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Estimation of Concrete Mixed Proportion and Concrete Compressive Strength Forecasting Employing the Simple and Multiple Linear Regression Models

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Abstract

This study aims to 1) develop simple linear regression (SLR),develop multiple linear regression (MLR) equations, and 3) to validate the SLR and MLR models. The developed equations are used to predict both the concrete mix proportions and the compressive strength of concrete at 7 and 28 days of curing. A total of 29 concrete samples collected from various construction projects in Khammouane Province, and nearby areas were used to develop regression models. The dataset included key parameters such as compressive strength, maximum size of coarse aggregate, fineness modulus of sand, bulk specific gravity (SSD) of aggregates, water absorption of sand and aggregate, unit weight of coarse aggregate, entrapped air content, water content, cement content, water–cement ratio, slump value, and weights of the coarse and fine aggregates. These parameters were used to establish correlation equations for predicting concrete mix proportions and compressive strength. In addition, the properties of locally available materials were applied to verify the developed equations through laboratory retrial mixtures. The materials included mountain rock aggregate from Nakai Khia village and Mekong River sand supplied by Nonthakon Company in Thakhek District, Khammouane Province. Key aggregate properties such as specific gravity, water absorption, unit weight of coarse aggregate, and fineness modulus of sand were incorporated in the prediction process.

The results indicate that the regression equations developed using SLR and MLR show high reliability and good predictive accuracy. These equations can effectively estimate concrete mixed proportions and compressive strengths at 7 and 28 days. Furthermore, laboratory retrial concrete mixtures showed good agreement with the predicted 28-day compressive strength, confirming the applicability of the developed models for practical concrete mix design and strength prediction.

Keywords: *Fine and Coarse Aggregate Properties, Concrete Mixture Proportion, Concrete Compressive Strength, SLR, MLR*

1. Introduction

Nowadays, infrastructure work is an important task for the economic growth and development of the country's infrastructure. Whether it is a developing or developed country, it is considered a key task in the development of the country's infrastructure, such as the construction of roads, buildings, dams, airports, etc. All construction projects place great importance on construction materials, the design of construction material mixtures, the quality control of construction materials, all the way to the properties of the materials and the properties of the designed mixtures, including approval for use in the construction of the project. In particular, work related to concrete requires consideration of many factors, such as the properties of the materials, stone or aggregate, sand, cement, and sometimes additional additives.

In early, many researchers have presented the equation for estimating compressive strength of concrete containing fly ash from ages 3 days up to 1 year (*Nipatsat & Tangtermsirikul, 2000*), the regression equation for predicting compressive strength of in-situ concrete at 7 and 28 days of curing (*Namyong et al., 2004*), the new mathematical models of non-linear regression equation (*Zain et al., 2008*), a multiple regression model to predict the compressive strength of high-performance concrete at various ages and curing conditions including 3, 7, 14, 28, and 91 days of curing (*Sain and Abd 2009*), using the tabular data and graphs in the code to design the mixture ingredients of structural lightweight concrete is complicated because it requires scanning through many data points, instead of working with the variables in the equations proposed by *Abdullahi et al. (2009)*, ANN modeling for predicting compressive strength of structure light weight concrete *(Alshihri et al., 2009)*, mathematical and mechanical models to predict the concrete compressive strength affected by different matrix mixtures at a fixed age or at various ages of 1, 3, 7, 28, 56, 90, and 180 days (*Sayed-Ahmed, 2012*). Last decade, *Abd Elaty (2014)* presented two constant effects of a rate of strength gain constant and grade of strength constant on the compressive strength predictions of concrete mixes at any age, which were influenced by the mineral admixtures as a partial replacement of cement, metakaolin, nano silica fume, curing in water or lime, and the effect of curing temperature. Next, two-stage approaches of linear models, which are developing quadratic models by identifying the suitable combinations of the four variables: water-binder ratio, fine aggregate-binder ratio, coarse aggregate-binder ratio, and binder content, and selecting the best minimal subset of the predictors in full models of concrete compressive strength using Mallow's Cp statistic, is the second step *(Aggarwal et al., 2015)*. Then, *Moutassem & Chidiac (2016)* examined the theoretical and phenomenological models used to predict the compressive strength of concrete at 28 days and at various ages using experimental data reported in the literature. Afterward, *Dutta et al. (2018)* proposed the application of machine learning techniques and regression models (i.e., Gaussian Process for Regression, Multi-Adaptive Regression Spline, and Minimax Probability Machine Regression) to forecast the concrete compressive strength and perform an impact analysis of the input datasets on the output model.

In recent years, various researchers have applied statistical and soft computing techniques to predict concrete mix proportions and compressive strength. Gupta & Sihag (2022) employed four soft computing techniques-Gaussian Process, M5P model, Random Forest, and Random Tree-to develop models for estimating appropriate concrete mix proportions and compressive strength based on six input parameters: cement, sand, coarse aggregate, water, curing period, and fineness modulus. Similarly, Chansavang et al. (2023), Kumar et al. (2023), Almahameed & Sobuz (2023), Altuncı (2024), Parmo & Wardhana (2024) applied simple and multiple linear regression models (SLR and MLR) to establish correlation equations between experimental and predicted values of CBR using the index properties of GC soil. In addition, several advanced machine learning techniques have been used to predict concrete compressive strength containing different proportions of fly ash, silica fume, and other mineral admixtures. These techniques include Deep Neural Networks (DNN), Multivariate Adaptive Regression Splines (MARS), Extreme Learning Machine

(ELM), Random Forest (RF), Bagging Algorithm, Artificial Neural Networks (ANN), Gradient Boosting Regression (GBR), Multiple Linear Regression (MLR), Decision Tree (DT), Support Vector Regression (SVR), Adaptive Neuro-Fuzzy Inference Systems (ANFIS), and Gaussian Process Regression (GPR).

This study employed simple and multiple linear regression models (SLR and MLR) to develop prediction equations for forecasting the concrete mix of proportions and compressive strengths of 10 to 40 MPa. Furthermore, this research also applied all prediction equations obtained from SLR and MLR models to estimate the new concrete mixture ratios and to compare the concrete compressive strength between the laboratory and predicted values. The concrete mix proportions (i.e., cement, water, fine, and coarse aggregate quantities) and concrete compressive strength at 7 and 28 days of curing depend on the properties of fine and coarse aggregates, such as sieve analysis of fine and coarse aggregates, specific gravity of fine and coarse aggregates, and unit weight of coarse aggregate.

2. Material and Methods

For the properties of sand used in construction, these properties are usually considered, such as particle size, and specific gravity and water absorption percentage. These properties are key factors that must be studied or tested before being used in project work to ensure that the properties of the sand material are appropriate and meet the standards of construction material control. Currently, some construction projects use crushed stone powder as a replacement for sand material in concrete mixtures.

2.1 Sample Collection

The study of the Estimation of Concrete Mixture Proportion and Concrete Compressive Strength Forecasting Employing the Application of Simple and Multiple Linear Regression Models is a statistical study that will collect data on concrete mixtures in the past of construction projects in Khammouane province and construction projects in the surrounding areas of the province from 2013 to the present (data sources will be collected and compiled from educational institutions, relevant departments, construction companies and related business units). The total data of concrete mixtures employed in this study has 29 input and output datasets.

2.2 Identification of Fine Aggregate Sample (Sand)

The properties of sand employed to develop simple and multiple regression analysis models consist of Finess modulus (FM value), which obtained from the sieve analysis testing by using the AASHTO T27 standard method of test, ranging from 1.79 to 3.15, and bulk specific gravity and absorption percentage properties in the state of saturated surface dry (SSD) derived from the AASHTO T84 standard method of test range from 2.49 to 2.72 and in the range of 1.33 to 2.79, respectively.

2.3 Identification of Coarse Aggregate Sample (Crushed rock)

Table 1. Coarse aggregate properties used in SLR and MLR models

Item	Ranges		Mean	Unit
	Min	Max		
Maximum size	12.5	37.5	23.2	mm
Unit weight	1.43	1.78	1.5	g/cm^3
Specific gravity	2.55	2.74	2.7	-
Water absorption	0.14	1.50	0.7	%

Coarse aggregate properties obtained from the concrete mix design that were collected from different resources, such as grain size, unit weight, specific gravity, and water absorption percentage, by following the testing methods of AASHTO T27, AASHTO T19, and AASHTO T85, respectively, are summarized in Table 1.

2.4 Identification of Concrete Mixture Proportion

Sub-components used in concrete mix design, such as the concrete compressive strength (MPa), slump test (cm), and volume of entrapped air (%), were collected from 29 different resources and utilized to create the correlation equation for simple and multiple regression analysis models (SLR and MLR models), are summarized in Table 2. Additionally, the concrete mixture proportion selected from 29 different resources, consisting of the quantities of cement, coarse aggregate, fine aggregate, and water that were employed to develop a correlation equation for both simple and multiple regression analysis models (SLR and MLR models), is presented in Table 3.

Table 2. Sub-components used in SLR and MLR models

Item	Ranges		Mean	Unit
	Min	Max		
Concrete compressive strength at 7 days	8.6	35.1	22.97	MPa
Concrete compressive strength at 28 days	12.6	44.8	24.3	30.1
Concrete slump test	5	11	8.8	cm
Volume of entrapped air	1	2.5	1.8	%

Table 3. Concrete mixture proportion used in SLR and MLR models

Item	Ranges		Mean	Unit
	Min	Max		
Quantity of cement	200	500	347.5	Kg/m^3
Quantity of coarse aggregate	977	1241.5	1090.7	Kg/m^3
Quantity of fine aggregate	560	940	741.6	Kg/m^3
Quantity of water	136	220	182.3	Kg/m^3

2.5 Linear Regression Model

The relationship between concrete compressive strength and the properties of fine and coarse aggregates, mix design sub-components, and mix design proportions is analyzed using regression models with the highest possible correlation coefficient (R^2). The R^2 value is then employed in simple or multiple linear regression analyses to assess the goodness of fit, which is deemed satisfactory when $R^2 \geq 0.70$ (Pellinen, 2001) as shown in Table 4.

Table 4. Criteria goodness-of-fit statistical parameters (Pellinen 2001)

Criteria	Coefficient of determination (R^2)
Excellent	≥ 0.90
Good	0.70 – 0.89
Fair	0.40 – 0.69
Poor	0.20 – 0.39
Very poor	≤ 0.19

Simple linear regression analysis is a type of regression analysis that involves one independent variable and one dependent variable, both of which are related linearly. This form of analysis is the simplest form of regression analysis, with the following regression models:

$$y = a + bX + e$$

Where: y is dependent variable

a and b are the constants of the regression equation

X is the independent variable

e is the error value

Regression model is a statistical method used to study the relationship between an independent variable and a dependent variable. If the relationship between more than one independent variable and one dependent variable is studied, it is called multiple linear regression model.

$y = b_0 + b_1X_1 + b_2X_2 + \ldots, + b_kX_k + e$

Where: y is dependent variable

b_0 is a constant value of the regression equation

b_i is the regression coefficient of each independent variable

X_i is the value of each independent variable

k is the number of independent variables in the regression equation

e is the error value

The list of symbols utilizes to develop SLR and MLR models is summarized in Table 5.

Table 5. List of symbols

y_1 = Amount of cement	*SLR* = Simple Linear Regression
y_2 = Water-Cement ratio	*MLR* = Multiple Linear Regression
y_3 = Volume of entrapped air	f_c = Design concrete compressive strength
y_4 and y_5 = Prediction equations of concrete compressive strength at 7 days for SLR	R^2 = Coefficients of determination
y_6 and y_7 = Prediction equations of concrete compressive strength at 28 days for SLR	y_8 and y_9 = Coarse aggregate or crushed stone and fine aggregate quantities
A = Slump test value	B or y_3 = Volume of entrapped air
C = Maximum size of coarse aggregate	D = Unit Weight of coarse aggregate
E = Water absorption of fine aggregate	F = Water absorption of coarse aggregate
G = Bulk specific gravity of coarse aggregate	H = Bulk specific gravity of sand
y_9 = Volume of fine aggregate	y_8 = Volume of coarse aggregate
W = Volume of water	M = Finess modulus of fine aggregate

2.6 Simple Linear Regression (SLR) Model

The simple linear regression models in this study comprise seven models that establish correlations between: (i) design concrete compressive strength and cement content, (ii) design concrete compressive strength and water–cement ratio, (iii) volume of entrapped air and slump value, (iv) experimental concrete compressive strength at 7 days and cement content, (v) experimental concrete compressive strength at 7 days and water–cement ratio, (vi) experimental concrete compressive strength at 28 days and cement content, and (vii) experimental concrete compressive strength at 28 days and water–cement ratio.

2.7 Multiple Linear Regression (MLR) Model

The multiple linear regression models were used to estimate the proportion of concrete mix design (amounts of fine and coarse aggregates) and the concrete's compressive strength. The prediction of the quantities of fine and coarse aggregates in the concrete includes water volume, volume of entrapped air, maximum size of coarse aggregate, bulk specific gravity of both fine and coarse aggregates, water absorption of both types of aggregates, unit weight of coarse aggregate, finesse modulus of fine aggregate, and cement content. The concrete compressive strength forecasting at 7 and 28 days utilized these parameters are function, such as concrete slump test, volume of entrapped air, coarse aggregate maximum size, bulk specific gravity of fine and coarse aggregates, water absorption of fine and coarse aggregates, unit weight of coarse aggregate, contents of fine and coarse aggregates, and contents of water and cement.

3. Results

The results in this section present the concrete mix design proportions and the forecasting of concrete compressive strength using simple and multiple linear regression models, as illustrated in Subsections 3.1 and 3.2.

3.1 Results of SLR Models

This section develops the SLR models to estimate the mixed proportions and predict the compressive strength of concrete using simple linear regression models. Those evaluation models of mix proportions are equations (1), (2), and (3), and those forecasting models of concrete compressive strength at 7 and 28 days of curing are equations (4), (5), (6), and (7), respectively. The equations (1) through (3) are utilized to estimate the amount of cement (y_1), water-cement ratio (y_2 or W/C), and volume of entrapped air (y_3 or B), respectively. The correlation criterion of determination coefficient (R^2) achieved from the SLR models has fair to good correlation, which ranges from 0.457 to 0.863. The prediction equations and coefficients of determination for the SLR models are represented as follows.

$y_1 = 7.8263 \times f_{c,\,design} + 167.78,\ R^2 = 0.822$ (1)

y_2 or $W/C = -0.0014 \times y_1 + 1.0261,\ R^2 = 0.709$ (2)

y_3 or $B = -0.066 \times A + 3.2895,\ R^2 = 0.863$ (3)

$y_{4\ \text{at 7 days}} = 0.0859 \times y_1 - 5.5542,\ R^2 = 0.603$ (4)

$y_{5\ \text{at 7 days}} = -45.325 \times y_2 + 48.892,\ R^2 = 0.457$ (5)

$y_{6\ \text{at 28 days}} = 0.1088 \times y_1 - 7.6912,\ R^2 = 0.716$ (6)

$y_{7\ \text{at 28 days}} = -60.684 \times y_2 + 63.07,\ R^2 = 0.606$ (7)

3.2 Results of MLR Models

The MLR models of y_8 and y_9 are developed to evaluate the coarse aggregate or crushed stone and fine aggregate or sand quantities, respectively. For the MLR model of y_{10}, it is created to estimate the concrete compressive strength at 28 days of curing. According to the findings, all models have a good correlation of determination coefficient to excellent, which value of R^2 equals 0.713, 0.737, and 0.905.

$y_8 = 1412.4 - 1.369 \times W - 294.31 \times B - 13.96 \times C - 37.574 \times G + 2.722 \times F + 567.33 \times D, R^2 = 0.713$ (8)

$y_9 = -1217.157 + 57.2 \times B - 0.967 \times W - 0.67 \times y_8 + 150.04 \times F + 97.42 \times E + 9.22 \times M + 1002.01 \times H - 0.36 \times y_1, R^2 = 0.737$ (9)

$y_{10} = -34.25 + 0.436 \times A + 10.974 \times B + 0.556 \times C + 22.71 \times D + 4.682 \times E + 3.914 \times F - 64.932 \times G + 50.54 \times H - 0.008 \times y_9 + 0.0002 \times y_8 - 0.044 \times W + 0.112 \times y_1, R^2 = 0.905$ (10)

3.3 Validations of SLR and MLR Models

The results will be analyzed to present the influence of material properties on the mixture and compressive strength of concrete, and to create simple and multivariate relationship equations for use in predicting the proportion of concrete mixtures and concrete compressive strength, ensuring the accuracy and reliability of the equation.

3.3.1 Sand and Crushed Rock Samples

This study, therefore, remixed the concrete obtained from the prediction equation using the general properties of the mountain rock of Nakai Khia village and the Mekong River sand of Nonthakon Company, Thakhek District, Khammouane Province, with the following research procedures and methods.

3.3.2 Properties of Sand and Crushed Rock Sample

Based on the experimental results for fine aggregate, the fineness modulus, bulk specific gravity, and water absorption are 2.63, 2.62, and 1.29%, respectively. For the coarse aggregate, the maximum size, bulk specific gravity, water absorption, and unit weight are 19 mm, 2.76, 1.69%, and 1.628 g/cm^3, respectively.

3.3.3 Predicting of the Concrete Mix Proportions

The design concrete compressive strength used to predict the concrete mixing ratio in this study is 30 MPa, and the safety design, with an additional 15% of 30 MPa, is 34.5 MPa. Therefore, this study uses a value of 34.5 MPa for all calculations or predictions. The concrete mix proportions for 1 m^3 and 6-cylinder molds are summarized in **Tables 6 and 7** (Appendix A), respectively.

3.3.4 Re-Mix of Concrete

This section presents a re-mixing experiment conducted to assess the accuracy and reliability of the equations used to estimate concrete mix proportions and compressive strength at 7 and 28 days, derived from the SLR and MLR models. The concrete mix proportions for six cylindrical molds in this study are shown in Table 7. The quantities of cement, water, coarse aggregate, and fine aggregate were 10.95, 4.53, 28.13, and 20.98 kg, respectively.

The general procedures for concrete testing are illustrated in **Figures 2–4** (Appendix B). First, the fine and coarse aggregates were prepared in the saturated surface-dry (SSD) conditions by soaking them in water for 16–18 hours. Second, the concrete materials were mixed according to the specified mix proportions. Third, the workability of fresh concrete was evaluated using a slump test. Fourth, concrete specimens were cast in cylindrical molds and compacted. Finally, the concrete samples were cured for the required curing periods. The workability of fresh concrete was measured using the slump test in accordance with ASTM C143. The measured slump value was 8.5 cm, as shown in **Figure 3** (Appendix B).

3.3.5 Experimental Results of Concrete Compressive Strength

The experimental results of concrete compressive strength in this study are based on six samples. Three samples were tested after 7 days of curing, while the remaining three were tested after 28 days, as shown in Tables 8 and 9 (Appendix A).

The concrete compressive strength at 7 days equals 36.2 MPa, and when calculated as a percentage, it equals 109 %. It means that the strength of concrete at 7 days of curing is greater than or equal to 75% of the standard, which is 34%. The average concrete compressive strength at 28 days equals 41.9 MPa, and when calculated as a percentage, it equals 121%. It means that the strength of concrete at 28 days of curing is greater than or equal to 100% of the standard, which is 21%.

3.3.6 Comparisons

The comparison between the experimental and forecasting values in this section consists of two types of prediction comparisons: SLR and MLR results. Comparison of concrete compressive strength between the findings obtained from equations (5) and (7), developed using SLR models, and the remix concrete experimental results. Based on the equations predicting results of concrete compressive strength at 7 days of curing, and experimental value equal 32.1, 30.3, and 36.2 MPa, respectively. The comparison results show that the laboratory concrete's compressive strength exceeds the predicted and design values (34.5 MPa), which are 4.1 MPa (5), 5.9 MPa (7), and 1.7 MPa, respectively. When expressed as a percentage, the results are 105%, 113%, and 118%. The forecasting findings for concrete compressive strength at 28 days, utilizing equations (6) and (8), and experimental values are 39.96, 38.19, and 41.9 MPa, respectively. When represented as a percentage, the results are 105%, 110%, and 121%. The MLR concrete compressive strength comparison between the results derived from formula (16), the design value, and the experimental study is 39.1, 34.5, and 41.9 MPa, respectively. As a result, it can be seen that the experimental result is larger than both the formula and design values, which are 2.8 and 7.4 MPa.

4. Discussion

According to the goodness-of-fit statistical criteria proposed by Pellinen (2001), the results of the simple linear regression (SLR) models show that several key parameters have significant relationships with concrete mix proportions and compressive strength. The coefficient of determination (R^2) values range from 0.457 to 0.863, indicating fair to good correlations between the variables. Similar interpretations of R^2 values and their implications for model reliability have been widely discussed by Montgomery (2012) and Kutner et al. (2005).

Among the SLR models, Equation (3), which estimates the volume of entrapped air, exhibits the highest correlation (R^2 = 0.863), suggesting that the maximum aggregate size strongly influences air content in the concrete mixture. This observation is consistent with findings reported by the American Concrete Institute (ACI 211.1), which state that aggregate size significantly affects air-void distribution and workability. Equation (1) also demonstrates a strong relationship (R^2 = 0.822) between cement content and design compressive strength, indicating that higher cement content generally leads to increased concrete strength, as supported by classical studies such as Abrams (1918) and further discussed by Neville (2011).

However, Equations (4) and (5), which predict the 7-day compressive strength, show relatively lower correlations (R^2 = 0.603 and 0.457), suggesting that early-age strength may be influenced by additional factors such as curing conditions, temperature, and admixtures, as highlighted by ASTM International (ASTM C39/C39M) and Mindess et al. (2003).

The multiple linear regression (MLR) models show improved predictive performance compared with the SLR models. The R^2 values for Equations (8), (9), and (10) are 0.713, 0.737, and 0.905, respectively. In particular, Equation (10), used to predict 28-day compressive strength, exhibits an excellent correlation (R^2 = 0.905), indicating that the combined influence of material properties and mixture proportions significantly improves prediction accuracy. This result highlights the advantage of MLR models in representing the complex interactions among concrete components, which is consistent with previous studies by Yeh (1998) and Chou & Pham (2014).

The validation experiment using locally available materials—Mekong River sand and mountain rock aggregate—demonstrated that the predicted mix proportions produced concrete with satisfactory workability and strength. The slump value of 8.5 cm indicates good workability for practical construction applications, in agreement with recommendations from American Concrete Institute (ACI 211.1).

The experimental compressive strengths were 36.2 MPa at 7 days and 41.9 MPa at 28 days, which exceeded the design strength of 34.5 MPa. The experimental results were also higher than the predicted values from both SLR and MLR models, indicating that the developed equations provide conservative and reliable predictions.

Overall, the comparisons confirm that the regression models, particularly the MLR model, can effectively estimate concrete mix proportions and compressive strength, making them useful tools for practical concrete mix design and quality control, as also emphasized in standard concrete technology literature (e.g., Neville, 2011).

5. Conclusions

This study proposed prediction equations for concrete mix design proportions and concrete compressive strength at 7 and 28 days of curing using simple linear regression (SLR) and multiple linear regression (MLR) models. In addition, comparisons between the experimental results, predicted values, and design values were conducted using coarse aggregate from Nakai Khia village and Mekong River sand supplied by Nonthakon Company, Thakhek District, Khammouane Province. The main findings of this study can be summarized as follows:

- The prediction equations developed from the SLR and MLR models show good reliability and accuracy. The coefficients of determination (R^2) indicate correlation levels ranging from fair to excellent, demonstrating that the regression models can effectively represent the relationships between concrete mix parameters and compressive strength.
- The developed equations can be applied to estimate concrete mix proportions and compressive strength at 7 and 28 days of curing for normal-strength concrete within the range of 10–40 MPa, providing a practical reference for concrete mix design in engineering applications.
- The comparison between experimental results and predicted values indicates that the compressive strength obtained from laboratory testing is generally higher than the predicted values, suggesting that the

developed models provide conservative and reliable predictions.

▪ A limitation of this study is that the developed equations apply only to conventional concrete mixtures without chemical or mineral admixtures. Therefore, they cannot be directly used for concrete mixes requiring additives.

▪ Future research should include a larger dataset of concrete mix designs and consider applying advanced statistical or machine learning techniques to further improve the accuracy and applicability of prediction models for concrete mix proportions and compressive strength.

6. Conflicts of Interest

We certify that there is no conflict of interest with any financial organization regarding the material discussed in the manuscript.

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Appendix A

Table 6. Concrete mix proportions for 1 m^3

Mixing ratio 1 m^3	Weight	Unit
Cement	438	Kg/m^3
Water	181	Kg/m^3
Coarse aggregate	1125	Kg/m^3
Fine aggregate	839	Kg/m^3
Total	2583	Kg/m^3

Table 7. Concrete mix proportion for 6-cylinder molds

Mixing ratio for 6-cylinder molds	Weight	Unit
(Cement×25)/1000	10.95	Kg
(Water×25)/1000	4.53	Kg
(Coarse aggregate×25)/1000	28.13	Kg
(Fine aggregate×25)/1000	20.98	Kg

Table 8. Concrete compressive strength at 7 days

No.	Weight of Sample (g)	Axial Capacity (kN)	Unit Weight (Kg/m^3)	Compressive Strength (MPa)
1	13,409	630.26	2,530	35.68
2	13,294	650.88	2,510	36.85
3	13,260	635.34	2,500	35.97
Average value				36.2 MPa

Table 9. Concrete compressive strength at 28 days

No.	Weight of Sample (g)	Axial Capacity (kN)	Unit Weight (Kg/m^3)	Compressive Strength (MPa)
1	13,405	745.7	2,530	42.20
2	13,351	742.7	2,520	42.03
3	13,360	730.7	2,520	41.36
Average value				41.9 MPa

Appendix B

(a) (b)

Figure 1. (a) Mekong River sand of Nonthakon Company, (b) mountain rock of Nakai Khia village Thakhek District, Khammouane Province

(a) (b)

Figure 2. (a) Preparing materials and (b) mixing concrete

Figure 3. Testing the workability of fresh concrete

(a) (b)

Figure 4. (a) Taking samples and (b) curing concrete samples