Equations for Mix Design of Structural Lightweight Concrete

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Abstract

Equations for mix design of structural lightweight concrete are presented. Conventionally, mix design of concrete is conducted using the tabular data and charts in standards. This requires extra efforts of understanding the data in the code and interpolations are often required when intermediate values are needed. The process is also liable to human error as data may be erroneously taken by the mix designer. The tabular data and graphs in ACI 211.2-98 are converted to equations. Various models were tried and the best model that adequately represents the data was chosen based on the regression coefficient and its predictive capability. The equations were used to solve some mix design problems from reputable textural sources. The developed equations are capable of giving material constituents for the first trial batch of structural lightweight concrete. These equations can be used in place of the data in the code and would reduce the effort, time and energy expended in the manual process of mix design of structural lightweight concrete. The equations are also useful for mixture proportioning adjustment.

Keywords: Concrete, Equations, Regression, Mix design

1. Introduction

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 and Foo, 1994; Neville, 1995). The selection of ingredient is normally done using data from tables and charts in the relevant mix design standard. While these data and numerical examples in the codes are sufficient to
guide the mix designer, it is thought worthwhile to add more values to these data for convenience of
the users.

Researchers have supported the need to present mix design data in form of graphs or equations
(Hover, 1995; Popovics, 1993). Most people involved in mix design of concrete may be more
comfortable using equations to calculate the ingredient of concrete. The calculation of batch
compositions using the mix design codes only give the first starting point (Neville, 1995; ACI 211.2-
98; ACI 211.1-91; ACI 213-87). This is because the codes were developed from experience with
certain materials in some parts of the world which may not be applicable for some materials in other
parts of the world. The determination of accurate mix ingredient of concrete becomes more difficult
when lightweight aggregates are used because of the problem associated with it such as high water
absorption, lightweight, porous nature and surface texture. 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 are used for mixture proportioning.

The interest of this research is to use equations for mix design of structural lightweight concrete
rather than the tabular data and graphs in the code to obtain the mix ingredient of structural lightweight
concrete. The concrete mix designers do not have to scan through the numerous data in the code but
instead deal with the variables in the equations. This may reduce the effort and time required to
develop optimum mix compositions since adjustment can be done by choosing better input variables to
improve on the mix composition.

2. Methodology
The tabular data and charts in ACI 211.2-98 (Standard practice for selecting proportions for structural
lightweight concrete) are converted to equations. The equations were tested by determining the
ingredients of structural lightweight 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 211.2-98.
The chart wizard in excel spread sheet was used to plot the graph. By right clicking on the data point
and selecting ‘add trendline’ it is possible to choose any regression line to represent the data. The
option tab in the ‘add trendline’ was used to display the regression equation and 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. It was not possible to
develop equations for choice of slump but the table is simple enough to choose the value of slump. The
developed equations are shown as follows together with the numerical data that was used.

2.1.1. Mixing Water and Air Content
(i). Air-entrained Concrete
Table 1: Mixing water (kg/m³) (Adapted from ACI 211.2-98)

<table>
<thead>
<tr>
<th>Nominal Maximum Aggregate Sizes (mm)</th>
<th>25-50</th>
<th>75-100</th>
<th>125-150</th>
</tr>
</thead>
<tbody>
<tr>
<td>9.5</td>
<td>181</td>
<td>202</td>
<td>211</td>
</tr>
<tr>
<td>12.5</td>
<td>175</td>
<td>193</td>
<td>199</td>
</tr>
<tr>
<td>19</td>
<td>166</td>
<td>181</td>
<td>187</td>
</tr>
</tbody>
</table>

Mixing water
(125 to 150mm) slump,
\[ y_1 = 0.2267 * x_1^2 - 8.9879 * x_1 + 275.92 \]  \( (1) \ R^2 = 1 \)
(75 to 100mm) slump
\[ y_1 = 0.1215x_1^2 - 5.6721x_1 + 244.92 \]  \hspace{1cm} (2) \hspace{1cm} R^2 = 1

(25 to 50mm) slump
\[ y_1 = 0.0648x_1^2 - 3.4251x_1 + 207.69 \]  \hspace{1cm} (3) \hspace{1cm} R^2 = 1

**Table 2:**  Entrained air (%) (Adapted from ACI 211.2-98)

<table>
<thead>
<tr>
<th>Nominal Maximum Aggregate Sizes (mm)</th>
<th>Condition of exposure</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Mild exposure</td>
</tr>
<tr>
<td>9.5</td>
<td>4.5</td>
</tr>
<tr>
<td>12.5</td>
<td>4</td>
</tr>
<tr>
<td>19</td>
<td>4</td>
</tr>
</tbody>
</table>

Entrained air
(125 to 150mm) slump,
\[ y_2 = 0.0013x_1^2 - 0.1964x_1 + 9.2436 \]  \hspace{1cm} (4) \hspace{1cm} R^2 = 1

(75 to 100mm) slump
\[ y_2 = 0.0094x_1^2 - 0.3745x_1 + 8.7051 \]  \hspace{1cm} (5) \hspace{1cm} R^2 = 1

(25 to 50mm) slump
\[ y_2 = 0.0175x_1^2 - 0.5526x_1 + 8.1667 \]  \hspace{1cm} (6) \hspace{1cm} R^2 = 1

(ii) Non-air-entrained concrete

**Table 3:**  Mixing water (kg/m³) (Adapted from ACI 211.2-98)

<table>
<thead>
<tr>
<th>Nominal Maximum Aggregate Sizes (mm)</th>
<th>Slump range (mm)</th>
</tr>
</thead>
<tbody>
<tr>
<td>9.5</td>
<td>25-50</td>
</tr>
<tr>
<td>12.5</td>
<td>208</td>
</tr>
<tr>
<td>19</td>
<td>199</td>
</tr>
<tr>
<td></td>
<td>187</td>
</tr>
</tbody>
</table>

Mixing water
(125 to 150mm) slump,
\[ y_1 = 0.2996x_1^2 - 11.591x_1 + 320.08 \]  \hspace{1cm} (7) \hspace{1cm} R^2 = 1

(75 to 100mm) slump
\[ y_1 = 0.143x_1^2 - 6.8138x_1 + 279.82 \]  \hspace{1cm} (8) \hspace{1cm} R^2 = 1

(25 to 50mm) slump
\[ y_1 = 0.1215x_1^2 - 5.6721x_1 + 250.92 \]  \hspace{1cm} (9) \hspace{1cm} R^2 = 1

**Table 4:**  Entrapped air (%) (Adapted from ACI 211.2-98)

<table>
<thead>
<tr>
<th>NMAS (mm)</th>
<th>Entrapped air (%)</th>
</tr>
</thead>
<tbody>
<tr>
<td>9.5</td>
<td>3</td>
</tr>
<tr>
<td>12.5</td>
<td>2.5</td>
</tr>
<tr>
<td>19</td>
<td>2</td>
</tr>
</tbody>
</table>

Entrapped air
\[ y_3 = 0.0094x_1^2 - 0.3745x_1 + 5.7051 \]  \hspace{1cm} (10) \hspace{1cm} R^2 = 1
2.1.2. Water-cement ratio

Table 5: Water-cement ratio (Adapted from ACI 211.2-98)

<table>
<thead>
<tr>
<th>Compressive strength (N/mm²)</th>
<th>Non-air-entrained concrete</th>
<th>Air-entrained concrete</th>
</tr>
</thead>
<tbody>
<tr>
<td>42</td>
<td>0.41</td>
<td>-</td>
</tr>
<tr>
<td>35</td>
<td>0.48</td>
<td>0.4</td>
</tr>
<tr>
<td>28</td>
<td>0.57</td>
<td>0.48</td>
</tr>
<tr>
<td>21</td>
<td>0.68</td>
<td>0.59</td>
</tr>
<tr>
<td>14</td>
<td>0.82</td>
<td>0.74</td>
</tr>
</tbody>
</table>

Non-air-entrained concrete

\[
y_4 = -0.3749 \ln(x_2) + 1.8148
\]  
(11) \( R^2 = 0.999 \)

Air-entrained concrete

\[
y_4 = -0.3723 \ln(x_2) + 1.7225
\]  
(12) \( R^2 = 0.9999 \)

2.1.3 Volume of oven-dry loose coarse aggregate per unit volume of concrete

Table 6: Volume of coarse aggregate per unit volume of concrete (Adapted from ACI 211.2-98)

<table>
<thead>
<tr>
<th>Maximum size of aggregate (mm)</th>
<th>2.4</th>
<th>2.6</th>
<th>2.8</th>
<th>3</th>
</tr>
</thead>
<tbody>
<tr>
<td>9.5</td>
<td>0.58</td>
<td>0.56</td>
<td>0.54</td>
<td>0.52</td>
</tr>
<tr>
<td>12.5</td>
<td>0.67</td>
<td>0.65</td>
<td>0.63</td>
<td>0.61</td>
</tr>
<tr>
<td>19</td>
<td>0.74</td>
<td>0.72</td>
<td>0.7</td>
<td>0.68</td>
</tr>
</tbody>
</table>

F.M = 2.4

\[
y_5 = -0.002 * x_1^2 + 0.0745 * x_1 + 0.0546
\]  
(13) \( R^2 = 1 \)

F.M = 2.6

\[
y_5 = -0.002 * x_1^2 + 0.0745 * x_1 + 0.0346
\]  
(14) \( R^2 = 1 \)

F.M = 2.8

\[
y_5 = -0.002 * x_1^2 + 0.0745 * x_1 + 0.0146
\]  
(15) \( R^2 = 1 \)

F.M = 3.0

\[
y_5 = -0.002 * x_1^2 + 0.0745 * x_1 - 0.0054
\]  
(16) \( R^2 = 1 \)

or in terms of the fineness modulus

Nominal maximum coarse aggregate size= 19 mm

\[
y_5 = -0.1 * x_3 + 0.98
\]  
(17) \( R^2 = 1 \)

Nominal maximum coarse aggregate size= 12.5 mm

\[
y_5 = -0.1 * x_3 + 0.91
\]  
(18) \( R^2 = 1 \)

Nominal maximum coarse aggregate size= 9.5 mm

\[
y_5 = -0.1 * x_3 + 0.82
\]  
(19) \( R^2 = 1 \)
2.1.4. Weight of fresh lightweight concrete

Table 7: Weight of fresh lightweight concrete (kg/m3) (Adapted from ACI 211.2-98)

<table>
<thead>
<tr>
<th>Specific gravity factor</th>
<th>Entrained air (%)</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>4</td>
</tr>
<tr>
<td>1</td>
<td>1596</td>
</tr>
<tr>
<td>1.2</td>
<td>1679</td>
</tr>
<tr>
<td>1.4</td>
<td>1768</td>
</tr>
<tr>
<td>1.6</td>
<td>1851</td>
</tr>
<tr>
<td>1.8</td>
<td>1934</td>
</tr>
<tr>
<td>2</td>
<td>2023</td>
</tr>
</tbody>
</table>

Entrained air = 4%
\[ y_6 = 426.14 \times x_4 + 1169.3 \] \hspace{1cm} (20) \hspace{0.5cm} R^2 = 0.9999

Entrained air = 6%
\[ y_6 = 423 \times x_4 + 1135.7 \] \hspace{1cm} (21) \hspace{0.5cm} R^2 = 0.9999

Entrained air = 8%
\[ y_6 = 419.29 \times x_4 + 1102.6 \] \hspace{1cm} (22) \hspace{0.5cm} R^2 = 0.9999

Specific gravity factor = 2.0
\[ y_6 = -20.75 \times y_2 + 2106.2 \] \hspace{1cm} (23) \hspace{0.5cm} R^2 = 1

Specific gravity factor = 1.8
\[ y_6 = -19.25 \times y_2 + 2012.2 \] \hspace{1cm} (24) \hspace{0.5cm} R^2 = 0.9973

Specific gravity factor = 1.6
\[ y_6 = -19.25 \times y_2 + 1927.2 \] \hspace{1cm} (25) \hspace{0.5cm} R^2 = 0.9986

Specific gravity factor = 1.4
\[ y_6 = -19.25 \times y_2 + 1844.2 \] \hspace{1cm} (26) \hspace{0.5cm} R^2 = 0.9986

Specific gravity factor = 1.2
\[ y_6 = -17.75 \times y_2 + 1749.8 \] \hspace{1cm} (27) \hspace{0.5cm} R^2 = 0.9999

Specific gravity factor = 1.0
\[ y_6 = -19.25 \times y_2 + 1673.8 \] \hspace{1cm} (28) \hspace{0.5cm} R^2 = 0.9986

2.1.5. Determination of Cement Content by Volume Method

The equations for cement content as a function of compressive strength were developed using figure 3.3.2 in ACI 211.2-98. The boundary region in this figure is a straight line, so linear equations were used to describe the feasible region of cement content.

For all-lightweight concrete, the following coordinate points along the boundary of figure 3.3.2 in ACI 211.2-98 were chosen:
- Lower bound: A (27.60, 295.99), B (41.41, 413.98)
- Upper bound: C (27.60, 393.46), D (41.41, 516.58)

For sand-lightweight concrete, the coordinate points chosen are:
- Lower bound: A (20.7, 188.26), B (41.41, 367.81)
- Upper bound: C (20.7, 308.815), D (41.41, 485.8)

The notation of the coordinate points takes the form \((x_2, x_3)\).

Let the linear model be represented by
\[ x_2 = a_0 + a_1x_3 \] \hspace{1cm} (29)

Inserting the data for all-lightweight concrete in (29) yield
Equations for Mix Design of Structural Lightweight Concrete

\begin{align*}
41.41 &= a_0 + 413.98 a_1 \\ 27.6 &= a_0 + 295.99 a_1 \\ 41.41 &= a_0 + 516.58 a_1 \\ 27.6 &= a_0 + 393.46 a_1
\end{align*}

Solving equations (30) and (31) simultaneously gives
\( a_0 = -7.04385 \) and \( a_1 = 0.117044 \)

and the minimum cement content is
\[
x_{5L} = \frac{(x_2 + 7.04385)}{0.117044}
\]

Similarly, equations (32) and (33) give \( a_0 = -16.5291 \) and \( a_1 = 0.112159 \) and the maximum cement content is
\[
x_{5U} = \frac{(x_2 + 16.5291)}{0.112159}
\]

Similar equations were developed for sand-lightweight concrete. The minimum and maximum cement contents are:
\[
\begin{align*}
x_{5L} &= \frac{(x_2 + 1.014677)}{0.115344} \\
x_{5U} &= \frac{(x_2 + 15.408682)}{0.116959}
\end{align*}
\]

Where
\[
\begin{align*}
y_1 &= \text{Water requirement (kg/m}^3\text{)} \\
y_2 &= \text{Entrained air (\%)} \\
y_3 &= \text{Entrapped air (\%)} \\
y_4 &= \text{Water-cement ratio} \\
y_5 &= \text{Volume of oven-dry loose coarse aggregate per unit volume of concrete (m}^3\text{)} \\
y_6 &= \text{Weight of fresh lightweight concrete (kg/m}^3\text{)} \\
x_1 &= \text{Nominal maximum coarse aggregate sizes (mm)} \\
x_2 &= \text{Compressive strength (N/mm}^2\text{)} \\
x_3 &= \text{Fineness modulus} \\
x_4 &= \text{Specific gravity factor.} \\
x_5 &= \text{cement content (kg/m}^3\text{)} \\
a_0 &= \text{Intercept (regression coefficients)} \\
a_1 &= \text{Slope (regression coefficients)} \\
x_{5L} &= \text{Minimum cement content (kg/m}^3\text{)} \\
x_{5U} &= \text{Maximum cement content (kg/m}^3\text{)}
\]

2.2. Choice of equations for mix design of concrete

The appropriate equations required for specific task in the mix design process are shown as follows.

2.2.1. Weight Method

This is applicable to mix design of sand-lightweight concrete. The procedure for the mix design is as follows:
Step 1: Choice of Slump
Table 3.2.2.1 in the ACI code was used. It was not possible to provide equations for this table but the table is simple enough to enable users to decide on the required slump.

Step 2: Choice of Nominal Maximum Size of Coarse Aggregate
Recommended nominal maximum size of coarse aggregate by ACI 211.2-98 are: 9.5 mm, 12.5 mm and 19 mm.

Step 3: Estimation of Mixing Water and Air Content
Equations 1, 2, 3, 7, 8, 9 give the quantity of mixing water, while equations 4, 5, 6 and 10 give the quantity of air content.

Step 4: Selection of Appropriate Water-Cement Ratio
Equations 11 or 12 can be used.

Step 5: Calculation of Cement Content
This is the ratio of water content to water-cement ratio.

Step 6: Estimation of Lightweight Coarse Aggregate Content
Equations 13 to 19 can be used.

Step 7: Estimation of Fine Aggregate Content
Equations 20 to 28 can be used to obtain the weight of fresh lightweight concrete. Then the fine aggregate content is the total weight of fresh lightweight concrete less the weights of water, cement and coarse aggregate.

2.2.2. Volume Method
The volume method is used for mix design of sand-lightweight and all-lightweight concrete. Steps 1 (Choice of Slump), 2 (Choice of Nominal Maximum Size of Coarse Aggregate), and 3 (Estimation of mixing water and air content) are the same as in the weight method. The remaining steps of the mix design are as follows.

Step 4: Estimation of Cement Content
The minimum and maximum cement content can be obtained using equations (34) and (35) for all-lightweight concrete and equations (36) and (37) for sand-lightweight concrete.

Step 5: Estimation of Total Volume of Aggregate
The total volume of aggregates required (damp loose basis), as recommended by ACI 211.2-98, is between 1.04 m$^3$ to 1.26 m$^3$. It is at the discretion of the designer of the concrete mix to determine the required total volume of aggregate considering the nature of the lightweight aggregate and the properties of the concrete desired or recommendation from the manufacturer of the lightweight aggregate.

Step 6: Estimation of Loose Weight of Fine Aggregate
ACI 211.2-98 recommends the loose volume of fine aggregate to be between 40 to 60 percent of the total loose volume. The product of the loose volume of fine aggregate and the loose unit weight of fine aggregate gives the weight of fine aggregate.

Step 7: Estimation of Loose Weight of Coarse Aggregate
The total volume of concrete less the loose volume of fine aggregate gives the loose volume of coarse aggregate. The product of the loose volume of coarse aggregate and the loose unit weight of coarse aggregate gives the weight of coarse aggregate.
3. Application of the Derived Equations

The equations derived in this work were used to obtain the mix ingredient of concrete using sample mix design problems from reputable textural sources. The examples considered are as follows:

3.1. Case 1: Weight method

Design a concrete mixture by the weight method using lightweight coarse aggregate and normal-weight fine aggregate (sand-lightweight concrete) for structural lightweight concrete slab with a design 28-day compressive strength, $f_c = 35$ Mpa. Use the following data in the mix design:

- Coarse aggregate: 19 mm – N0.4 size; specific gravity factor = 1.5; absorption = 11.0 %.
- Fine aggregate: absorption = 1.0 %; fineness modulus = 2.80.
- Oven dry loose weight of coarse aggregate = 769 kg/m³ (Nawy, 2001).

3.2. Case 2: Volume method

A lightweight aggregate concrete containing normal weight fine aggregate is required to have a compressive strength (measured on standard cylinders) of 30 Mpa and a maximum air-dry density of 1700 kg/m³. Compliance with the density requirement is determined using ASTM C 567-91. The required slump is 100 mm. The damp, loose density of the coarse and the fine lightweight aggregates is 750 and 880 kg/m³, respectively. The normal weight fine aggregate has a density in a saturated and surface-dry condition of 1630 kg/m³. From past experience, the required cement content for the trial mix can be taken as 350 kg/m³. The volumes of aggregate to be used, in cubic metres per cubic metre of concrete, also chosen on the basis of experience, are: 0.60, 0.19, and 0.34, respectively, for the lightweight coarse, lightweight fine, and normal weight fine aggregate (Neville, 1995).

3.3. Numerical solutions

Case 1

1. Calculation of mixing water

From equation 2 $y_1 = 19$ mm.

$$y_1 = 0.1215 * x_1^2 - 5.6721 * x_1 + 244.92$$
$$y_1 = 0.1215 * (19)^2 - 5.6721 * (19) + 244.92 = 181 \text{ mm}$$

2. Calculation of water-cement ratio

From equation 12 $x_1 = 35$ Mpa

$$y_4 = -0.3723 \ln(x_4) + 1.7225$$
$$y_4 = -0.3723 \ln(35) + 1.7225 = 0.4$$

3. Cement content

$$Cement \ content = \frac{y_1}{y_4} = \frac{181}{0.4} = 452.5 \text{ kg} / \text{m}^3$$

4. SSD weight of coarse aggregate

The volume of oven dry loose coarse aggregate is given by equation (15)

$$y_5 = -0.002 * x_5^2 + 0.0745 * x_5 + 0.0146$$
$$y_5 = -0.002 * (19)^2 + 0.0745 * (19) + 0.0146 = 0.7 \text{ m}^3$$

$$Dry \ weight \ of \ coarse \ aggregate = 0.7 * 769 = 538.3 \text{ kg} / \text{m}^3$$

$$SSD \ weight \ of \ coarse \ aggregate = 1.11 * (538.3) = 597.51 \text{ kg} / \text{m}^3$$
5. SSD weight of fine aggregate
The weight of fresh concrete is obtained using equation 21 with \( x_4 = 1.5 \).
\[ \gamma_6 = 423^*x_4 + 1135.7 \]
\[ \gamma_6 = 423^*(1.5) + 1135.7 = 1770.2 \, \text{kg/m}^3 \]

\[ \text{SSD weight of fine aggregate} = 1770.2 - (181 - 452.5 - 597.51) = 539.19 \, \text{kg/m}^3 \]

Case 2
The solution to this problem is quite easy, but the derived equations will furnish options for possible cement content and water content if these are not given.

For \( x_2 = 30 \, \text{N/mm}^2 \), the cement content is calculated as follows:

From equation 36, the minimum cement content is
\[ x_{sl} = \frac{(x_2 + 1.014677)}{0.115344} \]
\[ x_{sl} = \frac{(30 + 1.014677)}{0.115344} = 268.89 \, \text{kg/m}^3 \]

From equation 37, the maximum cement content is
\[ x_{su} = \frac{(x_2 + 15.408682)}{0.116959} \]
\[ x_{su} = \frac{(30 + 15.408682)}{0.116959} = 388.24 \, \text{kg/m}^3 \]

The cement content assumed by the author, 350 kg/m³, is within the range found here.

The mixing water required (for air-entrained concrete) is calculated using equation 2, \( x_1 = 19 \, \text{mm} \).
\[ y_1 = 0.1215^*x_1^2 - 5.6721^*x_1 + 244.92 \]
\[ y_1 = 0.1215^*(19)^2 - 5.6721^*(19) + 244.92 = 181 \, \text{kg/m}^3 \]

Lightweight coarse aggregate = 0.63 * 750 = 472.5 kg/m³
Lightweight fine aggregate = 0.19 * 880 = 167.2 kg/m³
Normal weight fine aggregate = 0.34 * 1630 = 554.2 kg/m³

The results of mix design using equations were compared with those found in text books as indicated in table 8. The mix compositions calculated using the equations agree reasonably well with those of the two authors. The slight disparity is due to approximations in the course of the calculations.
Table 8: Results of first trial batch

<table>
<thead>
<tr>
<th>Weight method</th>
<th>Equation</th>
<th>Case 1</th>
</tr>
</thead>
<tbody>
<tr>
<td>Mix Ingredient</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Water (kg/m³)</td>
<td>181</td>
<td>180.96</td>
</tr>
<tr>
<td>Cement (kg/m³)</td>
<td>452.5</td>
<td>452.69</td>
</tr>
<tr>
<td>Fine aggregate, SSD (kg/m³)</td>
<td>539.19</td>
<td>538.12</td>
</tr>
<tr>
<td>Coarse aggregate, SSD (kg/m³)</td>
<td>597.51</td>
<td>597.45</td>
</tr>
<tr>
<td>Water/cement ratio (%)</td>
<td>0.4</td>
<td>0.4</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Volume method</th>
<th>Equation</th>
<th>Case 2</th>
</tr>
</thead>
<tbody>
<tr>
<td>Mix Ingredient</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Water (kg/m³)</td>
<td>181</td>
<td>180.00</td>
</tr>
<tr>
<td>Cement (kg/m³)</td>
<td>350</td>
<td>350</td>
</tr>
<tr>
<td>Lightweight fine aggregate (kg/m³)</td>
<td>167.2</td>
<td>168</td>
</tr>
<tr>
<td>Normal-weight fine aggregate (kg/m³)</td>
<td>554.2</td>
<td>550</td>
</tr>
<tr>
<td>Coarse aggregate, SSD (kg/m³)</td>
<td>472.5</td>
<td>473</td>
</tr>
<tr>
<td>Water/cement ratio (%)</td>
<td>0.52</td>
<td>0.51</td>
</tr>
</tbody>
</table>

4. Summary

The equations presented in this work are capable of giving the material constituents of structural lightweight concrete for the first trial batch from given performance criteria. Mix adjustment of the ingredients can be made simply by choosing suitable input variables and re-calculating the batch composition. The equations can be updated when new version of the code is developed by developing new equations to replace the once presented in this work. Interpolations are avoided if equations are used. For example, in the example of the weight method, the weight of fresh concrete can be obtained by interpolating between the tabulated weights for specific gravity factors of 1.4 and 1.6. Using an equation, the weight of fresh concrete was calculated directly. Addition of equations to future versions of mix design codes may add more value to the existing documents.

References

[1] ACI Committee 211.2-98 Standard Practice for Selecting Proportions for Structural Lightweight Concrete. American Concrete Institute, Detroit, 1998.