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Quality of Concrete of Recent Development Projects in Libya

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***Abstract*—**Numerous concrete structures projects are currently running in Libya as part of a US$50 billion government funding. The quality of concrete used in 20 different construction projects were assessed based mainly on the concrete compressive strength achieved. The projects are scattered all over the country and are at various levels of completeness. For most of these projects, the concrete compressive strength was obtained from test results of a 150mm standard cube mold. Statistical analysis of collected concrete compressive strengths reveals that the data in general followed a normal distribution pattern. The study covers comparison and assessment of concrete quality aspects such as: quality control, strength range, data standard deviation, data scatter, and ratio of minimum strength to design strength**.** Site quality control for these projects ranged from very good to poor according to ACI214 criteria [1]. The ranges (Rg) of the strength (max. strength – min. strength) divided by average strength are from (34% to 160%). Data scatter is measured as the range (Rg) divided by standard deviation (σ) and is found to be (1.82 to 11.04), indicating that the range is $\pm 3\sigma$. International construction companies working in Libya follow different assessment criteria for concrete compressive strength in lieu of national unified procedure. The study reveals that assessments of concrete quality conducted by these construction companies usually meet their adopted (internal) standards, but sometimes fail to meet internationally known standard requirements. The assessment of concrete presented in this paper is based on ACI, British standards and proposed Libyan concrete strength assessment criteria.

***Keywords*—**Acceptance criteria, Concrete, Compressive strength, quality control

I. Introduction

CONCRETE is one of the most commonly used as building materials worldwide. In Libya, concrete is probably the only materials used for building constructions. The quality of concrete is too difficult to control since it made up from different hetrogeuause materials. It is even much difficult to maintain a consistency of concrete quality while producing concrete from different batching plants and for different construction sites. In order to produce good concrete, there are certain criteria the concrete has to be satisfactory in its hardened state, and also in its fresh state. During concrete transportation from the mixer and placed in the form work, the concrete should show good consistence, easy compact and that the mix be cohesive enough for the method of placing. 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. To guarantee good durability. The basic factors which have to be considered in determining the mix proportion are presented in many research documents and text book such as [Nevel][2].

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Generally, engineers take daily concrete samples for strength tests and evaluation of the average compressive strength of concrete prescribed by ACI 318-02[3]. Kausay T. et al. [4] showed in their paper the role of the acceptance probability and the acceptance constant during the evaluation of test and their significance during the conformity verification procedure. Colorado procedure 65-01 [5] is one of the standard practices for evaluating low strength test results of concrete cylinders. ACI E702 [6] Shows an example of acceptance of concrete test results according to ACI *Building Code Requirements for Structural Concrete* 318-05. Mohamed [7], gave an assessment of the current two acceptance criterion of the Egyptian code for concrete compressive strength as tested by standard cubes molds.

II. Acceptance Criteria

The acceptance criteria for ACI-code, BS-code were explained in details in reference [8], and the following inequalities were reached

ACI-code:-

(a) First acceptance criteria leads to

$$\alpha \geq \frac{1}{1-1.34\text{COV}} \quad (1a)$$

(b) Second acceptance criteria leads to

$$\alpha \geq \frac{1}{1-2.33\text{COV}} \quad (1b)$$

Where, α is the bias factor (mean to nominal) and COV is the coefficient of variation

BS-code:-

The general acceptance criterion is written as

$$\alpha \geq \frac{1}{1-\frac{1.64\text{COV}}{\sqrt{n}}} \quad (2)$$

For n=1, 2, 3, 4. Where, n is group of test results

III. Evaluation Of Actual Strength Data

In order to get unbias and representative data, the twenty projects were selected randomly and scattered all over Libya. The statistical analysis of the data of these projects was preformed and the results were summarized in Table (I). From these results one can conclude that the site quality control of these projects ranged from very good to poor according to ACI214 [1] as shown in Table (II). In this paper the concrete compressive strength was defined as the strength obtained from standard cubes (150mm) and in sometimes it is converted to cylindrical molds with (150mm) diameter and (300mm) in height the conversion factor used is cylindrical strength = 0.8 of cube strength. Knowing that each given data point is an average of at least two strength test results, and the data for each project follows a normal distribution curve as shown in Fig (1).

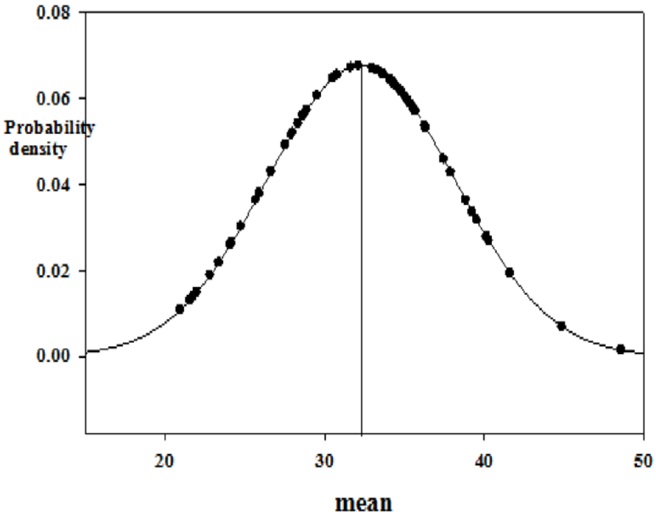

Fig. 1 Relationship between mean and characteristic strength for project P11

The statistical characteristics of the data gathered from all the projects are summarized in Table (I). The symbols in Table (I) are defined as follows:-

The number of data points (ns), the average strength (*fcm*), the standard deviation (σ), the maximum strength value (*fmax*), the minimum strength value (*fmin*), the range (*Rg=fmax-fmin*),The ratio of range to standard deviation (*Rg/σ*), the design strength of the project (*fcu*), the ratio of minimum strength to design strength (*fmin/fcu*), the ratio of range to the average strength (*Rg/fcm*), the coefficient of variation (*COV=σ/fcm*), and the bias (mean to nominal) factor (*α=fcm/fcu*). The data dispersion is implicitly included in the COV as well as the mean value. The values of α's reflects how far the required strength (*fcr*) is from the design strength (*fd*). Fig (2) and Fig (3) show acceptable/ unacceptable projects (in terms of concrete strength) according to ACI, BS respectively. hese curves that the number of acceptable projects by BS is about (11) as compared to those accepted by ACI, a criterion which is about (6).

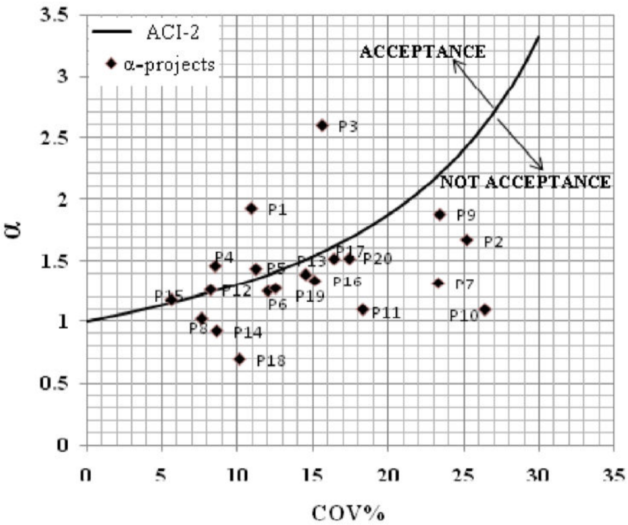

Fig. 2 Acceptance criterion (ACI) and actual strength data

That is because the BS code is based on 95% accepting criteria (one failed sample in 40 samples) to be rejected, while ACI code is based on 98% accepting (one failed sample in 100 samples) to be rejected. From Tables (I&II) the percentage of (*Rg/fcm*) for (20) projects ranges from (33.79 to 160.56) %, and the data scatter as given by (*Rg/σ*) ranged from (1.815 to 11.04) with an average= 4.703, which means that all data included in the range ±3σ. The ratio of (*fmin/fcu*) for (20) projects ranges from 0.364 to 1.14, and the factor α's for the (20) projects ranged from (0.693 to 2.078). It can be observed from this Table that the average of ($\alpha = \frac{fd}{fc'}$) is equal to 1.317 which is more than 1 which mean's the average strength for all projects is more than the design strength by about 32%.

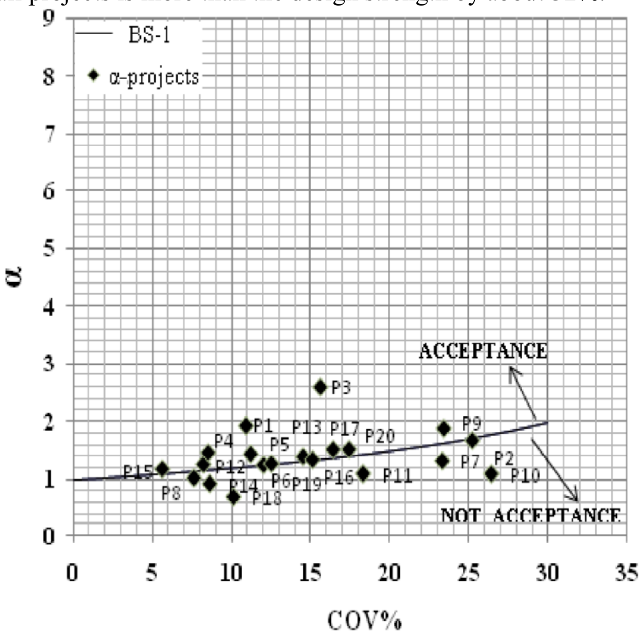

Fig. 3 Acceptance criterion (BS) and actual strength data

TABLE I
SUMMARY OF THE TWENTY PROJECTS' STRENGTH DATA

Project	n_s	f_{cm}	σ	f_{max}	f_{min}	R_g	R_g/σ	fcu
P1	443	48.15	5.25	59.14	15.75	43.39	8.265	30
P2	42	40.1	10.1	59.28	21.09	38.19	3.781	30
P3	30	62.326	9.696	69.1	26.93	42.17	4.349	30
P4	30	40.861	3.455	48.1	35.13	12.97	3.754	35
P5	28	21.518	2.416	23.95	17.1	6.85	2.835	15
P6	56	46.704	5.586	56.53	34.7	21.83	3.908	37.5
P7	51	39.49	6.994	48.89	24.44	24.45	3.496	30
P8	48	30.616	2.311	32	25.3	6.7	2.899	30
P9	15	56.3	13.491	53.74	29.25	24.49	1.815	30
P10	14	32.776	8.658	42.985	16.73	26.25	3.032	30
P11	177	32.826	5.992	51.11	15.4	35.71	5.96	30
P12	270	56.526	3.676	65.9	46.8	19.1	5.196	45
P13	221	48.648	5.057	64.86	35.7	29.16	5.766	35
P14	285	46.043	4.011	57.66	36.43	21.23	5.293	50
P15	69	41.102	2.294	44.1	29.73	14.37	6.265	35
P16	36	20.055	2.266	22.37	15.43	6.94	3.063	15
P17	228	45.487	4.927	55.56	33.9	21.66	4.396	30
P18	89	34.629	5.035	73.82	18.22	55.6	11.04	50
P19	105	47.554	5.952	62.27	32.44	29.83	5.012	37.5
P20	62	45.525	7.902	57.77	26.66	31.11	3.937	30

Project	n_s	$fmin/fcu$	Rg/fcm%	COV%	a	t	$\%\rho = (fcr - fc')/\sigma$
P1	443	0.525	90.11	10.90	1.605	3.457	99.97%
P2	42	0.703	95.24	25.19	1.337	1	84.13%
P3	30	0.898	67.66	15.56	2.078	3.334	99.96%
P4	30	1.004	31.74	8.46	1.167	1.696	95.50%
P5	28	1.14	31.83	11.23	1.434	2.698	95.52%
P6	56	0.925	46.74	11.96	1.245	1.648	95.03%
P7	51	0.815	61.9	23.30	1.316	1.357	91.26%
P8	48	0.843	21.88	7.55	1.021	0.267	60.53%
P9	15	0.975	43.5	23.4	1.877	1.949	97.43%
P10	14	0.558	80.1	26.42	1.093	0.321	62.59%
P11	177	0.513	108.79	18.25	1.094	0.472	68.15%
P12	270	1.04	33.79	8.17	1.256	3.135	99.92%
P13	221	1.02	59.99	14.45	1.390	2.699	99.65%
P14	285	0.729	46.11	8.64	0.921	-0.987	
P15	69	0.849	34.96	5.58	1.174	2.66	99.61%
P16	36	1.029	34.61	15.11	1.337	2.231	98.71%
P17	228	1.13	47.62	16.42	1.516	3.143	99.92%
P18	89	0.364	160.56	10.07	0.693	-3.053	
P19	105	0.865	62.27	12.52	1.268	1.689	95.44%
P20	62	0.889	68.3	17.4	1.518	1.965	97.35%

TABLE II
CLASSIFICATION OF LIBYAN PROJECTS ACCORDING TO STANDARD DEVIATION ACI 214[1]

Number of project	Overall variation				
	Standard deviation for different control standards, (Mpa)				
	Excellent	Very good	Good	Fair	Poor
	Below (2.81)	From (2.81) To (3.52)	From (3.52) to (4.22)	From (4.22) to (4.92)	Above (4.92)
P1					■
P2					■
P3					■
P4		■			
P5	■				
P6					■
P7					■
P8	■				
P9					■
P10					■
P11					■
P12			■		
P13					■
P14			■		
P15	■				
P16	■				
P17				■	
P18					■
P19					■
P20					■

IV. PROPOSED LIBYAN MIXED DESIGN AND ACCEPTING CRITERIA

The evaluated projects were scattered all over Libyan territory. Some of these construction projects were affected by Mediterranean Sea humid weather, while others were affected by desert hot weather. It is worth saying that these projects were constructed by different companies and concrete mixes were designed by different codes. Furthermore the concrete quality control and supervision were done by different consulting firms which follow different quality control and assessment procedures. The need of concrete unified strength accepting criteria to the in the Libyan construction market is essential. Due to lack of previous data from all batching plants used in these projects, the proposal concrete mixed design is based on the results of evaluating data from current and past 20 projects. The results of these data are shown in Table in which the standard deviation can be estimated as (σ=3) in order to get the concrete quality varies between excellent and very good, and the percentage of the tests below the required strength is 0.13% (1 in 741) [1], which leads to the probability factor (ρ) = (3). The required concrete compressive strength can be written as follow:-

$$f_{cr}=f_c'+\rho\sigma \quad (3)$$

By substituting the probability factor (ρ) = (3) and standard deviation (σ) = (3) in to the above equation (3) leads to:-

$$f_{cr}=f_c'+9.0 \quad (4)$$

The above relation show that the required strength is more than the design strength by (25% to 50%) depends on strength values, the lower the strength of concrete the larger the percentage increase. The relation is valid for cylindrical samples of 150mm diameter, 300 mm high, at 28 days of age wet cured and the relations adheres to the previous finding [10]. Generally the concrete technology tests the conformity of compressive strength on cubes with the size of 150mm at the age of 28 days which were mix cured (first 7 days under the water, 21 days on air)[4] to be closely compatible to the site condition. By applying the above analogy to the proposed Libyan criteria, the steps of transformation is carried out as follow:

$f_{cu}/f_c'=0.97/0.76$ is the strength ratio between the wet cube samples with size of 150mm and, wet cylindrical samples of 150mm diameter, and 300mm high.

$f_{cu}/f_{cuH}=0.92$ is the ratio of the compressive strengths of the wet cured and mix cured normal concrete cubic samples with the size of 150mm. Based on the above argument, one can find the relation between the mixed cured cubic samples (f_{cuH}) with size 150mm, andthe wet cured cylindrical samples of diameter 150mm, 300mm high (f_c')

$$f_{cuH}=[0.97/(0.76*0.92)]f_c'\approx 1.387f_c'$$

By substituting into right and left side of proposed Libyan formula, the result leads to

$$\frac{f_{cr,cube,H}}{1.387}=\frac{f_{cub\ H}}{1.387}+9.0 \quad (5)$$

$$f_{crcube\ H}=f_{cub\ H}+12.5\ \text{(MPa)} \quad (6)$$

This gives the relation of the mean compressive strength and the design strength for cube samples with dimensions 150*150*150 mm, cured as mixed currying (7 days wet, and 21 days on air).

$$f_{cr,cyH}=fc'H+9/0.92 \quad (7)$$

For cylinder mold,

$$f_{crcylH}=fc'_H+9.78\ \text{(MPa)} \quad (8)$$

This gives the relation of the mean compressive strength and the design strength for cylinder samples (150*300) mm cured as mixed currying, but the required average compressive strength when data are available to establish a standard deviation, the proposal Libyan criteria required that 99% of all tests to be equal or above the required strength. The standard-deviation is obtained by analyzing the concrete produced data. Since the standard-deviation for projects is not known at the beginning of the project, one can use similar data available from close by batching plant in condition that the plant use the same material which well be used in this new plant and the number of data point to be used in evaluating the standard deviation should not be less than 50 test results to overcome the variation in weather, material, quality control, testing equipments and method of testing. If the design strength $fd\leq(40/45)$ *Mpa* (cylinder strength / cube strength) the required strength in mix should be taken the larger of:-

$$fcr=1.15fd+1.5\sigma \quad (9)$$

$$fcr=fd+2.58\sigma \quad (10)$$

Equation (7) is based on a probability of (one sample failed in 200 samples) that the average of three consecutive tests may be less than *1.15fd* and equation (8) is based in similar probability that an individual test may be below the specified compressive strength *fd*.

The concrete strength is considered to be satisfactory as long as the following requirements are met:

- No individual strength test results (R1, R2, R3) falls below *fd.*
- Every arithmetic average of any three consecutive strength tests exceeds at least 15% *fd* (design strength).

If (R2-R1) $<$ 10%*fd.* $<$ (R3-R2), then the new average = $(\frac{R2+R1}{2})$

If$(R3 - R2) < 10\% fd < (R2 - R1)$, then the new average = $(\frac{R3+R2}{2})$.

If both (R2-R1) and (R3-R2) $<$ 10% *fd,* the average= $(\frac{R1+R2+R3}{3})$.

The acceptance criteria for Proposal Libyan code was explained in details in reference [8], and the following inequalities were reached**:-**

- First accepting criteria $\alpha \geq \frac{1}{0.87-1.304COV}$ (11)
- Second accepting criteria $\alpha \geq \frac{1}{1-2.58COV}$ (12)

It is clear from Fig (4) that the number of accepting projects by the proposed national Libyan criteria is less than both ACI and BS codes.

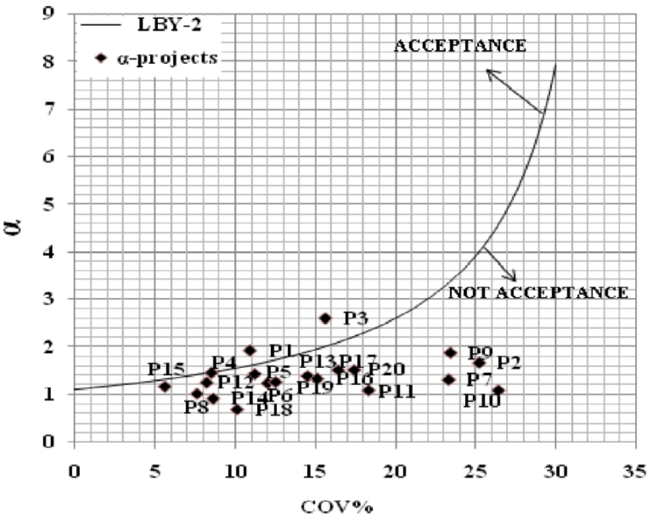

Fig. 4 Acceptance criterion (P.Libyon) and actual strength data

This was expected because ACI code specify that 98% of all test data to be accepted, and BS specifies that 95% of all data to be accepted. The comparison between the proposal Libyan accepted criteria & both ACI & BS codes is given in Fig (5).

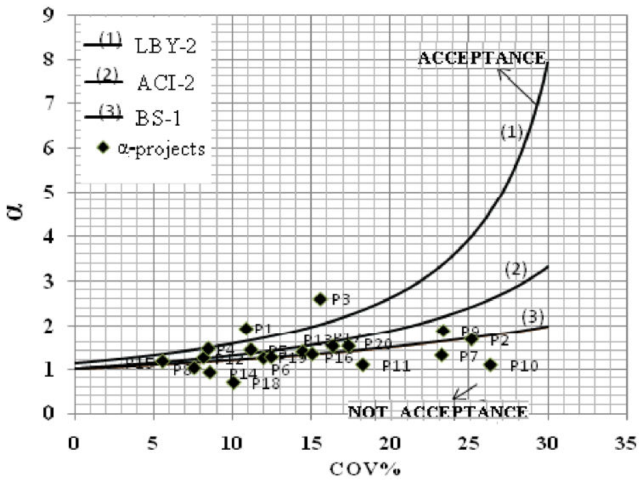

Fig. 5 Acceptance criterion (ACI, BS, P.Libyan) and actual strength data

V. Conclusions

The quality of concrete of twenty construction project in Libya was assisted by using both ACI & BS quality control criteria. The assessment of site concrete quality of these projects revealed that the quality. Ranged from very good to poor according to ACI214 criteria. Statistical analysis of data considered in this study show a normal distribution of the actual field with a bias factor for concrete compressive strength ranging from 0.693 to 2.078 with a COV ranging from 5.58 to 25.19 %. The proposal Libyan criteria of accepting concrete compressive strength gave an upper limit for both ACI & BS codes this proposal criterion can be used to overcome the deficiency in concrete production as well as the lack of accuracy in testing method.

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