Evaluation of Strength Test Results of Concrete in Libya (Case Study)

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ABSTRACT

Concrete is one of the major construction materials in building construction industry. In Libya, concrete is probably the only materials used for building constructions and it is produced from three basic ingredients; namely, cement, aggregate and water. Accordingly, the product should be compatible with the standard specifications within manufacturing stages to ensure acceptable quality. This study focuses on creating system called (Concrete Expert) based on American Standards ACI214, that monitors concrete quality continuously throughout the implementation period and records daily readings of compressive strength tests and accordingly the control charts were established for each strength test data. The importance of control charts for the variables lies in the expression of the system status (inside or outside the control limits). The system records data, analyzes, and then determines the individual strength tests, moving average, moving range, ratio of minimum strength to design strength, and the adequacy of control over concrete and testing operations. The test data could be beneficial for these purposes: to assist the batch plant in the production of high-quality concrete for projects; to determine the adequacy of testing procedures, and to establish and refine the statistical relationships for future similar projects. The system was applied to test efficiency of the performance of two huge projects in Libya, also comparison and assessment quality of concrete for ten projects by inserting different records in different intervals of time; results show that the quality control ranged from excellent to a good as per the classification (Overall Variation/General construction testing) and ranged from fair to poor as per the classification (Within-test variations/Field controlling testing) according to ACI214.[1]

Keywords: Quality control ،Concrete, Control charts, Compressive strength.

INTRODUCTION

In recent years, many of the concrete structures collapsed which have caused in many deaths and damaged the buildings, which is mainly due to the poor concrete quality and control. Moreover, the ingredients of concrete should be of good quality that satisfies the requirements set in standards, which in order to get quality concrete product and satisfy the strength and durability requirement. In addition, to follow the concrete production process, quality control and corrective procedures are to be followed to obtain the desired quality concrete. Therefore, a good and a bad concrete may be made of exactly the same ingredients if there is a difference on the quality control of the production. (Abebe et al. 2005) [2].

A previous study by Chen, Sung, and Shih (2004) [3] found that the usual primary requirement of good concrete in its hardened state is a satisfactory compressive strength, but there are properties must be ensured such as density, tensile strength, impermeability, resistance to abrasion.

Concrete in reinforced concrete structure (RC) is generally under significant compressive stress load. As reported by American Concrete Institute code (ACI318-95) [1] to guarantee required quality and ductility, various tests have to be conducted to measure the concrete's compressive strength. The ductility of the RC structure is mostly influenced by the compressive strength of its concrete. Then, the fit compressive strength of concrete can be determined based on the ductile ratio. It takes daily concrete samples for strength tests and evaluation of the average compressive strength of concrete. If the compressive strength of concrete greatly exceeds the specified strength, it will seriously affect the ductile ratio of the structure. On the other hand, if the deviation of compressive strength of concrete is over the limit, it causes imbalance to the ductile ratio of structure, and adversely influence the seismic capability of the structure (Chen, Sung, and Shih 2004) [3].

Statistical process control (SPC) is a powerful collection of problem-solving tools useful in achieving process stability and improving capability through the reduction of variability (Montgomery 2009) [4]. Thus, (SPC) is one of the greatest technological developments of the twentieth century, because it is based on sound underlying principle and easy to use, has significant impact, and can be applied to any process (Montgomery 2009) [4]. As reported by Evaluation of Strength Test Results of Concrete ACI Committee 214R-02 [7] statistical procedures provide tools of considerable value when evaluating the results of strength tests. Information derived from such procedures is also valuable in refining design criteria and specifications. (Kane 1986)[5].So statistical methods are used to evaluate the manufacturing capacity and quality control of manufacturers. First, the standard deviation is decided by at least thirty successive sets of test results of dispensed concrete prescriptions, and then the average compressive strength requirement of concrete is imposed to identify the quality control capability of a manufacturer. In the process of construction, although the dispensed prescriptions of concrete are the same, some uncertain factors may cause imbalance to the deviation of compressive strength of concrete and affect the engineering quality and the required compressive intensity and ductility of the structure. It may even cause an unexpected structure collapse. The purpose of this research is developing a quality control system of concrete to undertake qualitative and quantitative assessment on the quality of concrete of building construction industry of Libya by using computer program (Concrete Expert). It works to monitor concrete quality continuously throughout the implementation period, to assess the control level of concrete and apply the criteria of the required average strength based on (ACI 214R-02), to evaluate the fitness and stability degree of compressive strength of concrete, draw control charts for variables (Average, X), (Range, R) for any period of time required, and to display the results of all tests at any time and obtain respective reports.

QUALITY CONTROL OF CONCRETE

Quality Control (QC) is all the measures that are taken during material selection, concrete production processes and on finished concrete products to ensure the compliance of works with the specification. Hence, concrete quality affects the overall quality of buildings to a higher extent. Moreover, to get quality concrete products, proper care and control has to be done during ingredient selection and production processes. It should also be reminded that all professionals and firms involved in the construction industry have to give special emphasis to quality control (Abebe et al. 2005) [2].

According to the Evaluation of Strength Test Results of Concrete ACI Committee 214R-02 [7], the results represent the potential strength of the concrete rather than the actual strength of the concrete in the structure. Inevitably, strength test results vary. Variations in measured strength may originate from any of the following sources:

- Batch-to-batch variations of the proportions and characteristics of the constituent materials in the concrete, the production, delivery, and handling process, and climatic conditions; and
- Variations in the sampling, specimen preparation, curing, and testing procedures (within-test).

Conclusions regarding the strength of concrete can only be derived from a series of tests. The characteristics of concrete strength can be estimated with reasonable accuracy only when an adequate number of tests are conducted, strictly in accordance with standard practices and test method.

Variation in the measured characteristics may be either random or assignable depending on cause. Random variation is normal for any process; a stable process will show only random variation. Assignable causes represent systematic changes that are typically associated with a shift in some fundamental statistical characteristic, such as mean, standard deviation or coefficient of variation, or other statistical measure.

Acceptance Criteria for Concrete Quality Control

The acceptance criteria for ACI-code are criteria used to determine the required average strength for various specifications or elements of specifications.The required average strength fcr'should exceed the specified compressive strength fc',and fcr'should be the largest strength calculated using all relevant criteria.

First Acceptance Criteria Number of Tests Less Than 15 Leads To

$$fcr' = fc' + 6.9Mpa \quad \text{When } fc' < 20.7\text{Mpa} \tag{1}$$

$$fcr' = fc' + 8.3Mpa \quad \text{When } fc' \geq 20.7\text{MPa and } fc' \leq 34.5\text{MPa} \tag{2}$$

$$fcr' = 1.10fc' + 4.8Mpa \quad \text{When } fc' > 34.5\text{MPa} \tag{3}$$

Second Acceptance Criteria Number of Tests More Than 15 Leads To

$$fcr' = fc' + zs \tag{4}$$

$$fcr' = fc' / (1- zv) \tag{5}$$

Where the specified strength in these situations will generally be between 21 and 35 MPa, S is the standard deviation, V is the coefficient of variation, and Z probabilities factor commonly used 1.28 or 2.33.

$$fcr' = (fc'- 3.5)+ zs \tag{6}$$

$$fcr' =(fc'-3.5)/(1 - ZV) \tag{7}$$

Where the specified strength ≤ 34.5 MPa, S is the standard deviation, V is the coefficient of variation, and Z probabilities factor commonly used 1.28 or 2.33.

$$fcr' = 0.90 * fc' + zs \quad (8)$$

$$fcr' = 0.90 * fc'/(1\text{-}ZV) \quad (9)$$

Where the specified strength > 34.5 MPa, S is the standard deviation, V is the coefficient of variation, and Z probabilities factor commonly used 1.28 or 2.33.

Variable Quality Control Charts

Quality-control charts have been used by manufacturing industries for many years as aids in reducing variability, increasing production efficiency and identifying trends as early as practicable. It is an essential tool of continuous quality control; monitor processes to show how performing and how capabilities are affected by changing in processes.

Control charts determine if a process is under control or out of control, also monitor the variance of output of a process over different intervals of times, by comparing this variance against upper and lower limits to see if it fits within the expected, specific, predictable and normal variation levels. Control charts are strongly recommended for concrete in continuous production over considerable periods.

Average Charts (X-bar Chart) Shows the results of all strength tests plotted in succession based on casting date. The results of all strength tests plotted in succession based on casting date. Chart often includes the specified strength and may include the acceptance criteria for individual tests. This chart is useful because it shows all of the available data but it can be difficult to detect meaningful shifts in a timely fashion. When the moving average of three tests is plotted, the larger the number of tests averaged, the more powerful the chart is in helping identify trends.

Range Charts (R-Chart) Shows the moving average of the range, the maximum difference between companion cylinders comprising a single strength test, which is used to monitor the repeatability of testing. These changes will not reveal day-to-day differences in testing, curing, capping, and testing procedures or testing procedures that affect measured strength levels over long periods.

SOFTWARE (PROGRAMMING) CONCRETE EXPRET

Introduction

Concrete Expert is the module of the concrete quality package. It is created to improve quality control process, mix design and raw materials management. The compressive strength test results of concrete were evaluated according to ACI 214R-02 (Standard for guidance in planning, designing, executing, and inspecting construction). Moreover, the Concrete Expert was determined as follows:

Inputs

1. Details of projects information such as owner, location, contractor.
2. Physical tests types of raw materials (aggregates, cements, water).
3. Equipment calibration and verification.
4. Batch plant: actual and intended batch quantities (every truck), customer details.
5. Fresh concrete tests and in situ temperature records.
6. Hardened concrete test result.

Processing

1. Calculate the average results for strength and range for every test at any period of time.
2. Criteria for strength requirement-determine the minimum required average strength concrete performance.
3. Compare the status that the pattern will be out of control, with samples distribution in the chart for any period of time.

Outputs

1. Establish multiple functions at the database such as adding or deleting records.
2. Viewing the contents of the database Statistics table for any period of time include Standard Deviation, adjusted standard deviation, Coefficient of Variation, Within-Test Standard Deviation, Within-Test Coefficient of Variation, and number of tests.
3. Construct quality control charts for (Individual test, moving average for strength of three, and Moving average for range of ten) at any period of time required, and express the suitable treatment if it needs.
4. Printing all outputs as reported.

Robust Pro-Active Scheduling

The software was written in C-Sharp, which is a programming language, and development environment created by Microsoft that runs on the .NET Framework.

In addition, it is based on C++ and contains features similar to those of Java. It is a simple, modern, and object-oriented language that provides modern day developers flexibility and features to build software that will not only work today but will be applicable for years in the future.

User Interface

The software contains main forms which could be explained as follows:

The Main Form When starting the program, this form will display first. The title of this form is Projects (Fig.1), and anymore forms will carry out from the main form as Add Project, Materials, Batches, Concrete QA/QC.

Fig.1: Main Form

The Processing Screen This screen named Project Batches, which includes two tabs: The first tab (Fig. 2) called Batch add/edit which display add and save the daily batch quantities, fresh concrete testing data. The second tab (Fig. 3) called Specimen Test which enter the hardened concrete test (Test Results).

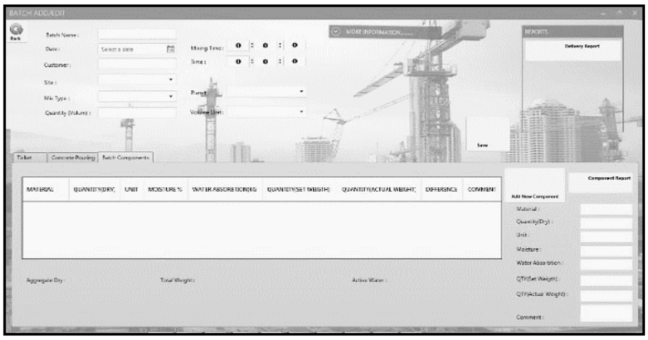


Fig.2: Project Batch Information

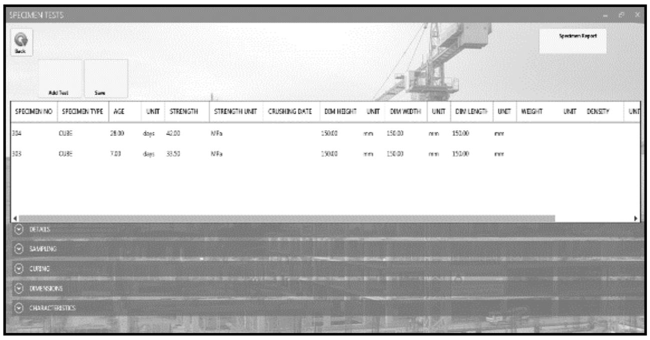


Fig.3: Specimen Test Information

Analysis Screen This screen named Concrete QC, which includes two tabs: The first tab (Fig.4) called Static Table which displays result of data at any certain period of project, where you can select starting and ending date for analysis data.

Fig. 4: Static Table for Project at Certain Period

The second tab (Fig.5) display data for determined Criteria for Strength Requirement fcr', and in this tab display the three main simplified Quality Control Charts.

Fig. 5: Criteria for Strength Requirement and Quality Control Charts

EVALUATION OF STRENGTH FIELD DATA

In order to get the representative data without bias, the two projects were selected randomly and scattered in Libya. The statistical analysis of the data of these by (Concrete Expert.ACI 214R) software was performied and the results were summarized in Table (1). From these results one can conclude that the site quality control of these projects ranged from Excellent to Good according to ACI214 as shown in Table (2). In this study the concrete compressive strength was defined as the strength obtained from standard cubes (150 mm) and converted to cylindrical molds with (150 mm) diameter and (300 mm) in height. The conversion factor used is cylindrical strength = 0.8 of cube strength. Each test result is an average of two test samples and average of three test samples.

The concept of statistics and probability nowadays is applied to so many industrial products so that to make productions or outputs have better quality and at the same time to become more cost effective. Therefore, construction as an industry, utilizes the basics of statistics and probability as a tool in improving quality and costs of productions.

The results of these data are shown in Table (1) the percentage of the tests below the required strength is 0.10% (1 in 10), and 0.01% (1 in 100) 214R [7], which leads to the probability factor (Z).

The statistical characteristics of the data gathered from all the projects are summarized in Table

(1). The range (Rg=fmax-fmin). Fig.6. Show acceptable/ unacceptable projects (in terms of concrete strength) according to ACI214 [7].

Table 1a: Summary of the Two Projects Strength Data

Project	P1	P2
Specified Strength (MPa)	28	25
Number of Samples (ns)	48	99
Number of Tests	24	33
Criterion No. Using	1	3
Criterion Equation Using	St. Deviation	St. Deviation
Class of Operation (Overall Variation)	General Construction Testing	General Construction Testing
Class of Operation (Within test Variation)	Field Control Testing	Field Control Testing

Table 1b: Summary of the Results of the Two Projects Strength Data

Project	P1	P2
Number of Samples(ns)	48	99
St. Deviation (s)	1.92	3.74
COV% Coefficient of Variation	6.11	13.48
Average Strength (fcm) MPa	31.41	27.75
Average of Range	2.12	3.4
Criterion Equation Using	St. Deviation	St. Deviation
Criterion No. Using	$fcr' = fc' + zs$	$fcr' = (fc' - 3.5) + zs$
Probabilities factor Z	1.28	2.33
Specified Strength fc' (MPa)	28	25
Required Average Strength (fcr)	30.65	30.21
Class of Operation (Overall Variation)	General Construction Testing	General Construction Testing
Class of Operation (Within test Variation)	Field Control Testing	Field Control Testing

Table 2: Classification of Libyan projects According to Standard of Concrete Control ACI 214

Number of projects	Overall variation				
	Standard deviation for difference control standard, MPa				
	Excellent	Very good	Good	Fair	Poor
	Below 2.8	2.8 to 3.4	3.4 to 4.1	4.1 to 4.8	Above 4.8
P1	■				
P2			■		

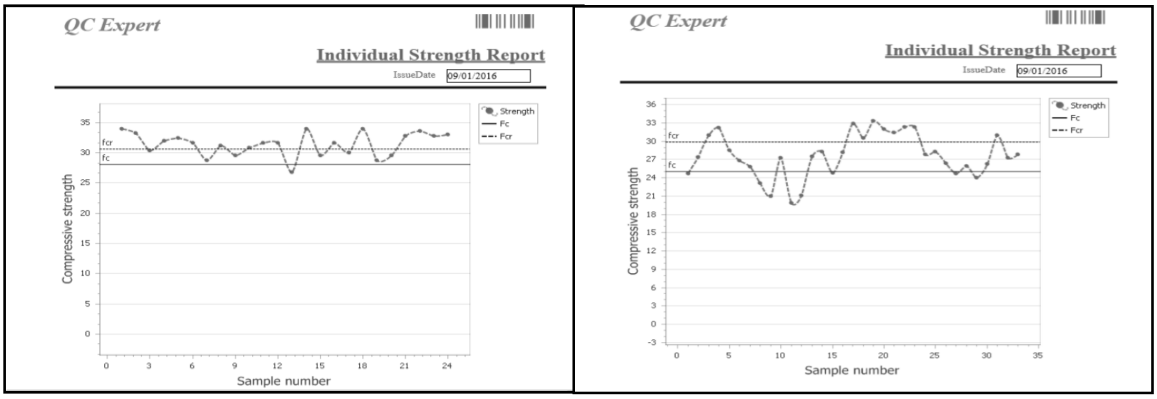
State of Control

As shown on Fig.6 the (Concrete Expert ACI214R), software monitors the state of control of the manufacturing process through the use of the QC charts. It is observed that:

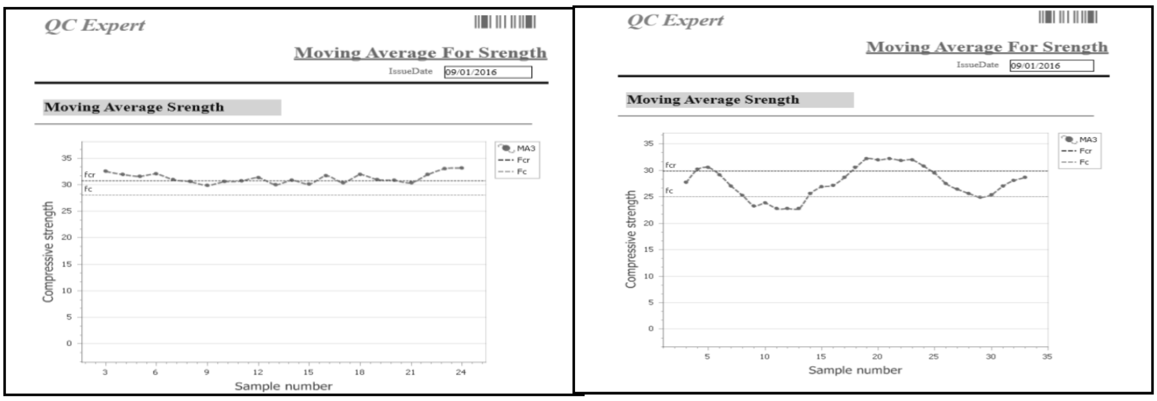
- The top chart in Fig.6 shows the results of all strength test results during the production. The action or interference limits are equal to the acceptance criteria specified for a particular

- project. Control chart of sample for project P2 shows the data outside lower control limit fc′. Comparison with control chart of sample for project P1 does not show any data fall outside established limits.
- The middle chart in Fig.6 shows the moving average of consecutive tests, in this chart more easily identified the influence of effects such as seasonal change and change in material. The comparison indicates increasing the number of data points averaged increases the ease with which the trend is detected and improves the reliability of the trend identification, that is, the likelihood that the trend indicates a real change.
- The lower chart in Fig.1 shows the moving average of the range, which used to detect change in variability of the process. Control chart of average range of the previous 10 consecutive tests for project P1 show smaller variations, comparison with control chart for project P2 the tests show greater variations or lower average strength levels than actually exist.

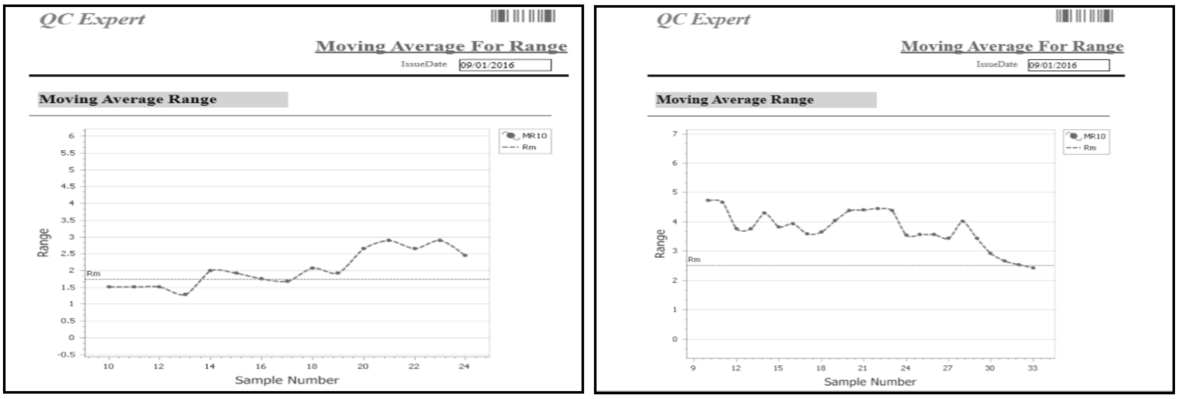
All of these comparison indicate satisfactory performance contractually and a process apparently in the control for Project P1.



a. Individual Strength Tests



b. Moving Average of Three Strength Tests



c. Moving Average for Rang

Fig. 6: Reports Comparison (Concrete Expert. ACI 214R Software) QC Charts between (Project P1 and Project P2)

CONCLUSIONS

1. This study investigated the quality of raw materials and the fitness and stability degrees of concrete quality that affect tremendously the stability of concrete structures. Based on the results of this study, the following conclusion can be drawn:
2. New software was created to evaluate the level of quality control of concrete by using ACI214R which prescribes a statistical approach.
3. The outcome of statistical analysis made on compressive strength test results of two huge projects in Libya indicated that the quality control ranged from excellent to a good. As per the classification: (Overall Variation) of ACI 214R-02, control over testing. The within test coefficient of variation (V1) indicates that the control over testing changed from “fair to poor” this corresponds to within-test range equation (R) which is (max strength – min strength) and confirms the believe that fluctuations in the range value are not due to variations in the manufacturing process but rather to variation in testing procedures.
4. To put the process of testing back to control, the quality control laboratory should find out what has caused the change in the inherent variation and make corrections accordingly. Normally, when the out-off control situation is due to inadequate testing, the probable causes may include a momentary lack of attention, the fatigue, a change in testing method, or errors in measurements and arithmetic.
5. The causes for poor quality can be summarized as ignorance, poor materials, poor design, poor detailing, and poor workmanship, improper quantity of cement, improper concrete mix, excess water, inadequate compaction, substandard forms, inadequate curing, inadequate cover and above all the lack of technical knowledge.
6. There is a need for further researches to improve the quality of workmanship involved in the building construction industry of Libya and its impact on concrete quality, and developing a new version of Software by addition of different data of performance improvements and new features.

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