregate maximum, additional variables are slump, the second equation is volume air content (VAC) = y3i, additional variables are exposures, water cement ratio (WCR) = y4i, with aggregate maximum variables, while additional variables are air requirements in concrete (non-air entrained/air entrained),weight of coarse aggregate (WCA) = y5i, with two variables aggregate maximum and FM (Finest Modulus), and initial estimates of fresh concrete weight (WFC) = y6i

Keywords: programming; cubic equation; polynomial regression; mix design; aggregate maximum.

INTRODUCTION

In general, according to [1], [2], concrete consists of water, cement, pozzolanic, coarse aggregates, fine aggregates, besides that concrete may contain air cavities, [3], [4], [5], it can also be intentionally given air, both air cavities are calculated using a mixture composition between water cement, pozzolanic, coarse aggregates, fine aggregates, [6], [7], [8] with the limitation of making normal concrete mixes [7], [9], [10], [11], which is not high-quality concrete [12], the variable used is not an exact thing, so the difference between designers is very reasonable, so the table tables in SNI (ACI), to facilitate calculations, are replaced by equation [13], [14], [15]. When on a computer program [16], [17], it is very inefficient to use a table, so it is necessary to change the existing table, into a Polynomial equation [18],[19]. Final result comparation between equation's method vs table's method [20]

RESEARCH METHODS

ACI [3], table A.1.5.3.3 or SNI [5] table 2 convert to cubic equation [18], Non-air-entrained concrete *:*

Slump = 25-50 (R^2=0.9977)

$$y11 = - 0.0000111*x^3 + 0.0089425* x^2 - 1.8147174*x + 221.533752 \quad (1.a)$$

Slump = 50-75 (R^2=0.9957)

$$y12 = - 0.0000291*x^3 + 0.0131584* x^2 - 2.088542*x + 234.3143 \quad (1.b)$$

Slump = 75-100 (R^2=0.9940)

$$y13 = - 0.0000426*x^3 + 0.0162374* x^2 - 2.2785993*x + 244.2855808 \quad (1.c)$$

Slump = 100-125 (R^2=0.9973)

$$y14 = - 0.000488*x^3 + 0.0728043* x^2 - 4.272658*x + 267.7511 \quad (1.d)$$

lump = 125-150 (R^2=0.9965)

$$y15 = - 0.0004987*x^3 + 0.076037* x^2 - 4.475151*x + 274.1917 \quad (1.e)$$

Slump = 150-175 (R^2=0.9959)

$$y16 = - 0.000536*x^3 + 0.0827147* x^2 - 4.7825228*x + 279.4357583 \quad (1.f)$$

(see figure 1)

Air-entrained concrete :

Slump = 25-50 (R^2=0.9968)
y21 = $- 0.0000038*x^3 + 0.0054866*x^2 - 1.2983588*x + 191.1850543$ (2.a)
Slump = 50-75 (R^2=0.9934)
y22 = $- 0.0000055*x^3 + 0.0064939*x^2 - 1.453547*x + 203.4307$ (2.b)
Slump = 75-100 (R^2=0.9910)
y23 = $- 0.0000097*x^3 + 0.0076815*x^2 - 1.558815*x + 212.7070388$ (2.c)
Slump = 100-125 (R^2=0.9983)
y24 = $- 0.0004524*x^3 + 0.0638114*x^2 - 3.538278*x + 236.2557$ (2.d)
Slump = 125-150 (R^2=0.9972)
y25 = $- 0.0004390*x^3 + 0.0649920*x^2 - 3.690117*x + 242.3494$ (2.e)
Slump = 150-175 (R^2=0.9950)
y26 = $- 0.0003385*x^3 + 0.0562362*x^2 - 3.5060661*x + 243.4023641$ (2.f)
(see figure 2)

where:
x = Aggregate Max (mm) ;
yij = mixing water (kg) note of i, j
i = 1 (non-air-entrained concrete)
i = 2 (air-entrained concrete)
j = slump's number (1, 2, 3, 4, 5, 6)

Level of exposure : 0) Entrapped air (%)
y30 = $- 0.0000052*x^3 + 0.0014847*x^2 - 0.1316092*x + 4.0214712$ (R^2=0.9958) (3.a)
Level of exposure : 1) Mild (%)
y31 = $- 0.0000041*x^3 + 0.0012139*x^2 - 0.1196683*x + 5.4068884$ (R^2=0.9955) (3.b)
Level of exposure : 2) Moderate (%)
y32 = $- 0.0000034*x^3 + 0.000977*x^2 - 0.0943738*x + 6.5976472$ (R^2=0.9668) (3.c)
Level of exposure : 3) Extreme (%)
y33 = $- 0.0000046*x^3 + 0.0013253*x^2 - 0.1233447*x + 8.3344736$ (R^2=0.9712) (3.d)
(see figure 3)

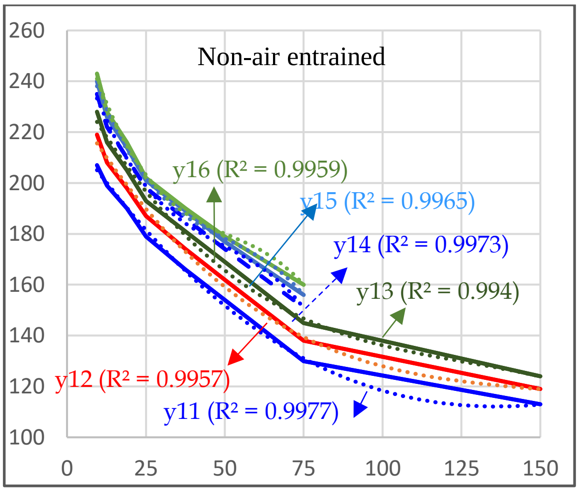

Figure 1. Aggregate maximum vs weight of water (Non-air-entrained)

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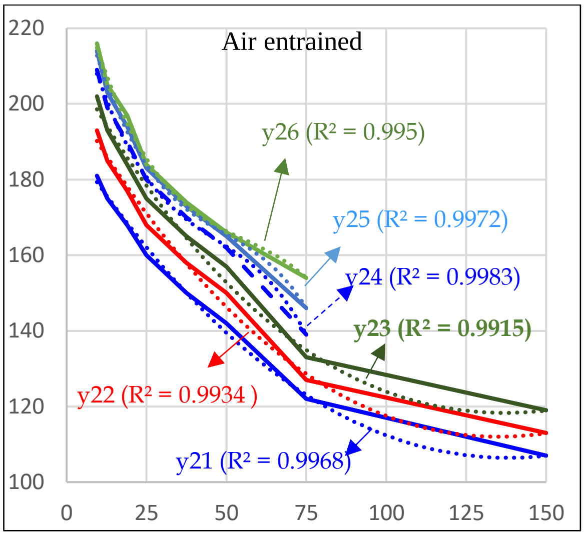

Figure 2. Aggregate maximum vs weight of water (Air-entrained)

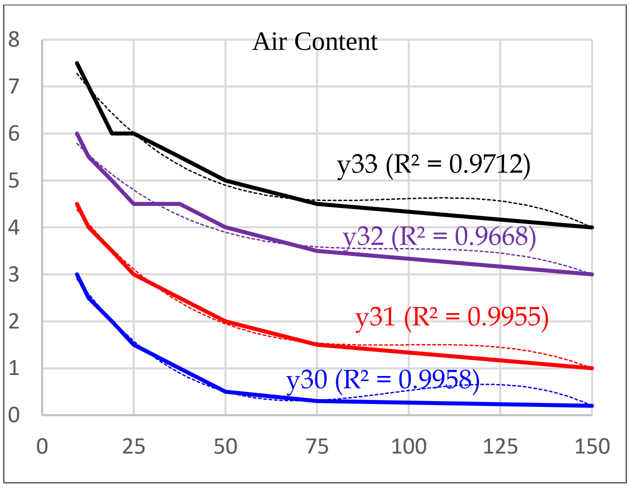

Figure 3. Aggregate maximum vs air content

where:
x = Aggregate Max (mm) ;
y3i = air content (%)
note of i
non-air-entrained concrete, i = 0
air-entrained-concrete,
if level of exposure = “mild”, i = 1
if level of exposure = “moderate”, i = 2
if level of exposure = “extreme”, i = 3

ACI[3], table A.1.5.3.4(a) or SNI [5] table 3 convert to cubic equation
Non-air-entrained concrete

$$y41 = - 0.0000022*x^3 + 0.0003905*x^2 - 0.0308968*x + 1.1721429 \quad (R^2=0.9996) \quad (4.a)$$

Air-entrained concrete

$$y42 = - 0.0000067*x^3 + 0.0007571*x^2 - 0.0401905*x + 1.1548571 \quad (R^2=0.9999) \quad (4.b)$$

(see figure 4)

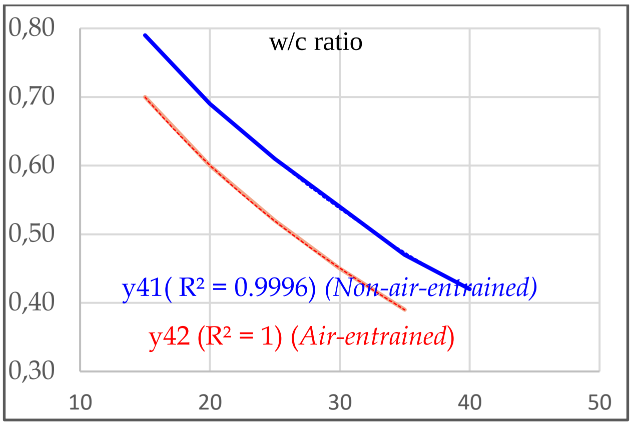

Figure 4. fck vs w/c ratio

where:
x = fck (MPa)
y4i = water cement ratio (unit less)
notes of i :
i = 1 (Non-air-entrained)
I = 2 (Air-entrained)

ACI[3], table A.1.5.3.4(b) or SNI [5] table 4 is condition of water content ratio maximum,
IF Exposures = "Mild" THEN WcMax = 1
IF Exposures = "Severe" AND Type = "thin" AND Structure = "wet" THEN WcMax = 0.45
IF Exposures = "Severe" AND Type = "thin" AND Structure = "sea" THEN WcMax = 0.40
IF Exposures = "Severe" AND Type = "other" AND Structure = "wet" THEN WcMax = 0.50
IF Exposures = "Severe" AND Type = "other" AND Structure = "sea" THEN WcMax = 0.45

ACI[3], table A.1.5.3.6 or SNI [5] table 5 convert to cubic equation :
$9.5 \text{ mm} \leq x < 25 \text{ mm}$ (R^2=1)
$$y51 = + 0.000118027*x^3 - 0.006863402*x^2 + 0.1378855*x - 0.051683 - 0.1(z) \quad (5.a)$$
$25 \text{ mm} \leq x \leq 150 \text{ mm}$ (R^2=0.9999)
$$y52 = + 0.000000121*x^3 - 0.000042577*x^2 + 0.0054684*x + 0.8381061 - 0.1(z) \quad (5.b)$$
where :
x = aggregate max (mm)
z = FM (Finest Modulus) of Fine Aggregate (unit less)
y5i = volume of coarse aggregate (m^3)
notes of i
i = 1, if $x < 25$ mm ; i = 2, if $x \geq 25$ mm
(see figure 5)

ACI[3], table A.1.5.3.7.1 or SNI [5] table 6 convert to cubic equation :
Non-air-entrained concrete
$$y61 = + 0.000214443*x^3 – 0.06765698*x^2 + 7.360915*x + 2224.583 \quad (R^2 = 0.9945) \quad (6.a)$$
Air-entrained concrete
$$y62 = + 0.000128711*x^3 – 0.04674232*x^2 + 5.941731*x + 2161.381 \quad (R^2 = 0.9836) \quad (6.b)$$
(see figure 6)
where :
x = Aggregate Max (mm)
y6i = mass of fresh concrete (kg/m^3)
notes of I : i = 1 , (non-air-entrained) ,
i = 2 , (air-entrained)

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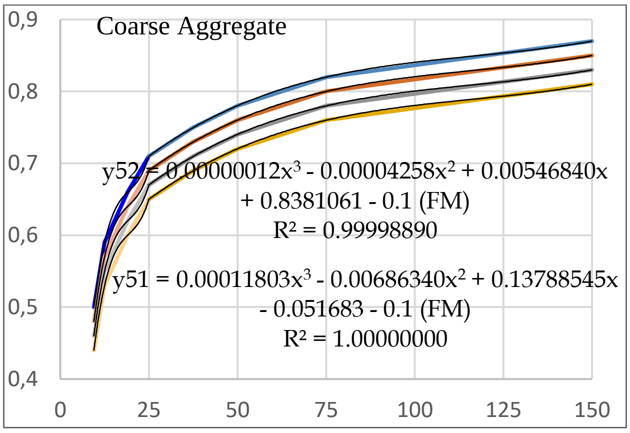

Figure 5. Aggregate maximum vs volume of coarse aggregate

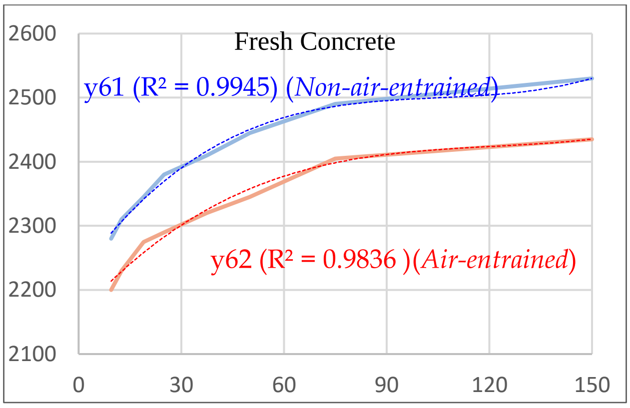

Figure 6. Aggregate maximum vs mass of fresh concrete

$$Fw = \frac{p}{c+p} \quad \text{(7)}$$

$$Fv = \frac{Fw}{Fw + \frac{Gp}{Gc}(1 - Fw)} \quad \text{(8)}$$

Fw = pozzolanic materials percentage by weight (expression in decimal)
Fv = pozzolanic materials percentage by volume (expression in decimal)
p = weight of pozzolanic materials
c = weight of cement
Gp = specific gravity of pozzolanic
Gc = specific gravity of cement

Method of concrete mix design is as follows:
Data requirements:
1. Average strength, **fck** (MPa)
2. Choose **Slump** [1, 2, 3, 4, 5, 6]
   (1="25-50"; 2="50-75"; 3="75-100"; 4="100-125"; 5="125-150"; 6="150-175")
3. Pozzolanic
   a. **Fw** pozzolanic (decimal)
   b. **Gp** (specific gravity of pozzolanic)
4. Cement

   a. **Gc** (specific gravity of cement)
   b. Choose concrete of air content, **Entrap** = [1 , 2]
      (1 = Non-air-entrained ; 2 = Air-entrained)
   c. Choose level of air content, **Level** = [0, 1, 2, 3]
      (0 = Entrapped ; 1= Mild ; 2 = Moderate ; 3 = Extreme)
5. Exposure of Concrete
   a. Choose **Exposure** = [1, 2]
      (1 = Mild ; 2 = Severe)
   b. If **Exposure** = 1("Mild") , go to step 6
   c. Choose type of structure, **Type** = [1, 2]
      (1 = Thins ; 2 = Others)
   d. Choose structure, **Structure** = [1, 2]
      (1 = Wet ; 2 = Sea or Sulphates)
6. Fine aggregate:
   a. **FM** (Fineness Modulus)
   b. **Gfa** (specific gravity of fine aggregate)
   c. **AbFA** (water absorption of fine aggregate, %)
   d. **MoFA** (moisture of fine aggregate, %)
7. Coarse aggregate
   a. **DRM** (Dry-rodded mass)
   b. **Gca** (specific gravity of coarse aggregate)
   c. **AbCA** (water absorption of coarse aggregate, %)
   d. **MoCA** (moisture of coarse aggregates, %)
   e. **AggMax** (maximum size of aggregate, mm)

Calculation:

8. Calculate mixing water (WW)
   WW = yij
   where : i = Entrap [1 , 2]
   j = Slump [1 , 2 , 3 , 4 , 5 , 6]
9. Water cement ratio
   a. Calculate water cement ratio (WCR)
      WCR = y4i ; i = Entrap [1 , 2]
   b. Calculate water cement ratio maximum (WMX)
      IF Exposure = 1 THEN WMX = 1
      IF Exposure = 2 AND Type = 1 AND Structure = 1 THEN WMX = 0.45;
      IF Exposure = 2 AND Type = 1 AND Structure = 2 THEN WMX = 0.40;
      IF Exposure = 2 AND Type = 2 AND Structure = 1 THEN WMX = 0.50;
      IF Exposure = 2 AND Type = 2 AND Structure = 2 THEN WMX = 0.45;
   c. Calculate final water cement ratio (WFR)
      WFR = MIN(WCR, WMX)
   d. Calculate final water cement ratio, by volume (WFRv)
      Fv = Fw/[Fw+Gp/Gc*(1-Fw)]
      WFRv = Gc * WFR / [Gc * (1 - Fv) + Gp * Fv]
      (Fw, Fv = expression in decimal)

Mass bases

Final method of concrete mix design base on mass is as follows:

10. Calculate Weight of Cement (WC)
    WC = Fw * WW/WFR
11. Calculate Weight of Pozzolanic (WP)
    WP = (1 – Fw) * WW/WFR
12. Calculate Weight of Coarse Aggregate (WCA)
    WCA = y5*i* * DRM ;
    where: IF AggMax < 25 mm THEN *i* = 1 ELSE *i* = 2
13. Calculate Weight of Fresh concrete (WFC)

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WFC = y6i ;
where: i = Entrap [1 , 2]

14. Calculate Weight of Fine Aggregate (WFA)
    WFA = WFC – (WW + WC + WP + WCA)
15. Adjusted weight of mixing water (WAW)
    WAW= WW – WCA*(MoCA – AbCA)/100 – WFA*(MoFA – AbFA)/100
16. Adjusted weight of fine aggregate (WAF)
    WAF = WFA*(1 + MoFA/100)
17. Adjusted weight of coarse aggregate (WAC)
    WAC = WCA*(1 + MoCA/100)
18. Final result (WAW, WC, WP, WAF, WAC)

Volume bases
Final method of concrete mix design base on volume are follows:

10. Calculate Volume of mixing water (VW)
    VW = WW/1000
11. Calculate Volume of Cement (VC)
    VC = (1 - Fv) * WW/ (1000*Gc*WFRv)
12. Calculate Volume of Pozzolanic (VP)
    VP = Fv * WW/(1000*Gp*WFRv)
13. Calculate Volume of Coarse Aggregate (VCA)
    VCA = y5i * DRM / (1000*Gca)
    where: IF AggMax < 25 mm THEN *i* = 1 ELSE *i* = 2
14. Calculate Volume of Air Content (VAC)
    VAC = y3i / 100
    where: i = level [0 , 1 , 2 , 3]
15. Calculate Volume of Fine Aggregate (VFA)
    VFA = 1 – (VW + VC + VP + VCA + VAC)
16. Calculate Weight of mixing water (WWv)
    WWv = VW*1000
17. Calculate Weight of Cement (WCv)
    WCv = Vc * 1000 * Gc
18. Calculate Weight of Pozzolanic (WPv)
    WPv = Vp * 1000 * Gp
19. Calculate Weight of Coarse Aggregate (WCAv)
    WCAv = VCA * 1000 *Gca
20. Calculate Weight of Fine Aggregate (WFAv)
    WFAv = VFA * 1000 *Gfa
21. Adjusted weight of mixing water (WAWv)
    WAWv= WWv – WCAv*(MoCA – AbCA)/100 – FAv*(MoFA – AbFA)/100
22. Adjusted weight of fine aggregate (WAFv)
    WAFv = WFAv*(1 + MoFA/100)
23. Adjusted weight of coarse aggregate (WACv)
    WACv = WCAv*(1 + MoCA/100)
24. Final result (WAWv, WCv, WPv, WAFv, WACv)

RESULTS AND DISCUSSION

Required average strength (fck) will be 24 MPa with slump of 75 to 100 mm (= 3). Cement : Type I with specific gravity (Gc) = 3.15. Concrete Air-entrapped (Entrap) = Non-air-entrapped (= 1), Level air content (Level) = Non-air (= 0). Exposure = Mild (= 1), type = Null, structure = Null. Coarse aggregate : bulk specific gravity (Gca) = 2.68, absorption (AbCA) = 0.5 % and moisture content (MoCA) = 3%, has a nominal maximum size (AggMax) = 37.5 mm and dry-rodded mass (DRM) = 1600 kg/m^3. Fine aggregate : bulk specific gravity (Gfa) = 2.64, absorption (AbFA) = 0.7 %, moisture content (MoFA) = 5% , fineness modulus (FM) = 2.8. Fly ash : specific gravity (Gp) = 2.14 and pozzolonic prosentase by weight (Fw) = 15%

Table 1. Result using cubic equation

Material	Weight (kg)	Volume (kg)
Water	115	117
Fly Ash	43	50
Cement	243	224
Coarse Aggregate (wet)	1169	1170
Fine Aggregate (wet)	858	820
Total	2428	2381

Table 2. Result using direct table

Material	Weight (kg)	Volume (kg)
Water	118	119
Fly Ash	43	52
Cement	246	224
Coarse Aggregate (wet)	1170	1170
Fine Aggregate (wet)	844	810
Total	2421	2375

Table 3. Comparison Equation method vs Table method base on mass

[1]	[2]	[3]	[4]	[5]	[6]
Water	115	118	3	2.61%	2.54%
Fly Ash	43	43	0	0.00%	0.00%
Cement	243	246	3	1.23%	1.22%
Coarse Aggregate (wet)	1169	1170	1	0.09%	0.09%
Fine Aggregate (wet)	858	844	14	1.63%	1.66%
Total	2428	2421	-	0.29%	0.29%

Table 4. Comparison Equation method vs Table method base on absolute volume

[1]	[2]	[3]	[4]	[5]	[6]
Water	117	119	2	1.71%	1.68%
Fly Ash	50	52	2	4.00%	3.85%
Cement	224	224	0	0.00%	0.00%
Coarse Aggregate (wet)	1170	1170	0	0.00%	0.00%
Fine Aggregate (wet)	820	810	10	1.22%	1.23%
Total	2381	2375	-	0.25%	0.25%

Note : Table 3 and Table 4

[1] = Material	[4] = ABS{ [2] – [3] }
[2] = by equation method	[5] = [4] / [2]
[3] = by table method	[6] = [4] / [3]

CONCLUSION

Comparison between Equation's method and Table's method base on Mass. Water 2.61% and 2.54%, Fly Ash 0% and 0%, Cement 1.23% and 1.22%, Coarse Aggregate 0.09% and 0.09%, Fine Aggregate 1.63% and 1.66%, total 0.29% and 0.29%, all result less than 5% , Equation Method can be used for Mass. Comparison between Equation's method and Table's method base on Volume. Water 1.71% and 1.68%, Fly Ash 4% and 3.85%, Cement and Coarse Aggregate 0% and 0% , Fine Aggregate 1.22% and 1.23%, total 0.25%, all result less than 5% , Equation Method can be used for Volume Base.

Calculation of mixing water (Non-air-entrained) used equation (1.a) …. (1.f).

Calculation of mixing water (Air-entrained) used equation (2.a) …. (2.f).

Calculation of air content used equation (3.a) …. (3.d).

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Calculation of water content ratio used equation (4.a) or (4.b).
Calculation of Volume Coarse Aggregate used equation (5.a) or (5.b).
Calculation of fresh concrete used equation (6.a) or (6.b).

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