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A STATISTICAL STUDY ON READY-MIXED CONCRETES PRODUCED IN ESKIŞEHIR AFTER THE 1999 EARTHQUAKE

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ABSTRACT : *In this study the compressive strength results of samples, which have been taken from concrete produced in ready-mixed concrete facilities in the province of Eskişehir and its vicinities after the earthquakes of 19th August and 12th November, have been statistically evaluated. Ready-mixed concrete facilities belonging to three different plants and results of Concrete Laboratory of Osmangazi University Civil Engineering Department have been evaluated separately for the years 1999, 2000 and 2001, and the results have been discussed according to the variability coefficient given by ACI (American Concrete Institution) and criteria of TS 500/1984 Standard with respect to concrete quality. To this extent, concrete compressive strength results of 3910 samples, 1909 of which are for 7 days and 2001 of which are for 28 days, have been evaluated. Average compressive strengths (f_{cm}), standard deviations (σ) and variability coefficients of the samples have been found and the results have been examined with respect to their compliance with TS 500/1984 and ACI criterias. By evaluating the available data we have tried to have an idea about the quality and reliability of concrete produced in Eskişehir after the earthquake.*

KEYWORDS : *Ready-mixed concrete facility, compressive strength, standard deviations, variability coefficients.*

1999 YILINDAKİ DEPREMLERDEN SONRA ESKİŞEHİR'DEKİ HAZIR BETON TESİSLERİNDE ÜRETİLEN BETONLAR ÜZERİNDE İSTATİSTİKSEL BİR ÇALIŞMA

ÖZET : *Bu çalışmada, Eskişehir ili ve çevresinde üretim yapan hazır beton tesislerinde 19 Ağustos ve 12 Kasım 1999 depremlerinden sonra üretilen betonlardan alınan numunelerin basınç dayanımı sonuçları istatistiksel olarak değerlendirilmiştir. Üç farklı firmaya ait hazır beton tesisi ve Osmangazi Üniversitesi İnşaat Mühendisliği Bölümü Beton Laboratuarındaki sonuçlar 1999, 2000 ve 2001 yılları için ayrı ayrı değerlendirilerek bulunan sonuçlar ACI (Amerika Beton Enstitüsü) tarafından verilmiş olan değişkenlik katsayısı ve TS 500/1984 Standardı kriterlerine göre beton kalitesi açısından tartışılmıştır. Bu kapsamda 1909 adedi 7 günlük ve 2001 adedi de 28 günlük olan toplam 3910 adet numuneye ait beton basınç dayanımı sonucu değerlendirilmeye alınmış ve numunelerin ortalama basınç dayanımları, (f_{cm}), standart sapmaları (σ), değişkenlik katsayıları bulunarak sonuçların TS 500/1984'e göre uygun olup olmadığı ve ACI kriterlerine göre durumu incelenmiştir. Elde edilen veriler değerlendirilerek depremden sonra Eskişehir'de üretilen betonların kalitesi ve güvenirliliği hakkında bir fikir edinilmeye çalışılmıştır.*

ANAHTAR KELİMELER : *Hazır beton tesisi, beton basınç dayanımı, standart sapmaları, değişkenlik katsayısı.*

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I. INTRODUCTION

The importance of concrete quality with respect to the structure is safety, durability and economy. People dealing with reinforced concrete have been building the projects on the concept of safety especially until recent years. The concept of safety bears importance for the whole supporting structure or the supporting structure element. The most important condition for ensuring the safety is some strength of the material forming the structure or the structure element. The first approach towards founding a relation between structure safety and concrete compressive strength has been the use of safety stress. On condition that the stress occurring upon loading on the structure is smaller than the safety stress, it is accepted that the safety of the structure has been ensured [1]. Although people preparing projects do not undervalue this principle in structure design when an investigation is carried out about the causes of damage on reinforced concrete buildings collapsed especially in earthquakes of recent years, it will also be seen that a result as "low concrete compressive strength" emerges [2].

When new products, new phases and physical structures, which result from hydration reactions of concrete cement that is a composite produced of at least three different materials, are considered the situation becomes more complex structurally. When compressive strength of concrete is under discussion, an explanation can not be made without considering the qualitative and quantitative condition of concrete components, new products and phases resulting from hydration and production, casting and maintenance conditions of concrete. Due to the fact that it is a multi-component grain composite and casting and maintenance conditions have an important influence on the characteristics of concrete, its quality control is also quite difficult. Besides, as a result of the fact that effects of the factors that stem from casting and maintenance and that may cause differences in concrete strength do not emerge immediately, and that the strength may be determined in at least 7 days under normal conditions and in 28 days exactly, statistical methods and theory of probability are used in order to remove the uncertainty occurred in the beginning. Thus, evaluation criteria based on results of statistical studies are given in standards and in terms of contracts concerning the concrete.

II. THE STATISTICAL EVALUATION OF THE CONCRETE

There are many random variables in concrete stemming from casting and maintenance regardless of how much the concrete components are controlled. This fact increases the effect of uncertainty on concrete compressive strength estimations. As it is known, phenomena of random character are explained by statistics and thus by probability theories. As a matter of fact, the acceptance conditions are defined with a certain probability in acceptance criteria concerning the strength [3]. The situation in which the probability is 0 means that the event in question will never happen and the situation when it is 1 shows that it will definitely happen. The approximation of probability from 0 towards 1 shows that the chance of the event to happen has increased. "*The probability of the obtained strengths to be smaller than the characteristic strengths should be 10 % at most*" condition given for characteristic strength in TS 500 necessitates the understanding of distribution parameters of strengths in concrete compressive strength evaluation

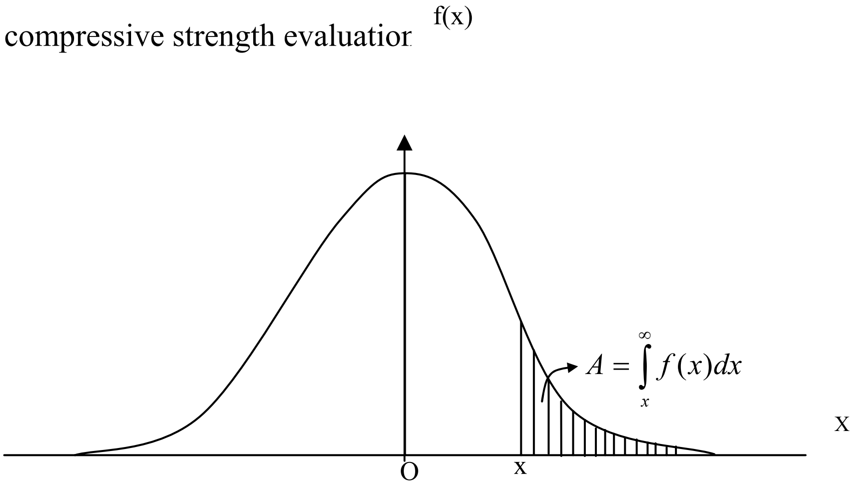

Figure 1. Gauss curve.

For this reason probability density and Gauss curve emerging as a result of this and also parameters of statistical moment type are frequently used in concrete compressive strength evaluations (Figure 1).

The top of the Gauss curve indicates the place of the average strength (f_{cm}) that has the highest possibility of being obtained. This value is the target value having the highest possibility of being obtained [4]. The strengths, obtained within a structure where every kind of variable possible to affect the strength is supervised, show a similar distribution as in Figure 2 and take their place close to the average strength by a slight difference. Otherwise they show distribution far from the average as in Figure 2. In this situation the possibility of obtaining the average will certainly decrease. This explained situation is closely linked with standard deviation (σ) and variance (V) known as variability coefficient (Figure 2). In statistical analysis, the less standard deviation value showing how much the results of concrete strength deviate from the average, the more convergence of values around the aimed value with the aimed value. In other words, the value to be aimed (f_{cm}) in order to obtain the characteristic compressive strength (f_{ck}), which establishes a basis in the preparation of projects, will be that much close to $f_{ck.}$ As a result of this, the chance to obtain f_{ck} and higher values with a possibility of 90 % is achieved by aiming at an f_{cm} value, which is not much high. This means, in a sense, the ensuring of economy [4].

The value used to get information about the central value of an average random variable and about the magnitude of the expansion around this value is variance. If the variance is big, this shows that the expansion of the variance is big within its own average environment (Figure 2). The size of the variance is like the square of the random variable. As this is physically meaningless for the most part the use of standard deviation, which is the square root of the variance, rather than the variance is chosen [5]. Standard deviation is more meaningful as it has the same size with the random variable. However, in order to understand which variable expands more out of two variables having different averages, the comparison of their standard deviations will not be sufficient. In this situation the use of variation coefficient, which is a non-dimensional coefficient, will be appropriate. TS 500/1984 criteria have been taken as a basis in the evaluation as the study also covers the year 2000 and before with respect to the period it belongs to. Within the scope of the study, the strengths evaluated in accordance with TS 500/1984 for C 20 concrete class is as it is shown in Table 1. Two different methods have been defined for the control of the mentioned standard concrete quality in TS 500;

a) As the concrete compressive strength (the characteristic strength) envisioned in the project is f_{ck}, the average strength $f_{cm,}$ which will be taken as a basis in concrete mixture calculations, is calculated by using the following correlation when the standard deviation (σ) is known.

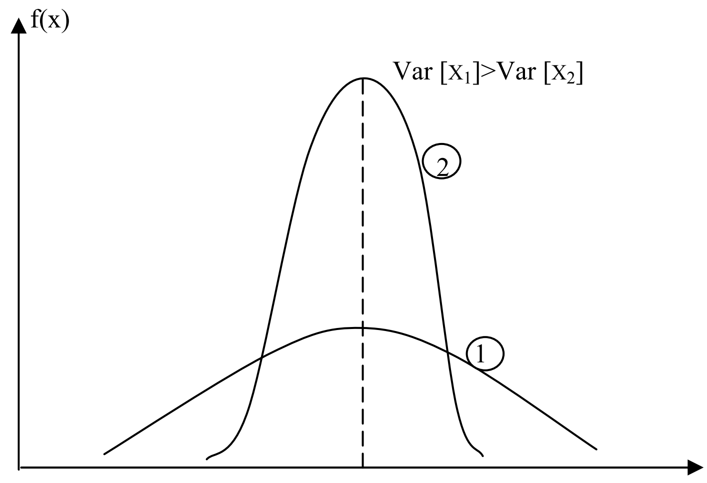

Figure 2. Possibility density functions of two random variables having the same average

$$f_{cm} = f_{ck} + 1.28\ \sigma$$

b) This is a method used to calculate the target strength when the standard deviation is unknown. But this method is not used to evaluate the results of the experiments. f_{cm} may be found approximately by increasing f_{ck} with a certain amount (Δf).

$$f_{cm} = f_{ck} + \Delta f$$

In the above-mentioned standard Δf is 6 MPa for C 20. TS 500/1984 stipulate the following conditions to be ensured for the acceptability of the concrete in the evaluation of experiment results:

$$f_{cm} \geq f_{ck} + 3\ \text{MPa}$$

$$f_{cmin} \geq f_{ck} - 3\ \text{MPa}$$

This evaluation is a criterion applied only to results of concrete parts, in other words the ones to be taken once, for example to 3 experiment results. This control is meaningless after all experiment results are obtained. For this reason, the only criterion to be applied to all experiment results should be;

$$f_{cm} = f_{ck} + 1.28\ \sigma \geq \text{Class Strength.}$$

c) The sample ratio smaller that f_{ck} should be 10 % at most.

American Concrete Institute (ACI) puts forward the following evaluation concerning the standard deviation and the variation coefficient in the committee report No. 214 (Table 1) [6].

Table 1. Evaluation Criteria Put Forward by the ACI

Standard Deviation, (MPa)	Variation Coefficient, %	***Evaluation Classes***
$\sigma < 2.81$	-	Perfect
$2.81 < \sigma < 3.52$	$V<10$	Very Good
$3.52 < \sigma < 4.22$	$10<V<15$	Good
$4.22 < \sigma < 4.92$	$15<V<20$	Average
$4.92 < \sigma$	$20<V$	Insufficient

III. INTERPRETATION OF THE RESULTS

The following evaluations are given by taking the 28-day compressive strength of concrete, which have been produced in Eskişehir after the earthquake and whose basic statistical parameters have been calculated in Table 2, as a basis [7-9].

III.1 Evaluation with Respect to TS 500

As the standard deviations of strengths being evaluated have been given in Table 2; on condition that some calculations are carried out by using the data on general evaluation column taking 28-day samples for C20 concrete strength class in the correlation $f_{cm} = f_{ck} + 1.28\sigma$ which is given when the standard deviation is known in TS 500/1984, we obtain the following values:

- For the year 1999 $f_{cm} = 20+1.28 \times 29 = 23.7$ MPa
- For the year 2000 $f_{cm} = 20+1.28 \times 36 = 24.6$ MPa
- For the year 2001 $f_{cm} = 20+1.28 \times 29 = 23.7$ MPa

By using the correlation $f_{cm} = f_{ck} + \Delta f$ in f_{cm} calculation which is done by assuming that standard deviation is unknown, a value is obtained as follows:

f_{cm}=20+6= 26 MPa

As it may be seen, the values calculated on standard deviation basis are lower than the values necessary to be found according to the precaution margin (Δf) calculation. The conditions given as an acceptance criterion in TS 500/1984 are as follows:

$f_{cm-} \geq f_{ck} + 3$ MPa

$f_{cmin} \geq f_{ck} - 3$ MPa

In evaluations, taking these conditions as a basis, the following values are obtained:

- f_{cm} and f_{cmin} values are obtained for the year 1999.
- f_{cm} condition is ensured but f_{cmin} values are not for the year 2000.
- f_{cm} and f_{cmin} conditions are ensured for the year 2001.

In evaluations carried out in the light of these evaluations and by considering the conditions, stated in TS 500, which read “sample ratio smaller than f_{ck} should be 10 % at most”, it is determined that concrete produced in years 1999 and 2001 comply with TS 500. The fact that concrete produced in 2000 do not comply with this condition stems from f_{cmin} itself and this is out of question for f_{cm} in respect to study results [10].

III.2 Evaluation with Respect to the Criteria of ACI

The following results are obtained as a result of evaluations carried out according to ACI 214 criteria given in Table 2 with respect to the standard deviation and the variability coefficient. It is put forward that;

- standard deviation of 28-day samples of the year 1999 is very good,
- standard deviation of 7-day and 28-day samples of the year 2000 is good,
- 7-day values of the year 2001 are average but 28-day results are very good.

It is put forward by the evaluation carried out by taking the variation coefficient as a basis that;

- values of 7-day and 28-day of the year 1999 are good,
- values of 7-day of the year 2000 are average but values of 28-day are good for the same year,

- values of 7-day of the year 2001 are average but values of 28-day are good for the same year.

Considering the fact that ACI 214 criteria have been given for values of 28-day, in the light of these evaluations, it is possible to say that compressive strength results for the years 1999, 2000 and 2001 are good on average.

Also another fact to be taken into consideration along with these evaluations is the evaluation carried out according to the lowest strength (f_{cmin}) value. If deviation of this value from arithmetical mean is more than 25, than this situation is suspicious and if it is more than 35, it should be evaluated statistically [11]. Within this context when the samples are being evaluated generally;

- If the lowest strength value (f_{cmin}) of 1999 is more than 25 in samples of 7-day and 28-day, this should be considered suspicious.
- If the lowest strength value (f_{cmin}) of 2000 is more than 35 in samples of 7-day, than it should not be considered for evaluation. When it is more than 25 in samples of 28-day it should be considered suspicious.
- If the lowest strength value (f_{cmin}) of 2001 is more than 35 in samples of 7-day and 28-day, these values should not be taken into consideration in statistical evaluation.

IV. CONCLUSION

he statistical evaluation about concrete quality control, which has been carried out on 3910 samples taken from four different laboratories and in accordance with TS 500/1984 and ACI 214 criteria, has been briefly given on Table 2.

Results of the studies on 3910 samples tested in three precast-concrete facilities and Osmangazi University Concrete Laboratory in Eskişehir are promising. Considering 28-day samples, which are especially taken as a basis in quality control and acceptance, nothing negative has been observed about concrete produced after 1999. However, there are two parties to the event; the first one is the concrete producer and the second one is the building site team applying this concrete. The experiment results here show that the first one has fulfilled its duty and this is of great importance. On condition that the second party fulfills its own duty, there will be no problem. For this reason the ready-mixed concrete is the only and definite solution to concrete problem for the first party. However, the real problem is the second party's putting itself in an order. Considering some negative effects, which may take place in accordance with TS 500/1984, the target strength is designed by increasing it just by the value of Δf. However, if the fact that bad – insufficient compression and insufficient maintenance cause about 50 % of strength loss in concrete is considered, it will be understood that an on-the-spot control, which is carried out by taking samples out of the real concrete, is a more proper approach [5].

When reasons concerning the concrete structure damages in our country, whose 90 % is on the seismic zone, are investigated it will be seen that insufficient concrete compressive strength covers an important ratio [1, 2]. When especially damages, which stem from the concrete as a result of low compressive strength during earthquakes, are evaluated, we are faced with a negative, economic and technical picture, which is not desirable for our country. Ready-mixed Concrete is an option that may be a solution to concrete problems to a certain level. For this reason, ready-mixed concrete should definitely be used especially in constructions, great water constructions and industrial facilities. With the help of the Construction Control Decree, which is made obligatory in some cities after 1999 earthquakes, this idea has been realized to a certain degree. In order to produce concrete which is of good quality or in other words which is for its aim and which has the quality to maintain its function without any problems, it is clear that machine equipment used, technical personnel and organization along with the quality of concrete components should be of good quality and that it necessitates specialization. The above-mentioned factors are a prerequisite for concrete of high quality. Along with all these facts, good concrete may be obtained by complying with the standards in installation, compression and maintenance topics, by auto-control necessary to be done in the production process and by quality control studies to be carried out upon following all these stages.

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Plants, (for C 20 Quality Concrete),(*)

Plants	Plant 1						OGU, (**)				Plant 2						Plant 3		General Evaluation					
Year	1999		2000		2001		2000		2001		1999		2000		2001		2001		1999		2000		2001	
Sample Age, (day)	7	28	7	28	7	28	7	28	7	28	7	28	7	28	7	28	7	28	7	28	7	28	7	28
Daily Average Sample Numbers	122	122	366	366	243	243	117	81	143	271	122	122	366	366	243	243	187	187	244	244	849	813	816	944
Mean (f_{cm})	22.7	24.6	22.9	23.3	22.8	23.2	20.8	25.7	21.1	24.8	23.1	17.8	23.8	26.9	24.2	29.1	22.9	30.7	25.3	26.2	25.4	26.4	26.2	26.2
Stan.Deviation (σ)	17	32	20	23	18	23	37	30	36	39	12	11	15	14	11	12	33	38	29	29	42	36	47	29
Vari. Coef. (V)	8	13	9	10	8	10	18	12	17	16	4	5	5	6	4	4	14	12	11	11	17	14	18	11
$f_{cmax.}$	28.0	34.7	34.4	34.4	29.6	31.3	33.8	32.0	33.8	41.9	28.3	31.3	28.4	33.4	24.3	31.2	34.7	40.6	28.3	34.7	34.4	34.4	34.7	41.9
$f_{cmin.}$	17.9	17.8	17.9	17.9	17.9	20.4	10.6	16.2	10.6	17.4	19.3	25.0	18.3	25.1	21.1	28.8	16.3	18.9	17.9	17.8	10.6	16.2	10.6	17.4
$f_{ck}+3$	23	23	23	23	23	23	23	23	23	23	23	23	23	23	23	23	23	23	23	23	23	23	23	23
$f_{cm} \geq (f_{ck}+3)$	-	Y	-	Y	-	Y	-	Y	-	Y	-	Y	-	Y	-	Y	-	Y	-	Y	-	Y	-	Y
$f_{ck}-3$	17	17	17	17	17	17	17	17	17	17	17	17	17	17	17	17	17	17	17	17	17	17	17	17
$f_{cmin} \geq (f_{ck}-3)$	-	Y	-	Y	-	Y	-	N	-	N	-	Y	-	Y	-	Y	-	Y	-	Y	-	N	-	Y
Sample % of less than f_{ck}	2.46	4.10	1.74	1.37	3.70	0.00	43.5	2.47	34.9	7.38	1.64	0.00	1.64	0.00	0.00	0.00	17.6	0.54	2.05	2.05	7.45	0.86	11.3	2.22
Is it proper to TS 500/1984?	-	Y	-	Y	-	Y	-	N	-	Y	-	Y	-	Y	-	Y	-	Y	-	Y	-	N	-	Y

(*) : Units of values given in Table are MPA

(**): Osmangazi University, Materials of Construction Records.

Y: Yes N: No