

# Statistical Study of the Physical-Mechanical Properties of Ordinary Concrete Manufactured in Congo-Brazzaville

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## Abstract

This research work is an extension of the study carried out on the physico-mechanical characterisation of aggregates used in the manufacture of standard concretes. The aim is to test the relevance and impact of the properties resulting from this characterisation in relation to the quality of the concretes formulated, using statistical normality tests. This research work reports on the statistical analyses of the physico-mechanical properties of concretes formulated using the Dreux-Gorisse method. The study is based on the development of eight (8) formulations of concrete obtained from different materials taken from the localities of Brazzaville and Pointe-Noire. To do this, in order to develop an optimal concrete formulation approach taking into account its microstructural and compactness matrix, a good granular distribution was considered using two types of sand (rolled and crushed) for the correction of rolled type sands with the variable proportions (from 30% to 50%) of crushed sands. Eight (8) formulations of the concretes were studied according to the Dreux-Gorisse method, and only six (6) formulations gave the expected results. This statistical study is part of the context of understanding the crucial parameters, the distribution of values and the variabilities of the measured properties, in particular the average, which provides an overview of the central value for each property and allows the data to be summarized into a representative indicator of the average performance of the concrete. As a result, the results suggest that the resistances of the two groups of results (7 days and 28 days of age) are significantly different, so the null hypothesis is rejected. In other words, the differences observed between the means of resistance at 7 days of age (20.40 MPa) and at 28 days of age (27.80 MPa) could not be due to

chance, which corresponds well to a C25/30 concrete. Thus, two tests were performed: the Shapiro-Wilk test and the Wilcoxon test. The first, just as specific, made it possible to know if the data collected followed the normal distribution, while the second, which is a non-parametric test, made it possible to test the data when they do not follow the normal distribution. For this, the use of Q-Q plots was essential and made it possible to visualize normality. On the six properties of concrete, namely strength, theoretical density, real density, gravel/sand ratio, subsidence and water/cement ratio, the Shapiro-Wilk test made it possible to verify and highlight the normality of the distributions. Indeed, only four properties whose data showed a normal distribution, thus justifying the use of parametric tests. However, two of them (subsidence and gravel/sand ratio) whose data did not follow a normal distribution, which motivated the use of nonparametric tests more appropriately.

### Keywords

Concrete, Parameters, Resistance, Statistical Studies, Tests, Variable, p-Value

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## 1. Introduction

The use of concrete as a building material for many diverse infrastructure projects requires great interest. Indeed, it remains one of the most widely used materials in civil engineering. Whether it is industrial construction, bridges and other types of engineering structures or real estate projects, concrete remains an essential material.

However, with the exception of cement, which is used as a hydraulic binder in its manufacture, the quality of the latter depends largely on the intrinsic characteristics of the aggregates used. It is therefore necessary to make a better choice of materials with the best physico-mechanical characteristics, such as grain size, the fine particle content of sands, the porosity of aggregates and many other significant parameters. Knowledge of the physico-mechanical characteristics of the various constituent elements (aggregates) of concrete is therefore of particular importance with regard to the specific requirements and standards on concrete quality [1].

However, the Brazzaville and Pointe-Noire sands sampled have distinct geological characteristics that are likely to affect the mechanical properties of the concrete. Consequently, understanding the differential performance of these materials over a 28-day curing period is essential to optimize the concrete formulations used in these regions and ensure the safety and durability of infrastructure. This study aims to authenticate valuable data for local engineering and to contribute to the development of construction practices better adapted to the specific conditions of the Republic of Congo [2].

The main objective of this study is to assess the normality of the results of the

physical-mechanical properties derived from characterisation and to test their consistency in relation to the physical-mechanical properties of concrete at 7 days and 28 days for samples taken in Brazzaville and Pointe-Noire, in the Republic of Congo. This comparative assessment is necessary to understand the evolution of concrete performance over time, which not only has a direct influence on the durability and reliability of the structures built, but also provides better guidance on the manufacture and quality of the concretes to be used.

All the data to be used in this study can be found in Annexes 1, 2, 3 and 4.

## 2. Materials and Methods

### 2.1. Presentation of Data

In order to test the specific influence in the cementitious matrix of hardened concrete, several laboratory tests were carried out on samples taken in Brazzaville and Pointe-Noire. In order to develop a variety of concrete formulations meeting rheological criteria (deformability, bleeding, segregation, etc.), and to develop an optimal concrete formulation approach taking into account its microstructural and compacting matrix, a good granular distribution was envisaged using two types of sand (rolled and crushed) with a view to correcting the rolled type sand with variable proportions (from 30% to 50%) of crushed sand [1]. The results obtained from the eight (8) concrete formulations studied, using the Dreux-Gorisse method, are summarized in Annex 3.

To optimize the different concrete formulations obtained, a statistical study was carried out using R software, a programming language used for data processing and statistical analysis of results.

### 2.2. Data Organization

Table 1 and Table 2 of the data structured by the R software, present the physical-mechanical properties of the concretes at 7 days and 28 days respectively. Each table includes essential variables such as slump, gravel/sand and water/cement ratios, the characteristic strength of the concretes, and the theoretical and actual densities of the concretes. This organization facilitates a comprehensive comparative analysis of concrete performance over time.

Table 1. Summary of 7-day concrete data.

Values									
Subsidence 1	Num [1:8]	6	6	7	6	7	9	9	6
Real density 1	Num [1:8]	2.38	2.37	2.42	2.41	2.25	2.22	2.37	2.36
Theoretical density 1	Num [1:8]	2.37	2.38	2.37	2.37	2.36	2.35	2.38	2.37
Water to cement ratio (w/c) 1	Num [1:8]	0.49	0.49	0.49	0.49	0.47	0.47	0.49	0.49
Gravel to sand ratio (G/S) 1	Num [1:8]	2.45	1.8	2.43	1.7	3.06	1.7	2.36	1.89
Resistance 1	Num [1:8]	27.8	20.5	23.9	18.1	16.5	12.60	21.50	22.10

**Table 2.** Summary of 28-day concrete data.

Values									
Subsidence 2	Num [1:8]	6	6	7	6	7	9	9	6
Real density 2	Num [1:8]	2.41	2.37	2.44	2.39	2.26	2.25	2.37	2.35
Theoretical density 2	Num [1:8]	2.37	2.38	2.37	2.37	2.36	2.35	2.38	2.37
Water to cement ratio (w/c) 2	Num [1:8]	0.49	0.49	0.49	0.49	0.47	0.47	0.49	0.49
Gravel to sand ratio (G/S) 2	Num [1:8]	2.45	1.8	2.43	1.7	3.06	1.7	2.36	1.89
Resistance 2	Num [1:8]	33.8	26.6	36.8	27.2	22.8	18.30	27.30	29.70

### 2.3. Descriptive Statistics

To analyze our two tables of data, we calculated key statistics: the mean, standard deviation and quartiles for each property. These parameters are crucial for understanding the distribution of values and the variability of the properties measured. The mean provides us with an overview of the central value for each property, allowing us to summarize the data into a representative indicator of the average performance of the concrete. The standard deviation (**sd**) measures the dispersion of the values around the mean, providing an idea of the consistency and reliability of the results: low values indicate greater uniformity, while high values suggest significant variability. Finally, quartiles (**p25**; **p50**; **p75**) allow the distribution of values to be assessed by dividing the data into equal segments, helping to identify gaps or concentrations of values, and to better understand the distribution of performance within each property. These parameters make it possible to explore the data and facilitate the identification of significant trends and the comparison of the stability and quality of concrete properties between the ages of 7 and 28 days [3].

#### 2.3.1. Resistance Statistics

**Table 3** presents the results of the different values of resistance at 7 and 28 days of age. The mean resistance at 7 days of age is 20.40 MPa while at 28 days of age it is equivalent to 27.80 MPa and the standard deviations (**sd**) are 4.65 and 5.81 respectively. The minimum values (**p0**) of the series are 12.60 and 18.30 respectively; the first quartiles (**p25**) are 17.70 and 25.70 respectively; the medians (**p50**) are 21.00 and 27.30 respectively; the third quartiles (**p75**) are 22.50 and 30.70 respectively; the maximum values (**p100**) of the series are 27.80 and 36.80 respectively. The statistical code can be found in Annex 5.

**Table 3.** Statistical summary of resistance at 7 and 28 days.

Age of concrete	The average	Standard deviation	The minimum	The maximum	The first quartile	The median	The third quartile	Coefficient of variation (C <sub>v</sub> )
Resistance after 7 days	20.40	4.65	12.60	27.80	17.70	21.00	22.50	0.23
Resistance after 28 days	27.80	5.81	18.30	36.80	25.70	27.30	30.70	0.21

### 2.3.2. Theoretical Density Statistics

**Table 4** shows the results for the various theoretical density values. The mean (mean) of the theoretical densities is 2.37 t/m<sup>3</sup> and the standard deviation (sd) is 0.00991. The minimum value of the series (p0) is 2.35; the first quartile (p25) is 2.35; the median (p50) is 2.37; the third quartile (p75) is 2.37 and the maximum value of the series (p100) is 2.38. The statistical code can be found in Annex 6.

**Table 4.** Summary of theoretical densities.

	The average	Standard deviation	The minimum value	The maximum value	The first quartile	The median	The third quartile	Coefficient of variation (Cv)
Theoretical Density	2.37	0.00991	2.35	2.38	2.37	2.37	2.37	0.0042

### 2.3.3. Real Density Statistics

**Table 5** presents the results of the different values of real densities at 7 and 28 days of age. The mean (mean) of the real densities at 7 days of age is 2.35 t/m<sup>3</sup> while at 28 days of age, it is equivalent to 2.36 t/m<sup>3</sup> and the standard deviations (sd) are 0.0729 and 0.0676 respectively. The minimum values (p0) of the series are 2.22 and 2.25 respectively; the first quartiles (p25) are 2.33; the medians (p50) are 2.37; the third quartiles (p75) are 2.39 and 2.40 respectively; the maximum values (p100) of the series are 2.42 and 2.44 respectively. The statistical code can be found in Annex 7.

**Table 5.** Statistical summary of actual densities.

Actual densities	The average	Standard deviation	The minimum value	The maximum value	The first quartile	The median	The third quartile	Coefficient of variation (Cv)
At 7 days old	2.35	0.0729	2.22	2.42	2.33	2.37	2.39	0.031
At 28 days old	2.36	0.0676	2.25	2.44	2.33	2.37	2.40	0.028

### 2.3.4. Water to Cement Ratio Statistics (W/C)

**Table 6** shows the results for the different water to cement ratios (W/C). The mean (mean) of the water to cement ratios is 0.485 and the standard deviation (sd) is 0.00926. The minimum value of the series (p0) is 0.47; the first quartile (p25) is 0.485; the median (p50) is 0.49; the third quartile (p75) is 0.49 and the maximum value of the series (p100) is 0.49. The statistical code can be found in Annex 8.

**Table 6.** Statistical summary of water to cement ratios (W/C).

	The average	Standard deviation	The minimum value	The maximum value	The first quartile	The median	The third quartile	Coefficient of variation (Cv)
Water to Cement ratios	0.485	0.00926	0.47	0.49	0.485	0.49	0.49	0.019

### 2.3.5. Gravel to Sand Ratios Statistics (G/S)

**Table 7** shows the results for the various gravel to sand (G/S) ratios. The mean

(mean) of the gravel to sand ratios is 2.17 and the standard deviation (sd) is 0.483. The minimum value of the series (p0) is 1.7; the first quartile (p25) is 1.78; the median (p50) is 2.12; the third quartile (p75) is 2.44 and the maximum value of the series (p100) is 3.06. The statistical code can be found in Annex 9.

**Table 7.** Statistical summary of Gravel to Sand ratios (G/S).

	The average	Standard deviation	The minimum value	The maximum value	The first quartile	The median	The third quartile	Coefficient of variation (Cv)
Gravel to Sand ratio	2.17	0.483	1.70	3.06	1.78	2.12	2.44	0.222

### 2.3.6. Subsidence Statistics

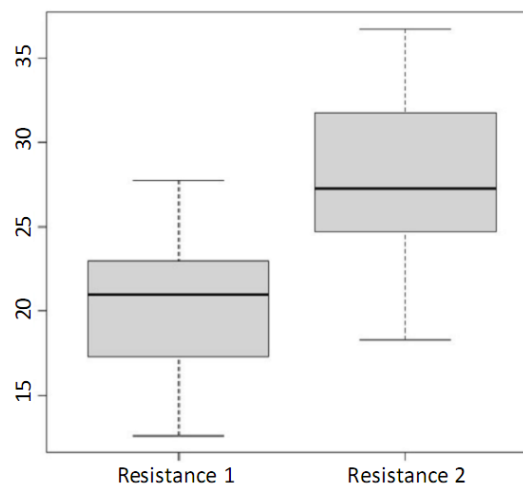
**Table 8** shows the results for the various subsidence values. The mean (mean) is 7 and the standard deviation (sd) is 1.31. The minimum value of the series (p0) is 6; the first quartile (p25) is 6; the median (p50) is 6.5; the third quartile (p75) is 7.5 and the maximum value of the series (p100) is 9. The statistical code can be found in Annex 10.

**Table 8.** Statistical summary of subsidence.

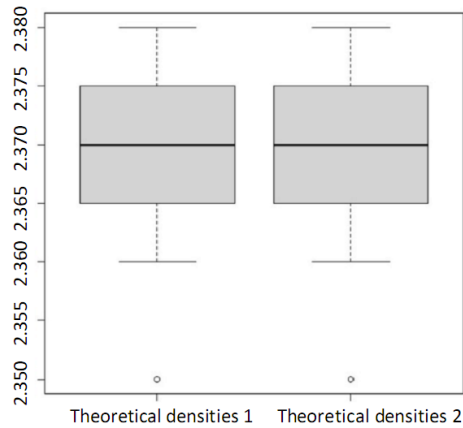
Consistency	The average	Standard deviation	The minimum value	The maximum value	The first quartile	The median	The third quartile	Coefficient of variation (Cv)
Subsidence	7.00	1.31	6.00	9.00	6.00	6.50	7.50	0.19

## 2.4. Visualising Data with Boxplots

Boxplots are schematic representations of the distribution of a variable [4]. In this section, we will visualize the data using boxplots (**Figures 1-6**) in order to compare the dispersion and centrality of properties, while identifying extreme values that could influence the analysis [5]. This step is crucial for understanding performance variability.

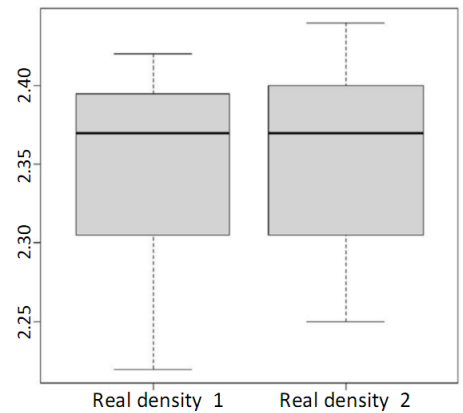


**Figure 1.** Comparison of the two resistance boxplots.

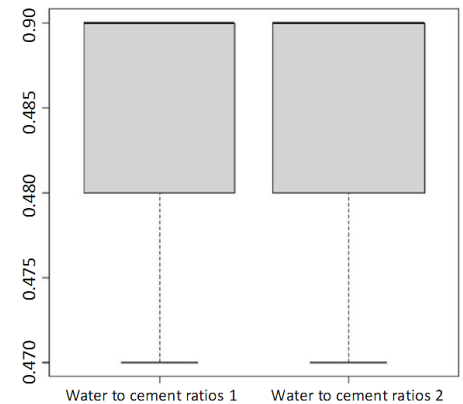


**Figure 2.** Comparison of the two theoretical densities of boxplots.

The whisker boxes corresponding to **Figure 1** (case of mechanical strengths), show a dispersion of properties. The statistical results obtained show that a positive trend in strength at 7 days (20.40 MPa) and 28 days (27.80 MPa) was observed for an expected strength of 25 to 30 MPa, which justifies the dispersion of the data. As for the whisker boxes corresponding to **Figure 2** (case of theoretical densities), an identical dispersion of the data was not observed, *i.e.*, a centrality of the properties.

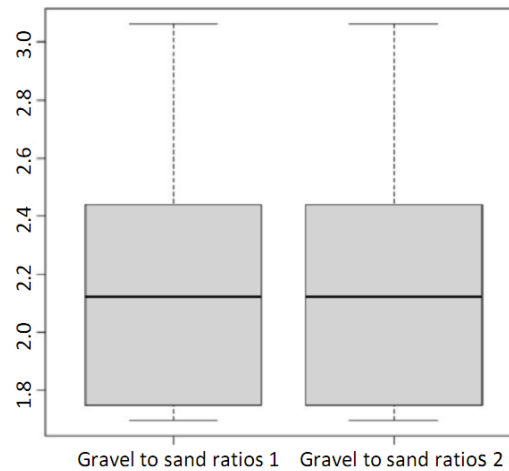


**Figure 3.** Comparison of the two real density boxplots.

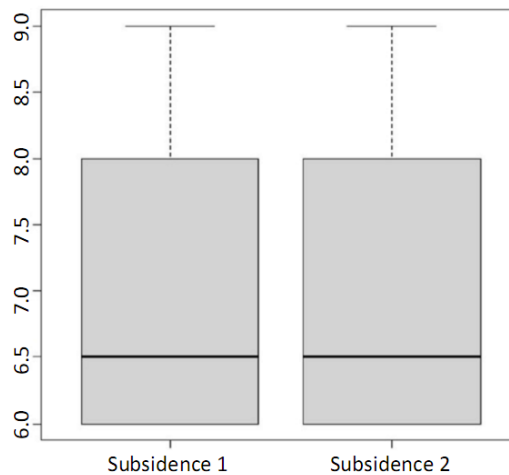


**Figure 4.** Comparison of two boxplots of water to cement ratios (W/C).

**Figure 3** shows the box plot corresponding to the actual density. This figure shows a slightly identical dispersion of the data at 7 days ( $2.35 \text{ t/m}^3$ ) and at 28 days ( $2.36 \text{ t/m}^3$ ). However, the differences can be seen in the extreme values, the first and third quartiles, which are different. These differences may influence the analysis of this parameter. As for **Figure 4**, a centrality of properties has been observed and the median, third quartile and maximum are confused.



**Figure 5.** Comparison of two boxplots of gravel to sand ratios (G/S).



**Figure 6.** Comparison of the two subsidence boxplots.

**Figure 5** and **Figure 6**, respectively, correspond to the gravel to sand (G/S) and subsidence ratios, showing the centrality of the properties. There is a constant variability of parameters in these cases.

## 2.5. Visualising Data with QQ-Plots

The use of QQ-plots is essential for determining whether a dataset follows a normal distribution [6]. The plots (**Figures 7-14**) show how well the data conforms to a theoretical distribution, usually normal. When the points represented on the

QQ-plots line up close to a straight line, this suggests that the data follows a normal distribution. On the other hand, if the points deviate significantly from this line, this indicates that the distribution of the data is different from normal.

This distinction is crucial when choosing the type of statistical test to use. If the QQ-plot shows an alignment of the points with the line, parametric tests based on the normality hypothesis can be reliably applied. On the other hand, when the QQ-plot reveals significant deviations, indicating that the data do not follow a normal distribution, it is preferable to use non-parametric tests [7]. Non-parametric tests are more robust and better suited to situations where the distribution of the data is skewed or has features that deviate from normality.

### 2.5.1. Choice and Application of Statistical Tests

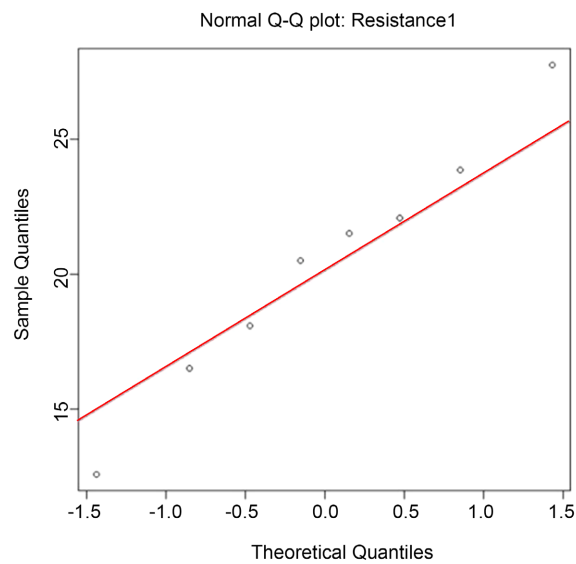


Figure 7. QQ-plot of characteristic strengths at 7 days of age.

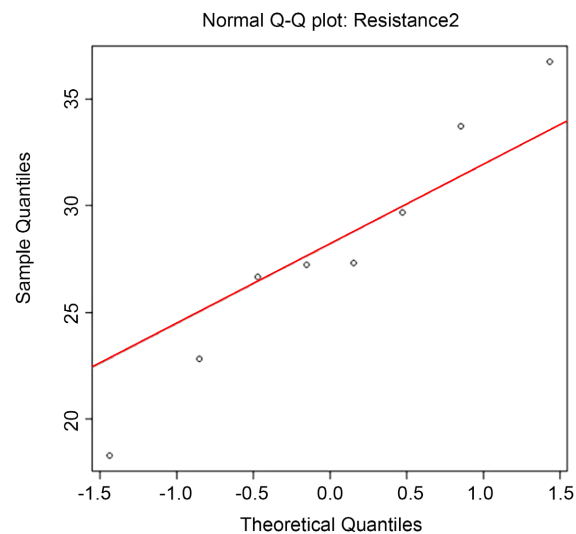
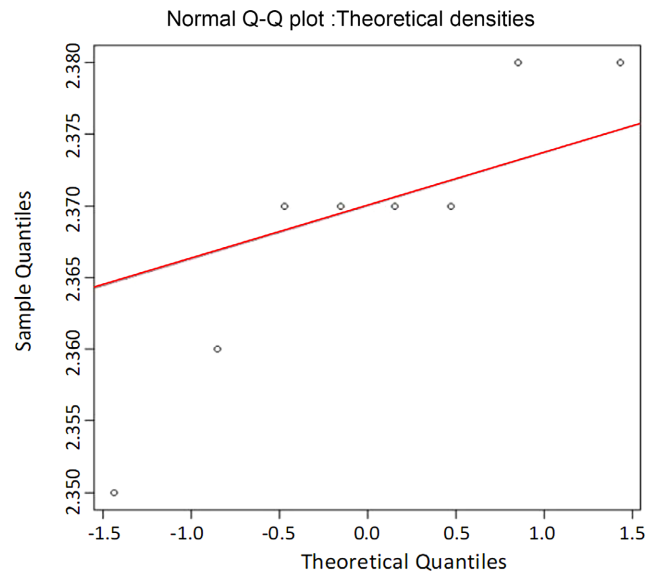
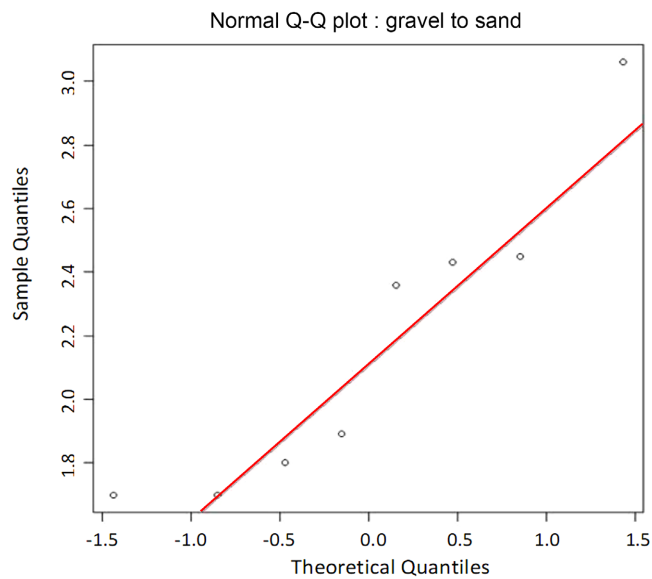


Figure 8. QQ-plot of characteristic strengths at 28 days of age.

**Figure 7** and **Figure 8** show an alignment of the points close to the straight lines. The points represented on the QQ-plots align close to the straight lines, which shows that the data appear to follow a normal distribution. Hence, parametric tests are applied to these types of data. The values of the coefficients of variation of the resistances (21% and 23%) are between 15% and 30%, then the data have a moderate dispersion.



**Figure 9.** QQ-plot of theoretical concrete densities.



**Figure 10.** QQ-plot of gravel to sand ratios (G/S).

**Figure 9** and **Figure 10** show an alignment of the points more or less close to the straight lines, with the majority of the points represented on the QQ-plots aligned close to the straight lines. A Shapiro-Wilk test is required to confirm the

normality of the data before parametric tests can be applied. In the case of theoretical densities, there is little dispersion in the data. As for the gravel to sand ratio, the dispersion is moderate.

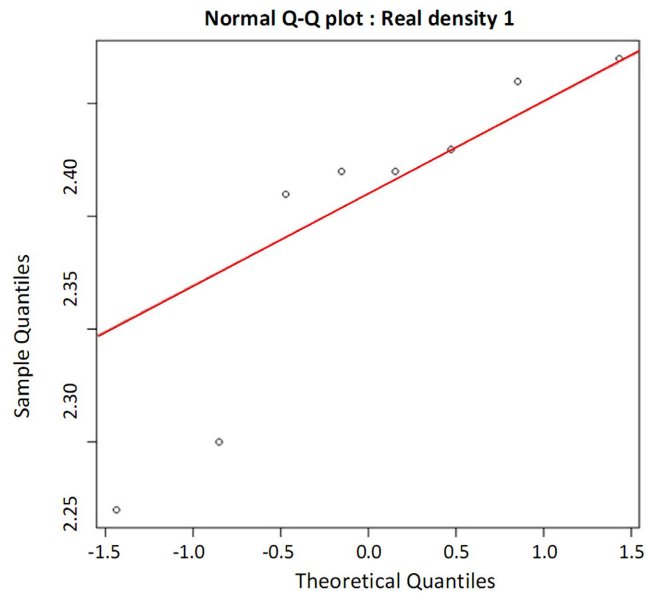


Figure 11. QQ-plot of real densities at 7 days of age.

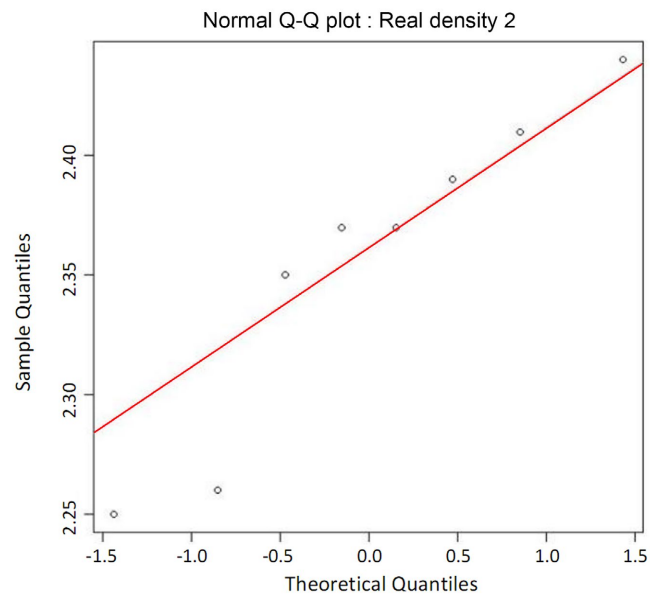
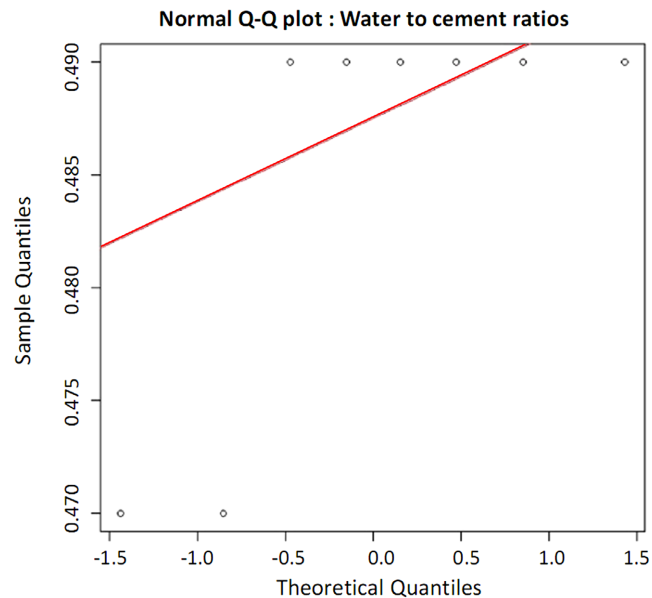
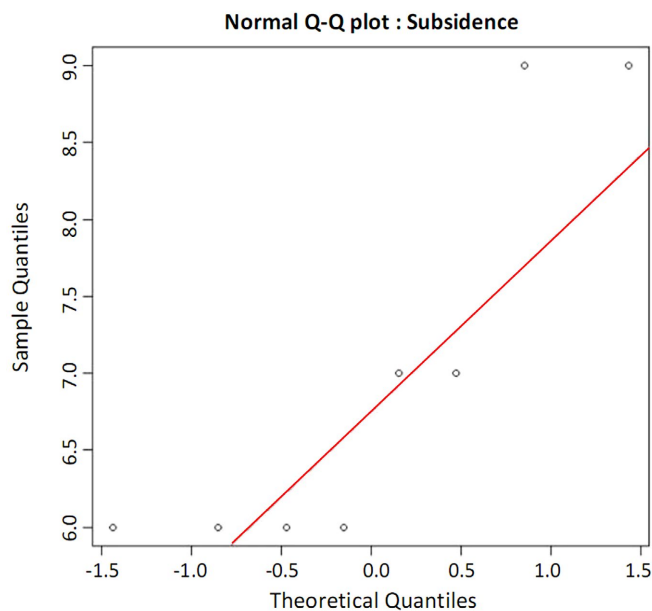


Figure 12. QQ-plot of real densities at 28 days of age.

Figure 11 and Figure 12 show an alignment of the points close to the straight lines. The points represented on the QQ-plots align close to the straight lines, which shows that the data appear to follow a normal distribution. Hence, parametric tests are applied to these types of data. There is little dispersion in the data for real densities, since their coefficient of variation is less than 15%.



**Figure 13.** QQ-plot of water to cement ratios (W/C).



**Figure 14.** QQ-plot of concrete subsidence.

**Figure 13** and **Figure 14** show the points moving away from the straight lines. The points represented on the QQ-plots do not align closely with the straight lines, which proves that the data do not follow a normal distribution. Hence, non-parametric tests are applied to these types of data. The data show a low dispersion for the water to cement ratio, while they show a moderate dispersion for subsidence.

### 2.5.2. Normality Test

In this section, we apply the Shapiro-Wilk test for each property (**Table 9**) to confirm whether or not the data follows a normal distribution. To do this, we will

apply the parametric tests when the data follows the normal distribution, otherwise, we will apply the non-parametric test. The statistical code can be found in Annex 11.

**Table 9.** Statistical summary of tests of Shapiro Wilk.

Parameters	Ages	p-value		Type of test
Résistance	7 days old	0.9967	≥5%	Parametrical
	28 days old	0.9229		
Theoretical density		0.156	≥5%	Parametrical
Real density	7 days old	0.05331	≥5%	Parametrical
	28 days old	0.2708		
Gravel to sand ratio (G/S)		0.1816	≥5%	Parametrical
Water to cement ratio (W/C)		6.323 e−05	≤5%	Non Parametrical
Subsidence		0.007732	≤5%	Non Parametrical

### Hypotheses

#### ✚ Case of characteristic concrete strengths at 7 and 28 days of age

In this section, we develop two hypotheses **H0** against **H1** at the risk threshold  $\alpha = 5\%$ . The Shapiro test reveals that the two samples follow a normal distribution and we assume that they are independent.

**Null hypothesis (H0):** There is no significant difference between the strengths at 7 days of age and 28 days old at the  $\alpha$  risk threshold.

**Alternative hypothesis (H1):** There is a significant difference between the strengths at 7 days and 28 days old.

#### ✚ Case of theoretical concrete densities

Here, we develop two hypotheses **H0** against **H1** at the risk threshold  $\alpha = 5\%$ . The Shapiro test reveals that both samples follow a normal distribution, but both samples have the same standard deviation.

**Null hypothesis (H0):** There is no significant difference between the theoretical densities at 7 days and 28 days old at the  $\alpha$  risk threshold.

**Alternative hypothesis (H1):** There is a significant difference between the theoretical densities at 7 days and 28 days old.

#### ✚ The case of real concrete densities

Here, we develop two hypotheses **H0** against **H1** at the  $\alpha$  risk threshold. The Shapiro test reveals that the two samples follow a normal distribution, but the two samples do not have the same standard deviation.

**Null hypothesis (H0):** There is no significant difference between the real densities at 7 days and 28 days old at the  $\alpha = 5\%$  risk threshold.

**Alternative hypothesis (H1):** There is a significant difference between the actual densities at 7 days and 28 days old.

#### ✚ Case of gravel/sand ratios

Here, we develop two hypotheses **H0** against **H1** at the  $\alpha = 5\%$  risk threshold. The Shapiro test reveals that both samples follow a normal distribution and both samples have the same standard deviation of 0.483.

**Null hypothesis (H0):** There is no significant difference between the gravel/sand ratios of the concrete at 7 days and 28 days at the  $\alpha$  risk threshold.

**Alternative hypothesis (H1):** There is a significant difference between the gravel/sand ratios of the concrete at 7 days and 28 days.

### 3. Results, Interpretation, Discussion and Mathematical Formulation

#### 3.1. Results and Interpretation

Two types of tests have been developed for parametric tests that follow the normal distribution: the Welch test and the Student's test. The Student's test will be used when the variances are equal, whereas Welch's test is designed to work even when the variances are unequal. In the context of this work, parameters such as resistance and real density do not have the same variance (standard deviation), which justifies the use of the Welch test, whereas theoretical density and the ratio of gravel to sand (G/S) have identical variances, which led to the use of the Student's test. For the non-parametric test, the Wilcoxon Signed-rank test was used for subsidence.

##### 3.1.1. Characteristic Strengths of Concrete at 7 and 28 Days Old

**Table 10.** Welch test for resistances.

Welch two Sample t-test	
Data: Resistance 1 and Resistance 2	
t = -2.8318, df = 13.359, p-value = 0.01383	
Alternative hypothesis: true difference in means	
Is not equal to 0	
95 percent confidence interval:	
-13.118143	-1.781857
Sample estimates:	
Mean of x mean y	
20.3625	27.8125

The result of Welch's test to compare concrete strengths at 7 days and 28 days (**Table 10**) shows the following:

t-statistic: -2.8318; Degrees of freedom (df): 13.359; p-value: 0.01383.

##### 1) Analysis of p-value

The p-value of 0.01383 is well below 0.05, indicating that there is a statistically significant difference between the means of the two samples at the 0.05 level of significance [8].

**2) The confidence interval**

The 95% confidence interval for the difference in means is  $-13.1181$  to  $-1.7819$ , which does not include zero, reinforcing the conclusion that there is a significant difference between the means.

**3) Estimates of average x and average y**

The average 7-day concrete strength is  $20.3625$ , while the average 28-day concrete strength is  $27.8125$ . This confirms that the two groups have different averages.

**4) Conclusion**

The results suggest that the resistances of the two groups are significantly different. In other words, the differences observed between the mean strengths at 7 days and 28 days could not be due to chance.

**3.1.2. Case of Theoretical Densities**

**Table 11.** Student’s test for theoretical density.

Two Sample t-test	
Data: theoretical densities 1 and theoretical densities 2	
t = 0, df = 14, p-value = 1	
Alternative hypothesis: true difference in means	
Is not equal to 0	
95 percent confidence interval:	
-0.01062775	0.01062775
Sample estimates:	
Mean of x mean y	
2.36875	2.36875

The result of Student’s t-test to compare the theoretical densities of two samples (**Table 11**) shows the following:

t-statistic: 0; Degrees of freedom (df): 14; p-value: 1

**1) Analysis of the p-value**

The p-value of 1 is well above 0.05, which means that the data provide absolutely no evidence against the null hypothesis. The means of the two samples are exactly equal, according to the sample observations. This means that the observed difference between the two means is totally compatible with the null hypothesis, with no indication of a significant difference. This can be explained by the fact that the samples may be very similar, or even identical [8].

**2) Confidence interval**

The 95% confidence interval for the difference in means is  $-0.01062775$  to  $0.01062775$ . Since this interval contains 0, this reinforces the idea that there is no significant difference between the means.

**3) Estimates of x-means and y-means**

The average theoretical density of the concrete at 7 days is 2.36875 and the average theoretical density of the concrete at 28 days is also 2.36875.

#### 4) Conclusion

In conclusion, the null hypothesis is not rejected. In other words, the differences observed between the theoretical densities at 7 days and 28 days are not significant.

### 3.1.3. Case of Real Densities

**Table 12.** Welch test for real densities.

Welch two Sample t-test	
Data: Real densities 1 and Real densities 2	
t = -0.21343, df = 13.923, p-value = 0.8341	
Alternative hypothesis: true difference in means	
Is not equal to 0	
95 percent confidence interval:	
-0.0829071	0.0679071
Sample estimates:	
Mean of x mean y	
2.3475	2.3550

The result of Welch's test for comparing the true densities of two samples (**Table 12**) shows the following:

t-statistic: -0.21343 Degrees of freedom (df): 13.923 p-value: 0.8341

#### 1) Analysis of the p-value

The p-value of 0.8341 is well above 0.05, indicating that there is insufficient evidence to reject the null hypothesis. This means that there is no statistically significant difference between the means of the two real density groups [8].

#### 2) Confidence Interval

The 95% confidence interval for the difference in means is -0.0829 to 0.0679. Since this interval contains 0, this reinforces the idea that there is no significant difference between the means.

#### 3) Estimates of average x and average y

The average of the real densities of the concrete at 7 days of age is 2.3475 and that at 28 is 2.3350. This confirms that the two groups have different averages.

#### 4) Conclusion

The results suggest that the actual densities of the two groups are very similar, with no significant differences. We can consider that these samples have comparable densities for our analysis. The null hypothesis is not rejected. In other words, the differences observed between the means of the actual densities at 7 days and 28 days could be due to chance.

### 3.1.4. Case of Gravel to Sand Ratios (G/S)

**Table 13.** Student's t test for the gravel to sand ratio.

Two Sample t-test	
Data: Gravel to sand ratios 1 and Gravel sand ratios 2	
t = 0, df = 14, p-value = 1	
Alternative hypothesis: true difference in means	
Is not equal to 0	
95 percent confidence interval:	
-0.5176748	0.5176748
Sample estimates:	
Mean of x mean y	
2.17375	2.17375

The result of the Student's test to compare the gravel to sand ratios of the two samples (**Table 13**) shows the following:

T-statistic: 0; Degrees of freedom (df): 14 p-value: 1 The t-statistic is 0, which means that the means of the two groups (gravel/sand ratio of the concrete at 7 days and 28 days) are identical or very close.

The result of Welch's test to compare the gravel to sand ratios of the two samples shows the following:

t-statistic: 0 Degrees of freedom (df): 14 p-value: 1 The t-statistic is 0, which means that the means of the two groups (gravel/sand ratio of the concrete at 7 days and 28 days) are identical or very close.

#### 1) Analysis of the p-value

For this case, the p-value corresponding to 1 is extremely high, meaning that there is no statistical evidence to reject the null hypothesis (which postulates that the means of the two groups are equal). This confirms that there is no significant difference between the two groups [8].

#### 2) Confidence intervals

The 95% confidence interval for the difference in means is  $-0.518$  to  $0.518$ . This means that, with 95% confidence, the true difference between the means of the two groups could lie within this interval. As this interval includes 0, this indicates that the real difference in means could be zero. In other words, it reinforces the idea that there is no significant difference between the groups.

#### 3) Estimates of average x and average y

The average gravel/sand ratio of the concrete at 7 days of age is 2.17375 and that at 28 days is also 2.17375. This confirms that the two groups have identical averages.

#### 4) Conclusion

The results of the two-sample test show that there is no significant difference between the averages of the two gravel/sand ratios of the concrete at 7 days of age and 28 days of age. The p-value of 1 and the confidence interval of 0 indicate that

it is likely that the two groups have equal means. We therefore do not reject the null hypothesis. We conclude that there is no statistical evidence of a difference between these two groups.

### 3.2. Discussion

Parametric and non-parametric tests are two broad classifications of statistical procedures. Parametric tests are based on assumptions about the distribution of the underlying population from which the sample was taken [9].

Parametric tests have limitations when applied to data that do not follow a normal distribution, because these tests are based on the fundamental assumption that the data are normal. In contrast, non-parametric tests are particularly advantageous in such situations [10], as they do not require the data to follow a specific distribution, offering greater flexibility and robustness in statistical analysis. In our study of six concrete properties (strength, theoretical density, actual density, gravel/sand ratio, slump and water/cement ratio), the Shapiro-Wilk test was used to check the normality of the distributions. For four of these properties, the data showed a normal distribution, justifying the use of parametric tests. However, for subsidence and the gravel/sand ratio, the data did not follow a normal distribution, prompting the use of more appropriate non-parametric tests. In the following, the null hypothesis ( $H_0$ ) designates that the median of the differences between subsidence at 7 days of age and subsidence at 28 days of age is equal to zero. This means that there is no significant difference between the two measurement times against the alternative hypothesis ( $H_1$ ) that the median of the differences between 7-day sag and 28-day sag is different from zero. This implies that there is a significant difference between the two measurement times.

As the characteristic strength of concrete is the most crucial parameter in a concrete mix in terms of durability [11], the test carried out on this parameter revealed the differences observed between the average strengths at 7 days and 28 days, which could not be due to chance. The influence of the materials that make up the concretes in a mix must therefore be taken into account, as these materials have a major influence on the formulation of quality concretes. The sands studied and sampled in Brazzaville and Pointe-Noire for concrete formulations have very high proportions of fine elements [2] [12]; once in a concrete mix, these increase the percentage of fines in the mix, which could be very detrimental in a concrete formulation and could also affect the characteristic strength expected for the concrete placed. Hence, the rejection of the null hypothesis which states that the difference in strength values is not due to chance.

In addition, the comparative study carried out by Japhet Tiegoum *et al.* [13], showed that compressive strength depends strongly on the percentage of fines. He also showed the importance of large quantities of fines in sand as a substitute for other sands, making it possible to produce concrete with very good performance in proportions of 65% crushed sand and 35% river sand.

Furthermore, the choice of aggregates is essential in the manufacture of concrete,

and their qualities are of great importance, because these aggregates can limit not only the strength of the concrete, but their intrinsic properties can also affect the durability and structural performance of the concrete. [2].

### 3.3. Mathematical Formulation of the Hypothesis for the Non-Parametric Test

Null hypothesis (H0): Median (7-day subsidence – 28-day subsidence) = 0

Alternative hypothesis (H1): Median (7-day subsidence – 28-day subsidence)  $\neq$  0

#### 3.3.1. Test de Wilcoxon Signed-Rank

The result of the non-parametric test is as follows:

---

Wilcoxon signed rank test with continuity correction
Data: subsidence1 and subsidence 2
V = 0, p-value = NA
Alternative hypothesis: true location shift is not Equal to 0

---

This test shows that the p-value has not been evaluated and the test statistic is zero.

#### 3.3.2. Analysis of the Results and Limitations of the Test for Subsidence at 7 and 28 Days Old

The Wilcoxon test [14] was used to compare subsidence measured at 7 days and at 28 days. However, the two sets of data were identical, leading to a particular result:

Test statistic (V): 0;

p-value: NA (not defined);

Alternative hypothesis: The location offset between the two periods is non-zero.

#### 3.3.3. Interpretation

The fact that the values are identical leads to a result where the V statistic is equal to 0 and the p-value cannot be calculated. This is because the Wilcoxon test relies on evaluating the ranks of the differences between pairs of values [15]. When all the differences are zero, the test has nothing to analyze, which prevents valid statistical conclusions from being drawn.

#### 3.3.4. Conclusion

There is no difference between the subsidence measured at 7 days and 28 days. This confirms that the two measurement periods give the same results. The fact that the values are identical makes the test result predictable, as the absence of any real difference prevents any statistical variation.

## 4. General Conclusion

The statistical analysis of the concrete properties revealed several interesting

results, particularly with regard to slump and the gravel/sand ratio measured at 7 and 28 days respectively. For slump, we found that the values at 7 days and 28 days were identical. The Wilcoxon signed-rank test was therefore unable to calculate a significant p-value, resulting in a zero V statistic and an undefined p-value. This situation can be explained by the fact that the test is based on a comparison of the ranks of the differences between pairs, and the absence of a difference between the measurements precludes any relevant statistical interpretation. This conclusion was to be expected and is corroborated by the observation of the boxplots, which show an absence of variation between the two measurement periods. Similarly, the last property of the concrete, namely the water/cement ratio measured at 7 and 28 days of age, also revealed identical values. Furthermore, these data do not follow a normal distribution, which would, in theory, have justified the use of non-parametric tests. However, as in the case of subsidence, non-parametric tests cannot be meaningfully applied when the values are identical.

Observation of the boxplots suggested this similarity and predicted the outcome of the statistical tests. The results show that it is essential to consider the characteristics of the data before carrying out statistical tests. Where values are identical, it is often more appropriate to rely on descriptive analysis and visualizations, such as boxplots, to reach clear conclusions. Statistical tests, whether parametric or non-parametric, reach their limits when there is no variability in the data. This study underlines the importance of direct observation of the data and the use of methods adapted to the nature of the samples. In the absence of measurable differences between the 7- and 28-day age periods, we conclude that the properties studied do not vary significantly over this period.

### Conflicts of Interest

The authors declare no conflicts of interest regarding the publication of this paper.

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## Annexes

### Annex 1: Physical Characteristics of Raw Sands [2]

Raw sand	Slimness modules	Percentage of fines in 80 $\mu\text{m}$ sieve (%)	Sand equivalent (%)	Specific weight ( $\text{t}/\text{m}^3$ )	Apparent density ( $\text{t}/\text{m}^3$ )	Methylene blue mass
Sand from Congo River (SF)	1.2	0.3	88	2.62	1.49	1.69
Sand from Mfilou (SMF)	0.93	0.7	89	2.64	1.62	1.15
Crushed sand from Brazzaville (SCB)	2.5	10	46	2.64	1.54	2.32
Sand from Pointe-Noire (SPN)	1.00	6.5	78	2.62	1.56	1.01
Crushed sand from Pointe-Noire (SCP)	2.20	7	63	2.63	1.54	2.04

### Annex 2: Physical Characteristics of Sands Improved with Crushed Sand at Different Percentages [2]

Improved sands	Slimness modules	Percentage of fines in 80 $\mu\text{m}$ sieve (%)	Sand equivalent (%)	Specific weight ( $\text{t}/\text{m}^3$ )	Apparent density ( $\text{t}/\text{m}^3$ )	Methylene blue mass
SF (30%)	1.7	3	82	2.62	1.59	1.49
SF (40%)	1.8	4.5	83	2.62	1.58	1.50
SF (50%)	1.8	5	81	2.62	1.58	1.50
SMF (30%)	1.7	3.6	83	2.61	1.59	1.52
SMF (40%)	1.8	4.5	71	2.62	1.57	1.49
SMF (50%)	1.9	5.5	64	2.62	1.60	1.49
SPN (30%)	1.5	6.7	76	2.61	1.62	1.01
SPN (40%)	1.6	5.8	79	2.62	1.61	1.00
SPN (50%)	1.7	6.2	71	2.60	1.60	0.99

### Annex 3: Physico-Mechanical Characteristics of Concretes [2]

Type of concrete formulation	Age of concrete/ days	Resistance (MPa)	Theoretical density of concrete ( $\text{g}/\text{cm}^3$ )	Real density of concrete ( $\text{g}/\text{cm}^3$ )	Ratio E/C	Ratio G/S	Subsidence (cm)	Consistency
Formulation 1	7	27.75	2.37	2.38	0.49	2.45	6	Plastic
	28	33.75		2.41				
Formulation 2	7	20.50	2.38	2.37	0.49	1.80	6	Plastic
	28	26.65		2.37				
Formulation 3	7	23.85	2.37	2.42	0.49	2.43	7	Plastic
	28	36.75		2.44				
Formulation 4	7	18.10	2.37	2.41	0.49	1.70	6	Plastic
	28	27.25		2.39				
Formulation 5	7	16.50	2.36	2.25	0.47	3.06	7	Plastic
	28	22.80		2.26				

**Continued**

Formulation 6	7	12.60	2.35	2.22	0.47	1.70	9	Plastic
	28	18.30		2.25				
Formulation 7	7	21.50	2.38	2.37	0.49	2.36	9	Plastic
	28	27.30		2.37				
Formulation 8	7	22.10	2.37	2.36	0.49	1.89	6	Plastic
	28	29.70		2.35				

**Annex 4: Physico-Mechanical Characteristics of Gravels**

Gravels	Tests Los-Angeles	Apparent density (t/m <sup>3</sup> )	Specific weight (t/m <sup>3</sup> )	Flattening coefficient	Cleanliness tests %	The Porosity	The Compactness
Kombé crushed gravel 5/15	24.4%	1.58	2.64	14%	0.3%	0.4	0.6
Kombé crushed gravel 10/14	24.4%	1.30	2.60	14%	0.3%	0.5	0.50
Mboubissi rolled gravel 3/8	62.5%	1.48	2.67	5%	0.8%	0.45	0.55
Louvoulou crushed gravel 10/14	27.0%	1.40	2.65	0	0.9%	0.47	0.53

**Annex 5: Resistance Statistics at 7 and 28 Days**

Data summary values

Name Resistance 1

Number of rows 8

Number of columns 1

Column type frequency numeric 1

Group variables none

Variable type: numeric.....

Skim_variable	n_missing	complete_rate	mean	sd	p0	p25	p50	p75	p100
Data	0	1	20.4	4.65	12.6	17.7	21	22.5	27.8

Skim (Resistance 2)

Data summary

Name Resistance 2

Number of rows 8

Number of columns 1

Group variables none

Variable type: numeric.....

Skim_variable	n_missing	complete_rate	mean	sd	p0	p25	p50	p75	p100
Data	0	1	27.8	5.81	18.3	25.7	27.3	30.7	36.8

**Annex 6: Theoretical Density Statistics**

Data summary values

Name Theoretical density 1

Number of rows 8  
 Number of columns 1  
 Column type frequency numeric 1  
 Group variables none  
 Variable type: numeric.....  
 Skim\_variable n\_missing complete\_rate mean sd p0 p25 p50 p75 p100  
 Data 0 1 2.37 0.00991 2.35 2.37 2.37 2.37 2.38

Skim (Theoretical density 2)

Data summary

Name Theoretical density 2

Number of rows 8

Number of columns 1

Group variables none

Variable type: numeric.....

Skim\_variable n\_missing complete\_rate mean sd p0 p25 p50 p75 p100  
 Data 0 1 2.37 0.00991 2.35 2.37 2.37 2.37 2.38

**Annex 7: Statistics on Real Densities at 7 and 28 Days**

Data summary values

Name Real densities 1

Number of rows 8

Number of columns 1

Column type frequency numeric 1

Group variables none

Variable type: numeric.....

Skim\_variable n\_missing complete\_rate mean sd p0 p25 p50 p75 p100  
 Data 0 1 2.35 0.0729 2.22 2.33 2.37 2.39 2.42

Skim (Real densities 2)

Data summary

Name Real densities 2

Number of rows 8

Number of columns 1

Group variables none

Variable type: numeric.....

Skim\_variable n\_missing complete\_rate mean sd p0 p25 p50 p75 p100  
 Data 0 1 2.36 0.0676 2.25 2.33 2.37 2.40 2.44

**Annex 8: Water to Cement Ratio Statistics**

Data summary values

Name Water to cement ratios 1

Number of rows 8

Number of columns 1

Column type frequency numeric 1

Group variables none  
 Variable type: numeric.....  
 Skim\_variable n\_missing complete\_rate mean sd p0 p25 p50 p75 p100  
 Data 0 1 0.485 0.00926 0.47 0.485 0.49 0.49 0.49  
 Skim (Water to cement ratio 2)  
 Data summary  
 Name Water to cement ratio 2  
 Number of rows 8  
 Number of columns 1  
 Group variables none  
 Variable type: numeric.....  
 Skim\_variable n\_missing complete\_rate mean sd p0 p25 p50 p75 p100  
 Data 0 1 0.485 0.00926 0.47 0.485 0.49 0.49 0.49

**Annex 9: Gravel to Sand Ratios Statistics**

Data summary values  
 Name Gravel to sand ratios 1  
 Number of rows 8  
 Number of columns 1  
 Column type frequency numeric 1  
 Group variables none  
 Variable type: numeric.....  
 Skim\_variable n\_missing complete\_rate mean sd p0 p25 p50 p75 p100  
 Data 0 1 2.17 0.483 1.7 1.78 2.12 2.44 3.06  
 Skim (Gravel to sand ratios 2)  
 Data summary  
 Name Gravel to sand ratios 2  
 Number of rows 8  
 Number of columns 1  
 Group variables none  
 Variable type: numeric.....  
 Skim\_variable n\_missing complete\_rate mean sd p0 p25 p50 p75 p100  
 Data 0 1 2.17 0.483 1.7 1.78 2.12 2.44 3.06

**Annex 10: Subsidence Statistics**

Data summary values  
 Name Subsidence 1  
 Number of rows 8  
 Number of columns 1  
 Column type frequency numeric 1  
 Group variables none  
 Variable type: numeric.....  
 Skim\_variable n\_missing complete\_rate mean sd p0 p25 p50 p75 p100

Data	0	1	7	1.31	6	6	6.5	7.5	9
Skim (Subsidence 2)									
Data summary									
Name	Subsidence 2								
Number of rows	8								
Number of columns	1								
Group variables	none								
Variable type:	numeric.....								
Skim_variable	n_missing	complete_rate	mean	sd	p0	p25	p50	p75	p100
Data	0	1	7	1.31	6	6	6.5	7.5	9

### Annex 11: Shapiro-Wilk Test

Data: Resistance 1	➤ Shapiro. Test (Water to cement ratios 1)
W = 0.99115, p-value = 0.9967	Shapiro-Wilk normality test
➤ Shapiro. test (Resistance 2)	Data: Water to cement ratios 1
Shapiro-Wilk normality test	W = 0.56594, p-value = 6.323e-05
Data: Resistance 2	➤ Shapiro. Test (Water to cement ratios 2)
W = 0.97334, p-value = 0.9229	Shapiro-Wilk normality test
➤ Shapiro. Test (Theoretical density 1)	Data: Water to cement ratios 2
Shapiro-Wilk normality test	W = 0.56594, p-value = 6.323e-05
Data: Theoretical density 1	➤ Shapiro. Test (Subsidence 1)
W = 0.87152, p-value = 0.156	Shapiro-Wilk normality test
➤ Shapiro. Test (Theoretical density 2)	Data: Subsidence 1
Shapiro-Wilk normality test	W = 0.74784, p-value: 0.007732
Data: Theoretical density 2	➤ Shapiro. Test (Subsidence 2)
W = 0.87152, p-value = 0.156	Shapiro-Wilk normality test
➤ Shapiro. Test (Real densities 1)	Data: Subsidence 2
Shapiro-Wilk normality test	W = 0.74784, p-value: 0.007732
Data: Real densities 1	
W = 0.82552, p-value: 0.05331	
➤ Shapiro. Test (Real densities 2)	
Shapiro-Wilk normality test	
Data: Real densities 2	
W = 0.89688, p-value = 0.2708	
➤ Shapiro. Test (Gravel to sand ratios 1)	
Shapiro-Wilk normality test	
Data: Gravel to sand ratios 1	
W = 0.87835, p-value: 0.1816	
➤ Shapiro. Test (Gravel to sand ratios 2)	
Shapiro-Wilk normality test	
Data: Gravel to sand ratios 2	
W = 0.87835, p-value = 0.1816	