MIX DESIGN EQUATIONS, FOR HEAVY WEIGHT, NORMAL WEIGHT AND MASS CONCRETE USING ACI 211.1-91.

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ABSTRACT

Equations, and graphs for mix design of normal, heavy weight and mass concrete are presented in this work. ACI's standards practices for normal, heavy weight, and mass concrete (ACI 211. 1-91) provides a wealth of information for the mix designer to be able to carry out the proper proportioning and selections of appropriate materials for the strength and general characteristics of the concrete needed to be produced. While the clearly written text and numerical examples work the designer through a manner in which the civil engineer or the mix designer will be able to achieve the properties of the concretes requires, the heart of the document is in the tables of mixture proportioning data provided in the ACI 211.1-91 for the selections and proportioning of heavyweight, normal and mass concrete. Such data may be more clearly presented as equations and graphs in order to assist the designer in given a good concrete mixes which will require lesser effort in understanding the data in the code and interpolations are often required when intermediate values are needed in the selections. Going through the process of presenting these data in codes and interpolating of the data to obtain the data not presented in this tables of value can grossly have resulted in human error, which will continue to frustrate the effort of the mix designer to obtain the required property of the concrete severally due to the human errors that are bound to occur during this interpolations and codes deriving. Prof. Ken Hover 1995, run graphs for the tables of data provided in the ACI 211.1-91 to carry the mix designs of the normal, heavyweight and mass concrete which required tracing some concrete characteristic required out of it which are liable to error too. The tabular data in ACI 211. 1-99 are converted in equations, and graphs. Using this standard practice various models were tried and the best adequately represents the data was chosen based on the regression coefficient and its predictive capability. The graphs, and equations used to solve some mix design problems from reputable textural sources. The developed graphs, and equations are capable of giving material constituents for the first trial batch of normal, heavy weight, and mass concrete. These graphs, and equation can be used in place of the data on the code and would reduce the effort, time and energy expended in the manual process of mix design of normal, heavy weight, and mass concrete. The process of mix design presented in this work if duly follow may reduce the possibility of errors that occur during manual computation of this mix designs procedure. This work is also very much useful for the mixture proportioning adjustment majorly for heavyweight, normal and mass concrete.

Key words: Heavy weight, normal and mass concrete, mix design, equations.

INTRODUCTION

Concrete is the second largest material consumed by human beings after food and water as per WHO. It is obtained by mixing cement, fine aggregate, coarse aggregate and water in required proportions. The mixture when placed in forms and allowed to cure becomes hard like stone. The hardening is caused by chemical action between water and the cement due to which concrete grows stronger with age.

The strength, durability and other characteristics of concrete depend upon the properties of its ingredients, proportion of the mix, the method of compaction and other controls during placing, compaction and curing.

Concrete mix design is the process of choosing suitable ingredients of concrete and determining their relative quantities with the objective of producing the most economical concrete while retaining the specified minimum properties such as strength, durability, and consistency (Akhras foo, 1994; Neville, 1995). The selection of ingredient is normally carried out using data from tables and charts in the relevant mix design standard. While these data and numerical examples in the codes are sufficient to the equations, and graphs for mix design of normal, heavy weight, and mass concrete, guide the mix designer, it is thought worthwhile to add more values to these data for convenience of the users. The equations were easy enough to be understand by the mix designer or the civil engineer in other to be able to insert the speculated property of the required concrete in it.

Researchers have invested their time and energy in supporting the need to present mix design data in form of graphs or equations (Hover, 1995; Popovics, 1993; Abdullahi, 2009). Abrams 1918, have equally relate the water-cementing materials ratio and strength relations of the concrete. Prof. Ken Hover in 1995 and 1998 presented graphs derived from the data presented in selections and proportioning of heavyweight, normal and mass concrete using ACI 211.1-91 for the properties of the concrete provided. Engr (Dr) M. Abdullahi 2009, presented equations for mix design of structural lightweight concrete. Most people involved in mix design of concrete may be more comfortable using equations, graphs or computer programs to calculate the ingredient of concrete. The calculation of batch compositions using the mix design codes only give the first starting point (Hover, 1995; Abdullahi, 2009; ACI 211.2-98; ACI 211.1-91. For this type of concrete, it is obvious that searching for the optimum mix ingredients is quite a laborious task. Optimum compositions may be attained by testing of concrete, re-calculations and mix adjustment as deem necessary. This process can be made less cumbersome if the relevant equations, graphs, and simple algorithm programs are simply put in place for the mixture proportioning.

The interest of this project work is to use equations, graphs, and simple algorithm program for mix design of normal, heavy weight, and mass concrete rather than the tabular data and charts presented in the code to obtain the mix ingredient of structural heavy weight concrete.

2.0 Methods

MODEL DEVELOPMENT

The tabular data and chart in ACI.211.1-91 (standard practice for selecting proportions for normal, heavy weight, and mass concrete) are converted to equations. The equations were tested by determining the ingredients of normal, heavyweight, and mass concrete using sample problems from textural sources.

2.1. MIX DESIGN EQUATIONS

Microsoft excel spread sheet was used to develop equations using the data in tables of ACI 211.1-91. The chart wizard in excel spread sheet was used to plot the graph. By right clicking on the data on data point and selecting 'add trendline' it is possible to choose any regression line to represent the data. The option 'add trendline' was used to display regression equation and coefficient (R-square value). Various regression models where tried and the trends of the graphs and correlation coefficients were used as the basis for selecting the best model that adequately represents the data. The developed equations are shown as follows together with the numerical data that was used.

2.2 The procedure for selection of mix proportions given in the following case is applicable to normal weight, heavy weight and mass concrete.

STEP 1: choice of slump. The table 6.3.1 in the ACI 211.1-91 was use to obtained the maximum and minimum slump require for various type of constructions work.

STEP 2: choice of maximum size of aggregate. Large nominal maximum sizes of well graded aggregates have fewer voids than smaller sizes. Table 6.3.2 provides the code for non-air-entrained concrete and air-entrained concrete which was used to form the equations for the different nominal maximum sizes of aggregate.

STEP 3: estimation of mixing water and air content. Table 6.3.3 provides estimates of required mixing water for concrete made with various maximum sizes of aggregate, with and without air entrainment.

STEP 4: Selection of water-cement or water-cementious materials ratio. The required w/c or w/(c+p) is determine not only by strength requirements but also by factors such as durability. Table 6.3.4(a) and Table 6.3.4(b) gives the required data which was used to form equations for calculating the water cement or water-cementitious materials ratio and compressive strength of concrete.

STEP 5: Calculation of cement content. The amount of cement per unit volume of concrete is fixed by the determinations made in steps 3 and 4 above. The required cement is equal to the estimated mixing-water content (step 3) divided by the water-cement ratio (step 4). However if the specification includes a separate minimum limit on cement in addition to requirements for strength and durability, the mixture must be based on whichever criterion leads to the larger amount of cement. The use of pozzolanic or chemical admixtures will affect properties of both fresh and hardened concrete.

STEP 6: Estimation of coarse aggregate content. The aggregate of essentially the same nominal maximum size and grading will produce concrete of satisfactory workability when given volume of coarse aggregate, on an oven-dry-rodded basis, is used per unit volume of concrete. Table 6.3.6 gave the appropriate value for that. The value was converted to equations accordingly.

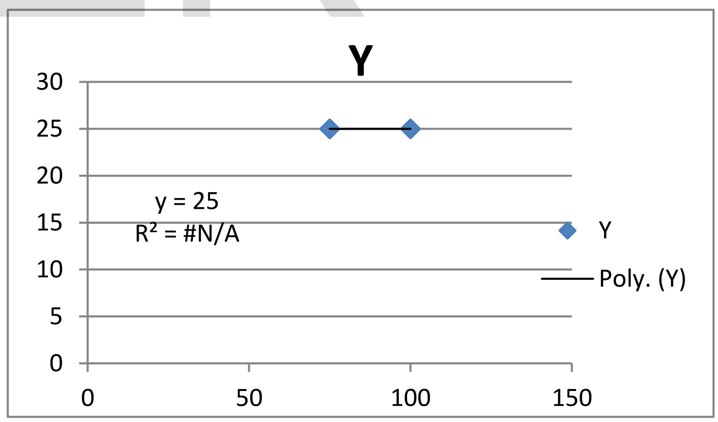
STEP 7: Estimation of fine aggregate content. At the completion of step 6, all ingredients of the concrete have been estimated except the fine aggregate. Its quantity is determined by difference. Table 6.3.7 was used to derive the equations for the first estimate.

STEP 8: Adjustment for aggregate moisture. The aggregate quantities actually to be weighed out for the concrete must allow for moisture in the aggregates. Generally, the aggregates will be moist and their dry weights should be increased by the percentage of water they contain, both absorbed and surface. The mixing water added to the batch must be reduced by an amount equal to the free moisture contributed by the aggregate. i.e. total moisture minus absorption.

STEP 9: Trial batch adjustments

Table 3.1.2

X	Y
75	25
75	25
100	25
100	25
75	25
75	25



Recommended slumps for various type of concrete. The maximum and minimum slump.

NON-AIR-ENTRAINED CONCRETE

TABLE 3.2: Mixing water (kg/m3) (Adapted from (ACI 211.1-99)

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Nominal maximum aggregate sizes (mm)	Slump Range (mm)		
	25 to 50	75 to 100	150 to 175
x	Y1	Y2	Y3
9.5	207	228	243
12.5	199	216	228
19	190	205	216
25	179	193	202
37.5	166	181	190
50	154	169	178
75	130	145	160
150	113	124	-

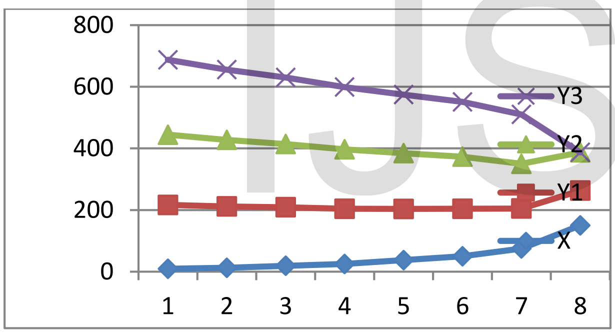

Figure 3.2

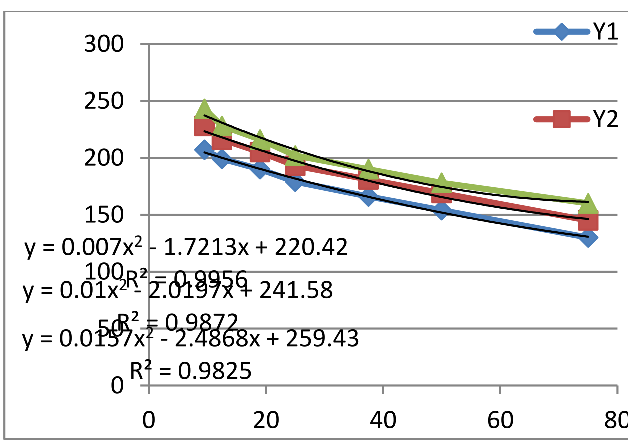

Figure 3.2.1

Non Air entrained concrete.

Mixing water for 25 to 50mm slump range.

$Y = 0.007x^2 - 1.7213x + 220.42$
$R^2 = 0.9956$

Mixing water for 75 to 100mm slump range.

$Y = 0.01x^2 - 2.0197x + 241.58$
$R^2 = 0.9872$

Mixing water for 150 to 175 slump range.

$Y = 0.0157x^2 - 2.4868x + 259.43$
$R^2 = 0.9825$

AIR-ENTRAINED CONCRETE

TABLE 3.3: Mixing water (kg/m3) (Adapted from (ACI 211.1-99)

Nominal maximum aggregate sizes (mm)	Slump Range (mm)		
	25 to 50	75 to 100	125 to 150
9.5	181	202	216
12.5	175	193	205
19	168	184	197
25	160	175	184
37.5	150	165	174
50	142	157	166
75	122	133	154
150	107	119	-

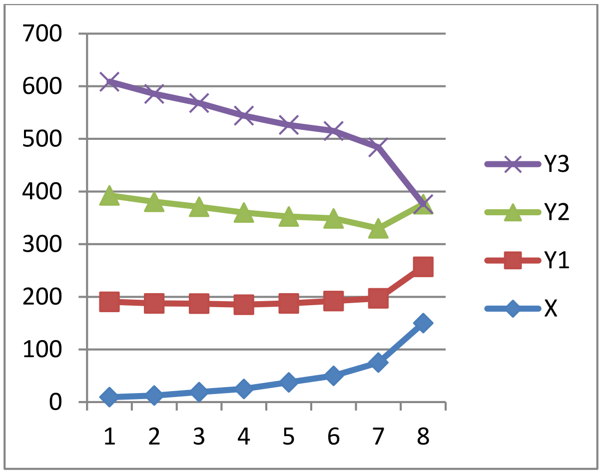

Figure 3.3

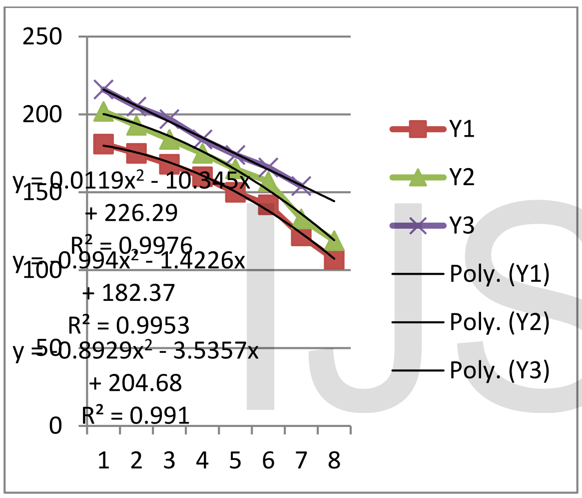

Figure 3.3.1

Air entrained concrete.

Mixing water for the slump range of 25 to 50mm.

$$y = 0.0119x^2 - 10.345x + 226.29$$

$R^2 = 0.9976$

Mixing water for the slump range of 75 to 100mm.

$$y = -0.994x^2 - 1.4226x + 182.37$$

$R^2 = 0.9953$

Mixing water for the slump range of 125 to 150mm.

$$y = -0.8929x^2 - 3.5357x + 204.68$$

$R^2 = 0.991$

APPROXIMATE AMOUNT OF ENTRAPPED AIR IN NON-AIR-ENTRAINED CONCRETE (%)

TABLE 3.4: Entrapped air (%) (Adapted from ACI 211.1-99)

Nominal maximum aggregate sizes (mm)x	Entrapped air (%) y
9.5	3
12.5	2.5
19	2
25	1.5
37.5	1
50	0.5
75	0.3
150	0.2

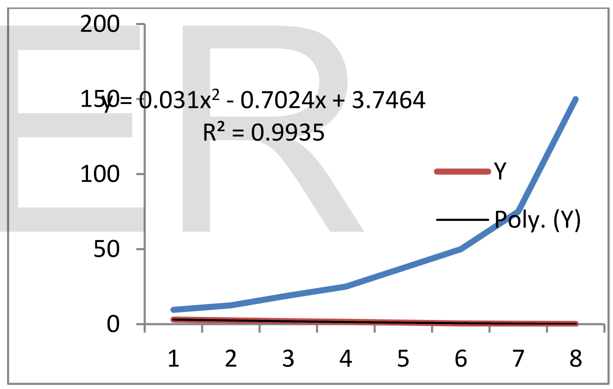

Figure 3.4

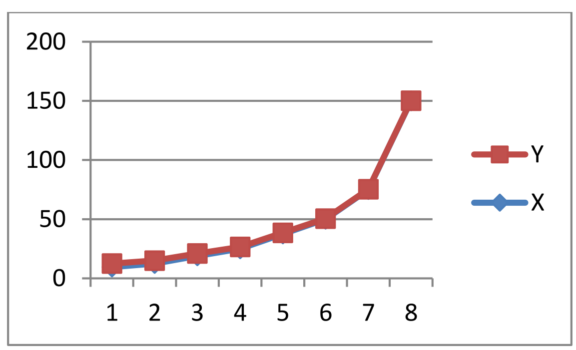

Figure 3.4.1

Entrapped air (%)

$y = 0.031x^2 - 0.7024x + 3.7464$
$R^2 = 0.9935$

RECOMMENDED AVERAGE TOTAL AIR CONTENT, PERCENT FOR LEVEL OF EXPOSURE.

TABLE 3.5: Entrained air (%) (Adapted from ACI211.1-99)

Nominal maximum aggregate sizes x	CONDITION OF EXPOSURE		
	Mild exposure Y1	Moderate exposure Y2	Extreme exposure Y3
9.5	4.5	6.0	7.5
12.5	4.0	5.5	7.0
19	3.5	5.0	6.0
25	3.0	4.5	6.0
37.5	2.5	4.5	5.5
50	2.0	4.0	5.0
75	1.5	3.5	4.5
150	1.0	3.0	4.0

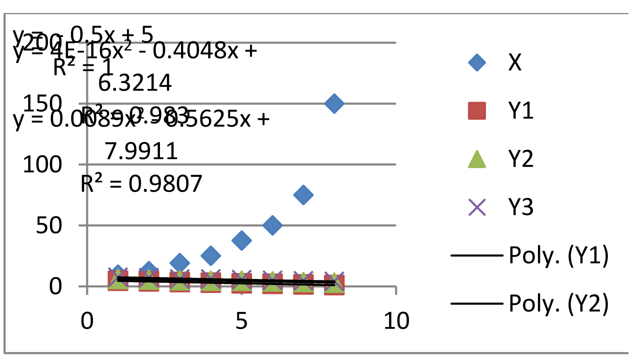

Figure 3.5

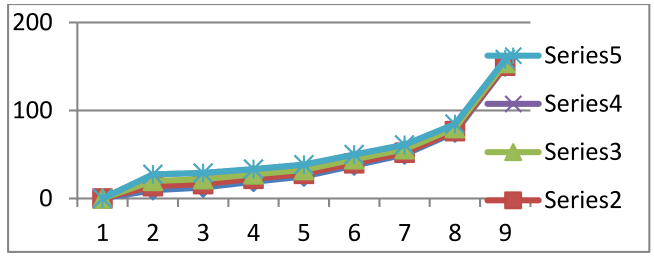

Figure 3.5.1

Entrained air (%) for mild exposure.
$Y = -0.5x + 5$
$R^2 = 1$
Entrained air (%) for moderate exposure.
$Y = 4E\text{-}16x^2 - 0.4048x + 6.3214$
$R^2 = 0.983$
Entrained air (%) for extreme exposure.
$Y = 0.0089x^2 - 0.5625x + 7.9911$
$R^2 = 0.9807$

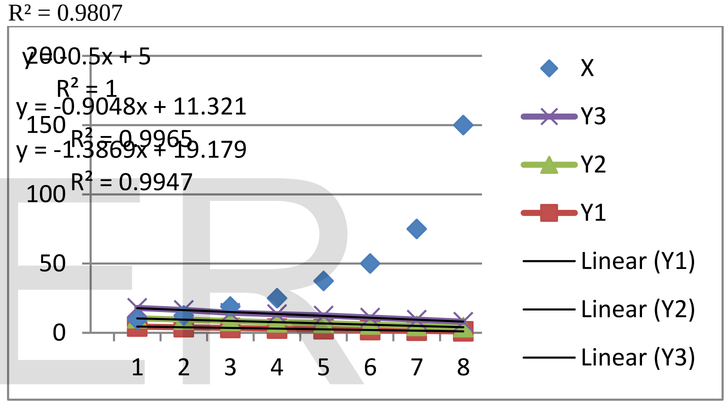

Figure 3.5.2

Entrained air (%) for mild exposure.
$y = -0.5x + 5$
$R^2 = 1$
Entrained air (%) for moderate exposure.

$y = -0.9048x + 11.321$
$R^2 = 0.9965$

Entrained air (%) for extreme exposure.

$y = -1.3869x + 19.179$
$R^2 = 0.9947$

RELATIONSHIP BETWEEN WATER-CEMENT RATIO AND COMPRESSIVE STRENGTH.TABLE 3.6: Water- Cement Ratio (Adapted from ACI 211.1-99)

Compressive strength (N/mm2)	Non-Air-Entrained concrete	Air-Entrained concrete

x	Y1	Y2
40	0.42	-
35	0.47	0.39
30	0.54	0.45
25	0.61	0.52
20	0.69	0.60
15	0.79	0.70

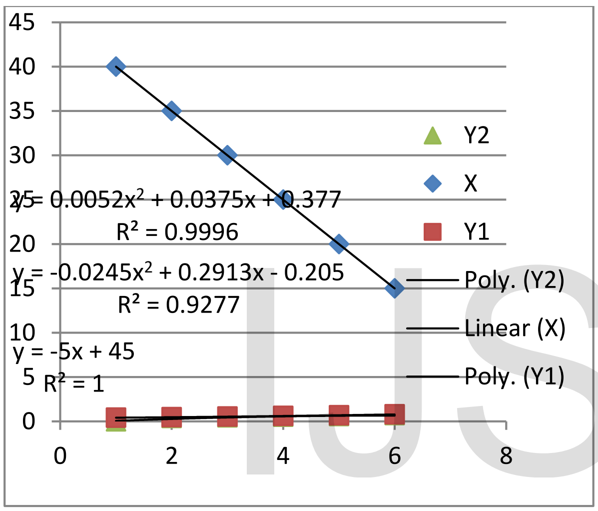

Figure 3.6

$y = 0.0052x^2 + 0.0375x + 0.377$
$R^2 = 0.9996$

$y = -0.0245x^2 + 0.2913x - 0.205$
$R^2 = 0.9277$

$y = -5x + 45$
$R^2 = 1$

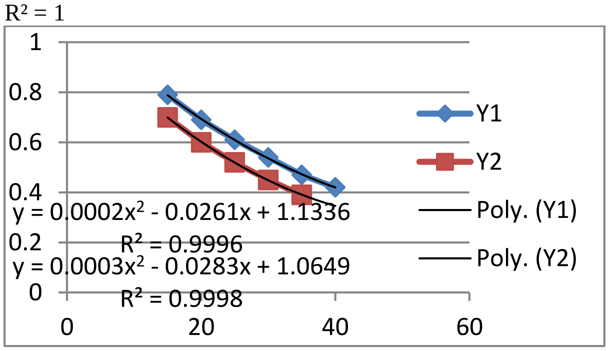

Figure 3.6.1

Water cement ratio of Non-Air-Entrained concrete.

$y = 0.0002x^2 - 0.0261x + 1.1336$
$R^2 = 0.9996$

Water cements radio of Air-Entrained concrete.
$y = 0.0003x^2 - 0.0283x + 1.0649$
$R^2 = 0.999$

VOLUME OF COARSE AGGREGATE PER UNIT OF VOLUME OF CONCRETE (SI)

TABLE 3.7: Volume of dry-rodded coarse aggregate per unit volume of concrete adapted from (ACI 211.1-99)

Nominal maximum sizes of Aggregate (mm) x	Fineness Modulus			
	2.40 Y1	2.60 Y2	2.80 Y3	3.00 Y4
9.5	0.50	0.48	0.46	0.44
12.5	0.59	0.57	0.55	0.53
19	0.66	0.64	0.62	0.60
25	0.71	0.69	0.67	0.65
37.5	0.75	0.73	0.71	0.69
50	0.78	0.76	0.74	0.72
75	0.82	0.80	0.78	0.76
150	0.87	0.85	0.83	0.81

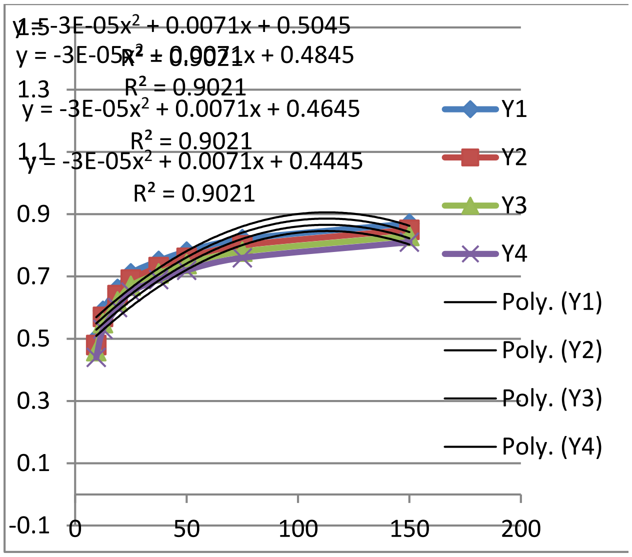

Figure 3.7

Fineness modulus for 2.40 specific gravity.

$Y = -3E\text{-}05x^2 + 0.0071x + 0.5045$
$R^2 = 0.9021$

Fineness modulus of 2.60 specific gravity.

$Y = -3E\text{-}05x^2 + 0.0071x + 0.4845$
$R^2 = 0.9021$

Fineness modulus of 2.80 specific gravity.

$Y = -3E\text{-}05x^2 + 0.0071x + 0.4645$
$R^2 = 0.9021$

Fineness modulus of 3.0 specific gravity.

$Y = -3E\text{-}05x^2 + 0.0071x + 0.4445$
$R^2 = 0.9021$

FIRST ESTIMATE OF MASS OF FRESH CONCRETE (SI)

TABLE 3.8: Weight of fresh concrete (kg/m3) Adapted from (ACI 211.1-99)

Nominal maximum size of Aggregate (mm) x	Non-air entrained concrete Y1	Air-entrained concrete Y2
9.5	2280	2200
12.5	2310	2230
19	2345	2275
25	2380	2290
37.5	2410	2350
50	2445	2345
75	2490	2405
150	2530	2435

fig. 3.8

Weight of fresh concrete Non-Air entrained concrete.

$y = -0.0197x^2 + 4.7695x + 2254.8$
$R^2 = 0.9834$

Weight of fresh concrete Air-entrained concrete.

$y = -0.0194x^2 + 4.5944x + 2179.4$
$R^2 = 0.9626$

The equation derives are as follows:

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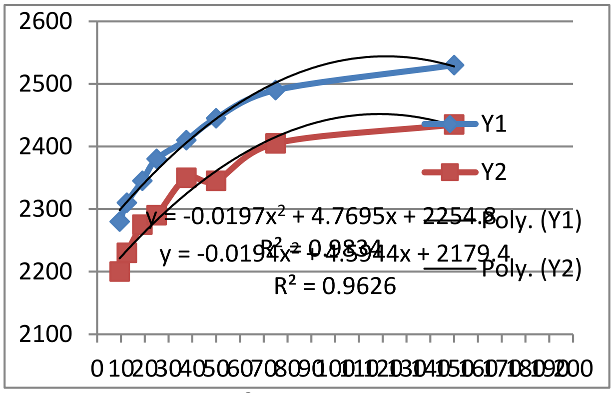

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Reference

ACI Committee 211. 1-91 Standard practice for selecting proportions for Normal, Heavyweight and Mass Concrete. Detroit, American Concrete Institute.

Hover, K., 1995 ''Graphical Approach to Mixture Proportioning by ACI 211.1-91'', Concrete International, 7(9) 49-53.

Popovics, S., 1993 Discussion, Technical session on Proportioning of Concrete Mixtures, ACI Fall Meeting, Minneapolis.

Abdullahi M., Al-Mattarneh H.M.A. and Mohammed B.S (2009) Equations for Mix design of structural light weight concrete. European Journal of Scientific Research. 31(1), 132-141.

Abdullahi M., Al-Mattarneh H.M.A., Hassan A.H, Abu Hassan M.H and Mohammed B.S. (2008) A Review on Expert systems for concrete Mix Design. ICCBT. A (21), 231-238.

Durocrete (2010). Mix Design Manual. Western Maharashtra: Durocrete Engineering service private limited.

Kett, I. (2010) Engineered concrete: Mix Design and Test methods (second edition). New York.

Montana Department of Transportation (1990) concrete mixture optimization: concrete Aggregate Combined Gradation concrete international. 2(9).

ACI. Committee 211.2-98 Standard Practice for selecting Proportions for Structural Lightweight concrete. American Concrete institute, Detroit, 1998.