Journal of Structural Engineering and Geotechnics,

7 (2), 37-50, Summer 2017

Case study of the statistical distribution of the concretes implemented at Qazvin

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Received 30 June 2017, Accepted 16 August 2017

Abstract

Characteristics of produced concrete become changed through changing the characteristics of materials constituting the concrete. These changes include the quality of cement, the real ration of water to cement: with neglecting the further water within the aggregates or lack of that, the considered ratio fluctuates and the characteristics of the aggregate which are related to the following dimensions: quality of aggregate, the shape of aggregate and aggregate grading. The calculated strength of the mix design is the mean target strength which is marginally further than the specified strength. This further margin lowers the ration of water to cement in calculations and consequently, for a stable flow, the amount of consumption or alloy of cement in concrete increases. On the other hand, the amount of the margin depends on the following factors: The sensitivity level of the concrete project (with K coefficient) and standard deviation of concrete production. The purpose of defining this laboratory project is to obtain an optimal concrete mix design for different consumptions and consequently comparison of theoretical and workshop results in the mix design, lowering the cement consumption and the costs of concrete productions in batching and increasing or stabling the specified strength of concrete through lowering the level of cement consumed in concrete. In this procedure, concrete is produced through a common method that is segregating sand from cement to compare that with the results obtained and to calculate standard deviation fall, strength margin and cement alloy fall in order to produce concrete which is statistically suitable for the required strength.

Keywords: *Standard Deviation, Specified Strength, Target Strength, Strength Margin, project Sensitivity Coefficient.*

1. Introduction

Nowadays, concrete is widely used across the world and it is known as the structural material of the century. Regarding the increasing development procedures and constructive investments in the country, it is necessary to pay particular attention to this important material[1]. Concrete mix design is the process of determining the ration of concrete components. So that the concrete become economical as much as possible and it meets the requisites including compressive strength, efficiency, and persistence. The method of concrete mix design conforming to local technology and materials of the country speeds the procedure of decision making in choosing appropriate ratios for concrete components and lead to a common language for those involved in the concrete industry[2]. Lasisi and Osunade[3] were among the first researchers who tried to investigate the factors which can change the strength of concrete samples, on a practical project. The mentioned project was related to Heathrow airport in England. To build this airport, about half a million yard 3 concrete was produced and controlled[3].In order to be able to identify the sources and change factors, precise experiments were conducted and the resulted were published as in table1.

According to table 1, it can be concluded that the level of cement quality is the most important factor of changes of concrete strength[4]. Therefore, about 50 percent of the changes occurring in concrete strength is out of the engineers' control[5].

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Table 1. Factors affecting in the changes of concrete strength

Change factor	The percentage of interference in the amount of concrete strength change
Cement quality	48.2
W/C Ratio	18.4
Method and accuracy in sampling and manufacturing of molds	11.5
Samples testing	13.8
Mix time	4.6
Specific gravity of aggregates	3.5
The total of change factors	100

Also, for common concretes, in the instruction which has published about integration ratios, American Concrete Institute (ACI) has offered a method for producing a combination; however, it has not suggested any procedure to find the ratios which simultaneously meet a number of efficiency criteria. Also, in this instruction, no method has been introduced to optimize the combination of concretes with high strengths [6]. In recent years, with investigating the persistence of reinforced concrete structures, most experts and those involved in concrete activities have paid attention to the fact that strength cannot solely meet all the characteristics of concrete, especially its persistence, and in designing concrete for different regions, it is necessary to consider its perpetuity and persistence in addition to strength and load tolerance during exploitation [7]. Although up to now, much effort has been devoted to theoretical aspects of mix design, empirical methods are still used. In other words, integration methods are useful for primary choose of the ratios. However, to determine the ultimate ratios, there is a need to make experimental mixtures and adjust the ratios [8]. The purpose of this study is to investigate the mix design of the concretes implemented at Qazvin city and then, present the optimal mix design using optimization principles. On the other hand, regarding the simultaneous theoretical and experimental observations basis of this study, and considering difficult conditions of concrete production in Iran, its practical aspect is of specific importance.

2. Materials

2.1. Aggregate materials

Aggregate materials of concrete constitute about 75 percent of its mass. Hence, their quality is of particular importance. Aggregate materials influence not only concrete strength but also the persistence and strength of concrete [9]. The aggregates used in concrete including coarse aggregate, fine aggregate materials, or a mixture of them should have such a quality that can be changed into a strong and persistent concrete. In this research, all aggregate materials are supplied from Kordan mine.

2.2. Cement

The cement in this project is cement type II. It should be noted that the used cement should be sound and its physical and chemical characteristics should conform to characteristics inserted in ASTM C150 standard (ordinary Portland cement) and ASTM C595 (Pozzolans mixed Portland cement)[10]. The characteristics of type 2 Portland cement are presented in the following table. Also, particles grading will be explained in the following section (these are characteristics of the cement of Delijan factory).It should be mentioned that according to the information offered by Delijan cement factory, the 28-day compressive strength of this type of cement is 460 kg/cm2[11].

Table 2. Characteristics of cement type 2

Chemical compounds	Mass percentage
SiO2	20.9
Al2O3	5
Fe2O3	4.30
CaO	65.02
MgO	1.02
SO3	1.80
K2O	0.6
Sa2O	0.32
Cl	0.013
L.O.l	0.93
l.R	0.50

2.3. Water

According to Iranian’s concrete regulation, the water used to produce concrete should be clean and pure. It should be avoided to use any water containing much of any material which can harm the concrete or reinforcements, including oils, acids, alkalis, and minerals. Generally, drinking water is considered appropriate to produce concrete (Table 2 shows Iran’s concrete regulation in which the maximum admissible amount of harmful materials in the water used to produce concrete is represented).

According to Iranian's concrete regulation, the PH of water of concrete should not be less than five and more than 8.5. It should be mentioned that the PH of the water used in the experiment is 8.1[12].

2.4. Additives

The additive material is a substance other than Portland cement, aggregate and water, which is added to the mixture as one of the materials constituting concrete to improve its characteristics before or during the process of combination. In presenting concrete models, a Superplasticizer additive with the brand name of Carboxyl SRF521 has been used.

3. Method

In order to determine the effect of materials used in concrete on its general behavior, the amount of cement and the ratio of W/C have been chosen as the variables. In order to investigate the standard deviation, twelve different mix designs have been used.

Table 4 corresponds to the considered mix design, cubic samples which are totally 3136 samples.

4. Concrete mix design

The final ratios of mix design for 3136 samples are presented in the table 4 with W/C ratios equal to 0.33, 0.35, 0.37, .44, 0.45, 0.47, 0.48, 0.65, 0.78 for categories including 43, 58, 245, 89, 16, 218, 436, 278, 545, 158, 452 and 569.Table 3, It should be mentioned that about these ratios the results are obtained from the concrete production workshops (batching). Therefore, in these categories, it was tried for the ratios of aggregates and also water to cement not to be equal. Hence, as it can be seen in Tables 5 to 13, in each category the ratios of water to cement and aggregates are shown separately. Thus, the range of each category can be specified. It needs to be mentioned that every 3136 samples are a 150*150*150 mm cube, and 7-day and 28-day strengths of the samples are considered. The weights of the materials constituting 1 m^3concrete are shown in table 4.

Table3. The number of tests for every mix design

Number of tests	Mixing plan
43	MP1
58	MP2
245	MP3
89	MP4
16	MP5
218	MP6
436	MP7
278	MP8
545	MP9
158	MP10
452	MP11
569	MP12

Table 4. The weights of the materials constituting 1 m^3 fresh concrete (in weights)

Mixing number	Mixing specification	Materials used in the construction of concrete mix design	Materials weight in dry saturated (kg/m^3) state (SSD).
Mix 1	Concrete mix design F_{CC}=100 kg/m^2 With cube mold 15*15*15 Cm	Water	146
		Type II cement	187
		Gravel	686
		Sand	1277
Mix 2	Concrete mix design F_{CC}=200 kg/m^2 With cube mold 15*15*15 Cm	Water	165
		Type II cement	254
		Gravel	667
		Sand	1238
		Superplasticizer	1.27
Mix 3	Concrete mix design F_{CC}=300 kg/m^2 With cube mold 15*15*15 Cm	Water	169
		Type II cement	376
		Gravel	628
		Sand	1157
		Superplasticizer	1.88
Mix 4	Concrete mix design F_{CC}=300 kg/m^2 With cube mold 15*15*15 Cm (Cement alloy=400)	Water	180
		Type II cement	400
		Gravel	619
		Sand	1177
		Superplasticizer	2.0
Mix 5	Concrete mix design F_{CC}=350 kg/m^2 With cube mold 15*15*15 Cm	Water	174
		Type II cement	392
		Gravel	642
		Sand	1199
		Superplasticizer	1.96
Mix 6	Concrete mix design F_{CC}=400 kg/m^2 With cube mold 15*15*15 Cm	Water	190
		Type II cement	423
		Gravel	633
		Sand	1173
		Superplasticizer	2.11
Mix 7	Concrete mix design F_{CC}=500 kg/m^2 With cube mold 15*15*15 Cm	Water	115.5
		Type II cement	350
		Slag	150
		Gravel	680
		Sand	1010
		Superplasticizer	3.5
Mix 8	Concrete mix design F_{CC}=300 kg/m^2 With cube mold 15*15*15 Cm	Water	165
		Type II cement	350
		Gravel	500
		Sand	1300
		Superplasticizer	-
Mix 9	Concrete mix design F_{CC}=300 kg/m^2 With cube mold 15*15*15 Cm	Water	132
		Type II cement	375
		Gravel	700
		Sand	1150
		Superplasticizer	-
Mix 10	Concrete mix design F_{CC}=300 kg/m^2 With cube mold 15*15*15 Cm	Water	180
		Type II cement	400
		Gravel	700
		Sand	1100
		Superplasticizer	-
Mix 11	Concrete mix design F_{CC}=300 kg/m^2 With cube mold 15*15*15 Cm	Water	180
		Type II cement	375
		Gravel	650
		Sand	1150
		Superplasticizer	-
Mix 12	Concrete mix design F_{CC}=300 kg/m^2 With cube mold 15*15*15 Cm	Water	139
		Type II cement	375
		Gravel	650
		Sand	1150
		Superplasticizer	-

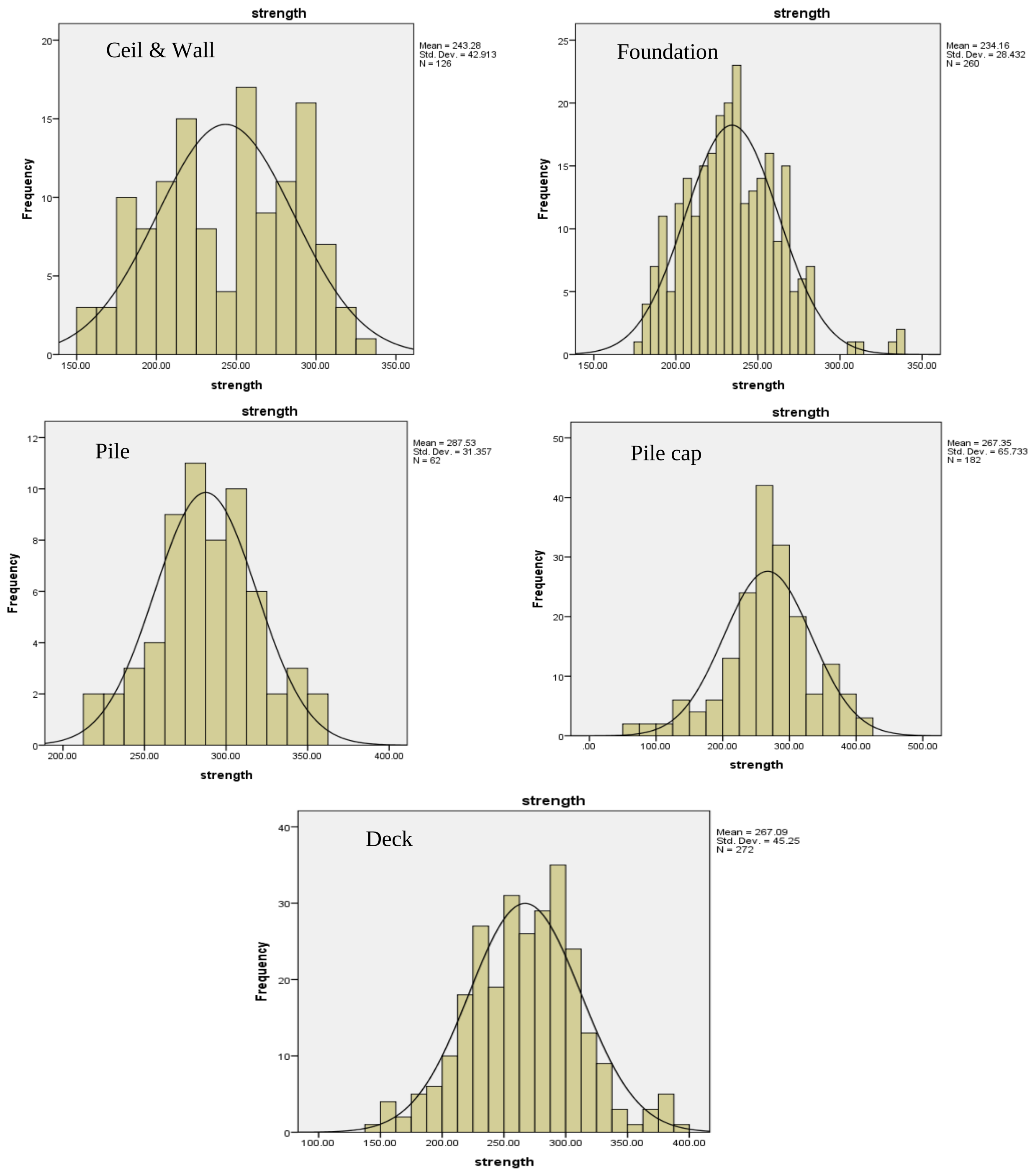

Figure 1: Histogram charts and normal distribution of 7-Day strength of Ceil and Wall, Foundation, Pile, Pile cap and Deck (Ansar Co)

5. Analysis of the normal distribution of samples

In this section, the distribution of the compressive strengths is presented. To do so, the different positions and ages of the samples are analyzed using the normal histograms. The chart for each specimen is plotted on SPSS software. The results are presented as follows. As can be seen in Figure 1, at the position of the pile cap, with a standard deviation of 6.57 MPa, the most improbable mixing design is observed, which needs to be modified in the mixing design and also, the position of the ceiling, wall, and deck are similar. Also, it should be noted that the average strength of the deck is higher than the average strength of the ceiling and wall, so, in this regard, it shows a more suitable design. On the other hand, the positions of pile and foundation have a good dispersion that with a standard deviation of 2.84 MPa and an average strength of 23.42 MPa, this mixing design has the most suitable design. However, in the position of the Foundation, the difference between the target strength and the characteristic strength is low.

As it can be seen, the distribution of dispersion is similar to the age of 7 days, so that the design of the pile cap is the most inappropriate design. On the other hand, the design of the foundation also needs the most optimal mixing design.

Therefore, according to Figure 1 and 2, this fact it should be reconsidered in the mixing design.

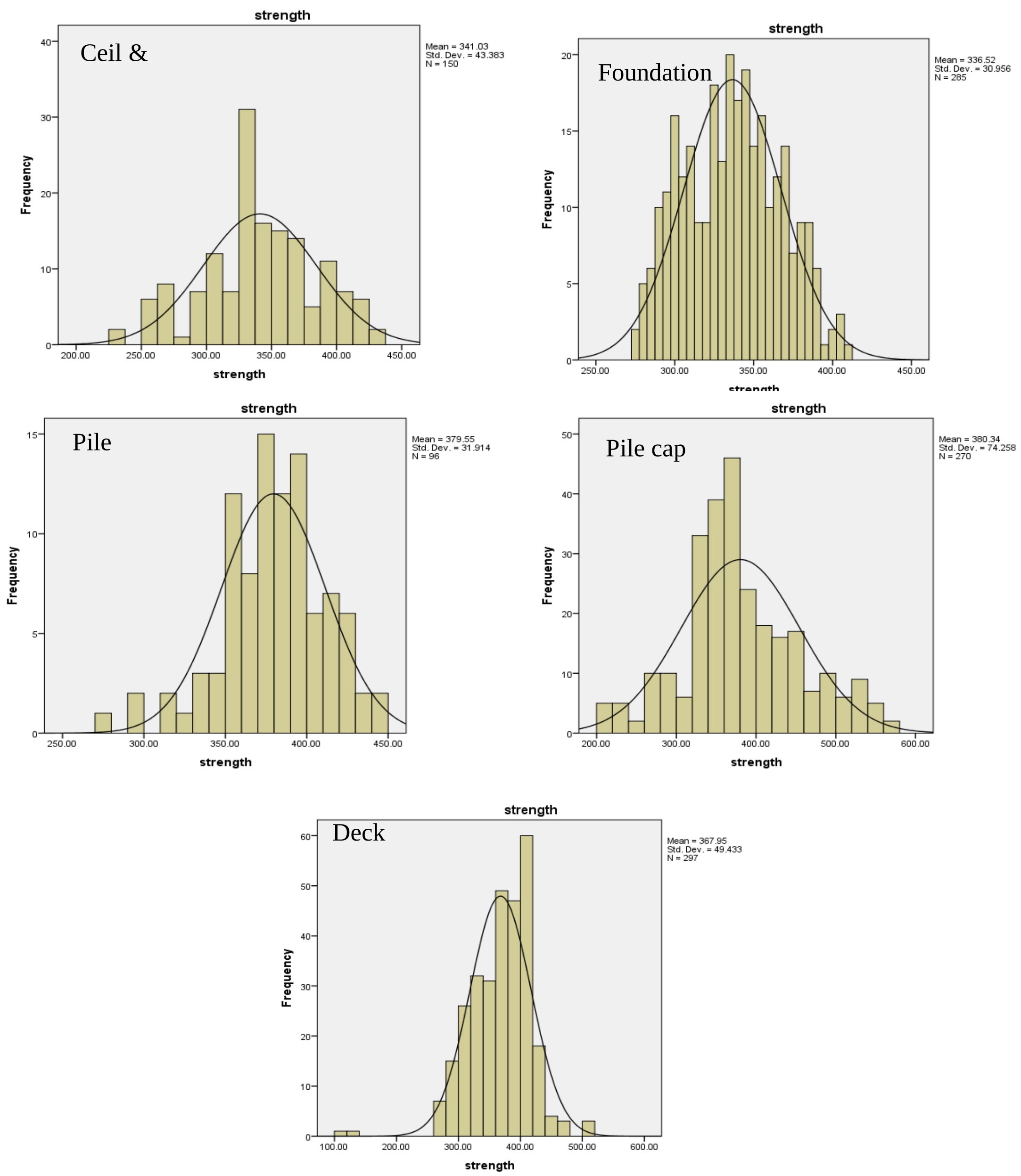

Figure 2: Histogram and normal distribution of 28-Day strength of ceil, wall, Foundation, pile, pile cap, and deck (Ansar Co)

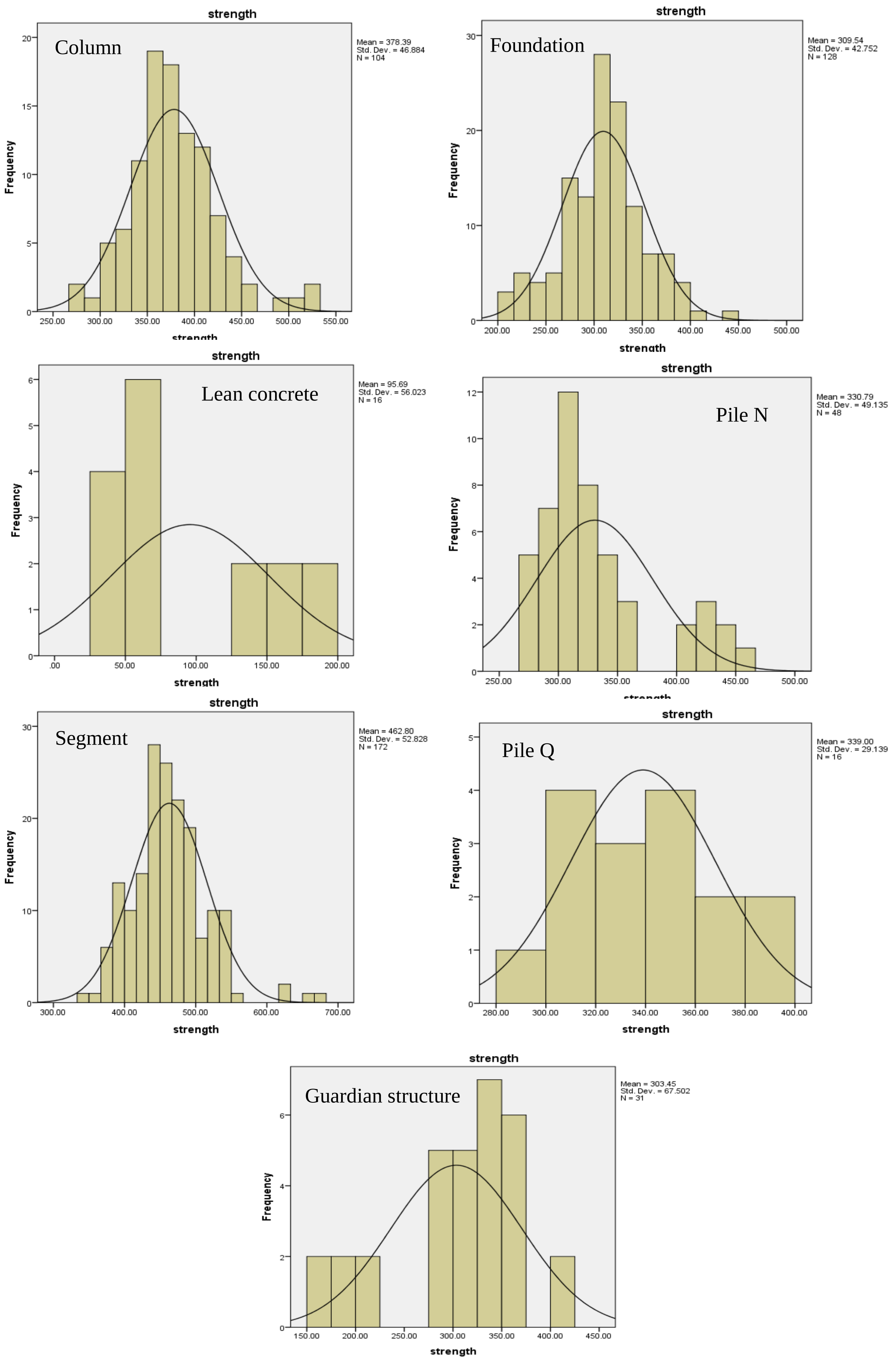

Figure 3: Histogram and normal distribution of 7-Day strength of column, foundation, lean concrete, pile N, pile Q, segment, and guardian structure (Shahid Rajaee Co)

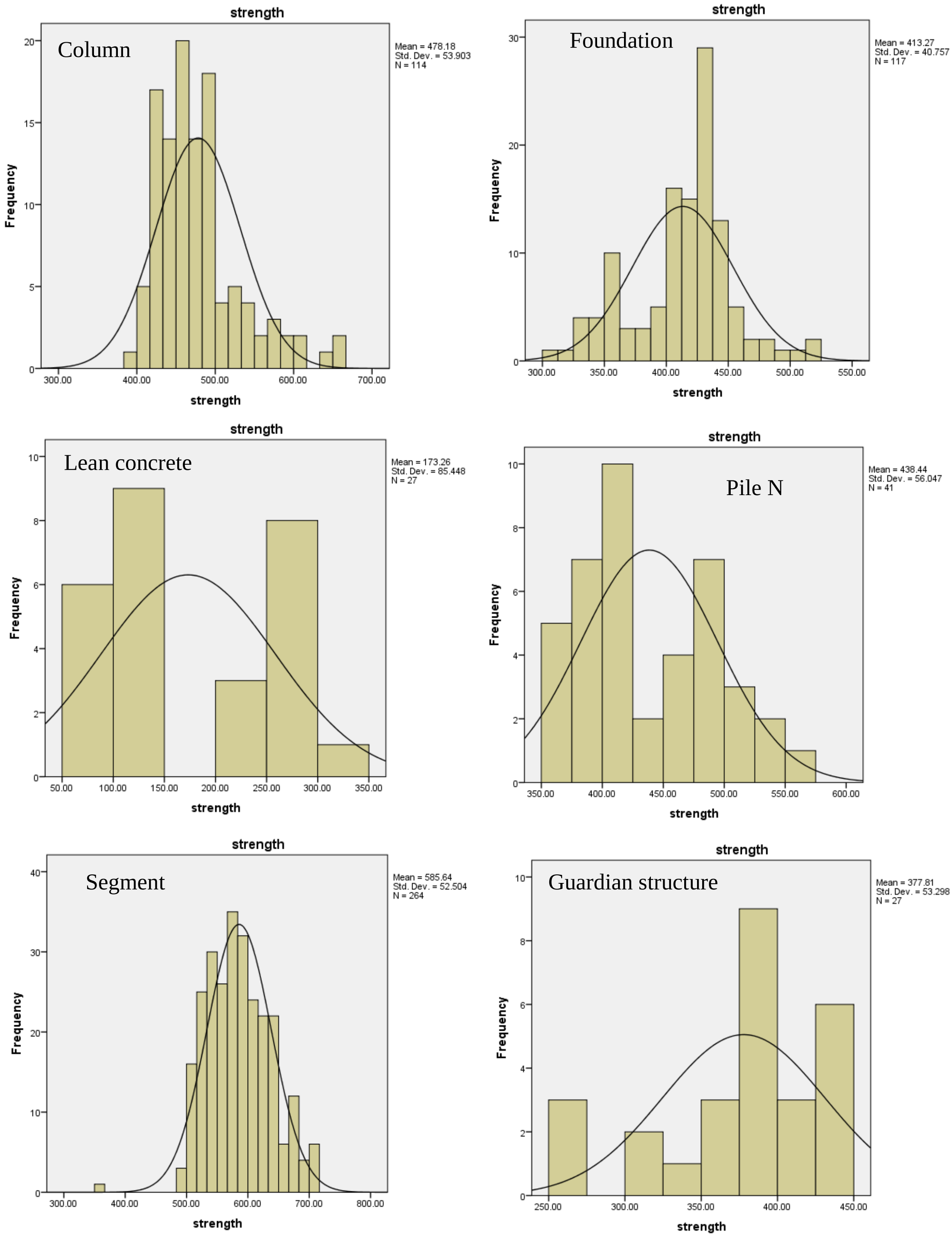

Figure 4: Histogram and normal distribution of 28-Day strength of column, foundation, lean concrete, pile N, pile Q, segment, and guardian structure (Shahid Rajaee Co)

According to the 7-day strength charts of the Qods project, the inappropriate dispersion is detected in the positions of the foundation, N-pile, lean concrete and guardian structure, which need to be modified in the mixing design.

In addition, in the Foundation and N-Pile positions, the strengths of 7-day, indicates a better design with regard to the modified mixing design. Similarly, in the 28-day strength charts of the Qods project, the Column and Segment have an appropriate mixing design. The mixing design of the segment with characteristic strength of 50 MPa, SD of 5.25Mpa and an average strength of 58.86Mpa is proposed as an optimal mixing design

amount. On the other hand, the mixing design of the lean concrete and guardian structure are the most improbable mixing design, Figure 3 and 4.
Due to the almost acceptable dispersion of N-pile, foundation positions and the high strength of the mentioned positions, it can be stated that by slightly refining the mixing design a more optimal design can be achieved.

6. Analysis of the standard deviation of lab results

Standard deviation is a quantity which specifies the difference between the strength of tests and the mean value of the strength. The method used to find the standard deviation is based on the results of previous similar projects using the following formula: [8]

$$S = \sqrt{\frac{\Sigma(X-m)^2}{n-1}}$$

X: compressive strengths of tests
m: the average of compressive strengths of tests
n: the number of tests
The calculated strength of the mix design is the mean target strength (f_{cm}) which is marginally further than the specified strength.
This further margin lowers the ratio of water to cement in calculations and consequently, for a stable flow, the amount of consumption or alloy of cement in concrete increases.
According to tables 5 and 6, it can be found that there is a direct relation between standard deviation and f_{cm} target strength.
With the strength closed to the specified strength, that mix design is more optimized than other proposed designs.

Table 5. Mix design, standard deviation, for 7-day and 28-day strengths of Shahid Rajaee Company

`Batching of Khatam-Al-Anbia construction site (Qods, Imam Reza and Persian Gulf project)												
Row	Position	Standard deviation SD	Strength average (MPa)	Number of sample	Target strength f_{cm} (MPa)	Specified strength (MPa)	Amount of cement (kg)	Water to cement ratio W/C	Fine aggregate (kg)	Coarse aggregate (kg)	Superplasticizer (kg)	Sample age
1	Lean concert	5.6	9.57	16	19.05	10	187	0.78	1277	686	-	7_day
2	Guardian structure	6.75	30.34	31	31.73	20	254	0.65	1238	667	1.27	
3	Foundation	4.27	30.95	128	37.22	30	376	0.45	1157	628	1.88	
4	N pile	4.91	33.08	48	38.08	30	400	0.45	1177	619	2	
5	Q pile	2.91	33.9	16	40.40	35	392	0.44	1199	642	1.96	
6	Column	4.69	37.84	104	47.78	40	423	0.45	1173	633	2.11	
7	segment	5.28	46.28	172	58.58	50	350	0.33	1010	680	3.5	
8	Lean concert	8.54	17.33	27	25.90	10	187	0.78	1277	686	-	28_day
9	Guardian structure	5.33	37.8	27	28.64	20	254	0.65	1238	667	1.27	
10	Foundation	4.08	41.33	117	36.97	30	376	0.45	1157	628	1.88	
11	N pile	5.6	43.84	41	39.05	30	400	0.45	1177	619	2	
12	Q pile	-	-	-	-	35	392	0.44	1199	642	1.96	
13	Column	5.39	47.82	114	48.72	40	423	0.45	1173	633	2.11	
14	segment	5.25	58.56	264	58.54	50	350	0.33	1010	680	3.5	

In segment mix design: in every 1 m^3 concrete, 150 kg slag is used.

Table 6. Mix design, standard deviation, for 7-day and 28-day strengths of Ansar Company

Batching of Ansar company (municipality buildings project and Imam Ali Bridge)												
Row	Position	Standard deviation SD	Strength average (MPa)	Number of sample	Target strength f_{cm} (MPa)	Specified strength (MPa)	Amount of cement (kg)	Water to cement ratio W/C	Fine aggregate (kg)	Coarse aggregate (kg)	Superplasticizer (kg)	Sample age
1	Ceiling and Wall	4.29	24.33	128	37.25	30	350	0.47	1300	500	-	7_day age
2	Foundation	2.84	23.42	260	35.31	30	375	0.35	1150	700	-	
3	Pile	3.14	28.75	62	35.71	30	400	0.45	1100	700	-	
4	Pile cap	6.57	26.73	182	41.31	30	375	0.48	1150	650	-	
5	Deck	4.52	26.71	272	37.56	30	375	0.37	1150	650	-	
6	Ceiling and Wall	4.34	34.1	150	37.32	30	350	0.47	1300	500	-	28_day age
7	Foundation	3.1	33.65	285	35.65	30	375	0.35	1150	700	-	
8	Pile	3.19	37.95	96	35.77	30	400	0.45	1100	700	-	
9	Pile cap	7.43	38.03	270	43.31	30	375	0.48	1150	650	-	
10	Deck	4.94	36.79	297	38.12	30	375	0.37	1150	650	-	

For example, looking at row 5 in the Table 5 which shows 7-day pile Q, it can be concluded that this position has the least standard deviation (2.89), and also with the target strength of 4.40 MPa, which has the least amount of difference between the target strength and the specified strength (35 MPa). It should be explained that also in rows 6 and 7, the situation is similar to pile Q, because of the positions of the column and deck the standard deviation is respectively 4.69 and 5.28 which are acceptable amounts of standard deviation regarding the specified strength of 40 (column) and 50 (deck). The analysis of the target strengths could have the same result. So, the target strength obtained for the 7-day column is 47.78 MPa and for the 7-day deck is 58.58 MPa. Comparison of these amounts with specified strengths of 40 (column) and 50 (deck) indicated that mix designs of column and deck are also optimized and proper designs. So, the analysis of the samples at the age of 28 days would have the same results as in 7 days. Unfortunately, at the age of 28 days, we could not analyze pile Q due to lack of its samples. On the other hand, regarding the standard deviation of 5.6 at the age of 7 days and 25.90 MPa at the age of 28 days for lean concrete, it can be concluded that the mix design of lean concrete is the most inappropriate design in Shahid Rajaee Company. Also, in foundation position of Table 7 which has the least amount of standard deviation both at the ages of 7 (2.84) and 28(3.1) days, the target strengths at the ages of 7 and 28 days are respectively 35.31 and 35.65, which have the least difference with specified strength (30 MPa). In other words, foundation difference design does have the most optimized mix design in municipality buildings project and Imam Ali Bridge. Also, pile cap mix design having the maximum standard deviation at the ages of 7 and 28 days and subsequently the maximum target strength (41.31 at the age of 7 days and 43.31 at the age of 28 days) has the most crucial situation.

6.1. Comparison of the standard deviations at the ages of 7 and 28 days

As it can be observed in the following table, the standard deviation of different situations in Ansar Company, at the age of 28 days is more than the standard deviation at the age of 7 days. Based on this comparison, it might be concluded that with the age of the samples growing, dispersion of their strengths increases. Also, it should be regarded that the number of samples at the age of 28 days becomes more than that at the age of 7 days. However, a little difference is observed in the comparison to the standard deviations calculated in the Qods project.

According to Table 8 which is about Shahid Rajaee Company, at the positions of the column, pile N and lean, the standard deviation at the age of 28 days is more than that at the age of 7 days. While at the positions of the foundation, guardian structure, and segment, there is an opposite situation. As shown in Tables 9 and 10, it can be again concluded that with the number of samples rising, the standard deviation increases, because at the positions of foundation, lean, guardian structure and column there is a direct relationship between the number of samples and the standard deviation.

6.2. Investigation of economic aspects of concrete mix designs.

Now in this section, we deal with investigation and comparison of mix designs regarding the material prices and thus the fixed price of concrete based on the specified strength and different mix designs, Table 11. The considered prices are all based on day market prices. It should be explained that due to the constant price of concrete delivery (in all cases), the price of concrete transportation has been ignored. Using the prices presented in the above table, it is possible to calculate and compare the fixed prices of different concretes. In table 12, regarding the fact that in all positions the specified strength is 30 MPa, it can be concluded that mix design of ceiling and wall is just economically

Table 7. Comparison of 7-day with 28-day standard deviations for Ansar company

Row	Position	Standard deviation in the 7_day age	Standard deviation in the 28_day age	Specified strength (MPa)
1	Ceiling and Wall	4.29	4.34	30
2	Foundation	2.84	3.10	30
3	Pile	3.14	3.19	30
4	Pile cap	6.57	7.43	30
5	Deck	4.52	4.94	30

Table 8. Comparison of 7-day with 28-day standard deviations in Shahid Rajaee company

Row	Position	Standard deviation In the 7_day age	Standard deviation In the 28_day age	Specified strength (MPa)
1	Column	4.69	5.39	40
2	Foundation	4.27	4.08	30
3	Lean concrete	5.60	8.54	10
4	N pile	4.91	5.60	30
5	Segment	5.28	5.25	50
6	Guardian structure	6.75	5.33	20

Table 9. Comparison of the number of samples at the ages of 7 and 28 days in Ansar Company

Row	Position	Number of samples	
		7_day age	28_day age
1	Ceiling and Wall	128	150
2	Foundation	260	285
3	Pile	62	96
4	Pile cap	182	270
5	Deck	272	297

Table 10. Comparison of the number of samples at the ages of 7 and 28 days in Shahid Rajaee Company

Row	Position	Number of samples	
		7_day age	28_day age
1	Column	104	114
2	Foundation	128	117
3	Lean concrete	16	27
4	N pile	48	41
5	Segment	172	264
6	Guardian structure	31	27

Table 11. Prices of materials used to produce concrete

	cement (of every bag of 50 kg)	Water (of every m^3 concrete)	Gravel of twice washed (of every ton)	Sand of twice washed (of every ton)	Super plasticizer (of every kg)	Slag (of every kg)
Fixed price (Rials)	86000	45000	230000	230000	89000	1500

Table 12. The fixed price of every 1 m^3 concrete for Ansar Company

Row	Position	Specified strength	Fixed price of every m^3 concrete
1	Ceiling and Wall	30	1023425 Rials
2	Foundation	30	1076350 Rials
3	Pile	30	1110100 Rials
4	Pile cap	30	1067100 Rials
5	Deck	30	1065300 Rials

appropriate. While, before the initiation of this design, foundation mix design was recognized as the most optimized mix design of municipality buildings project, and Imam Ali Bridge regarding the standard deviation and the target strength. However, economic comparison for the Qods project, regarding the total cost of concrete is a little difficult. However, it seems that like the projects of municipality buildings and Imam Ali Bridge, pile Q mix design which was previously known as an optimized design, is not economically very appropriate, table 13.

Looking at table 6 (row 5), this matter can be emphasized. The high amount of mean strength of pile Q at the age of 7 days (33.9 MPa) based on the specified strength of 35 MPa is an evidence for this matter. In other words, it can be said that the mix design of pile Q can be changed into the best and the most optimized position (both economically and strengths dispersion and target strength) with a little modification.

In general, comparing the fixed prices of the projects of the two companies, it is understood that in the Qods project more cost is spent on concrete production than in the projects of municipality building and Imam Ali Bridge. This matter can be indicated through comparing the fixed price of foundation concrete production and Pile N (Shahid Rajaee Company) with all prices of Ansar Company because both groups have the specified strength of 30 MPa.

The average cost of producing concrete with the specified strength of 30 MPa in Ansar Company is about 1,068,455 IRR, while the average cost of producing concrete with the same specified strength in Shahid Rajaee Company is about 1,259,688 IRR with difference of about 191,233 IRR.

Table 13. the fixed price of every 1 m^3 concrete for Shahid Rajaee Company

Row	Position	Specified strength	Fixed price of every m^3 concrete
1	Lean concrete	10	779700 Rials
2	Guardian structure	20	995485 Rials
3	Foundation	30	1232195 Rials
4	N pile	30	1287180 Rials
5	Q pile	35	1279940 Rials
6	Column	40	1339280 Rials
7	Segment	50	1532398 Rials

7. Conclusions

With the lower amount of standard deviation and also simultaneously approaching the target strength to the specified strength, the optimized mix design can be proposed.

- The most optimized situation for the mix design is when both the cases mentioned above take place and the amount of mean strength at the age of 28 days is close to the specified strength (a little more).
- With the age of the sample growing, dispersion and subsequently standard deviation increases.
- Mix design optimization system enables us to estimate and find the desired option which has both optimal economic and optimal concrete characteristics conditions. In addition, the most optimized mix design is not always the most economical design.

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