QUALITY CONTROL OF FIELD CONCRETE

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《要 旨》

콘크리트 工事示方에 있어서 그 強度는 最低強度를 指定하는 것이 오늘날 까지의 慣習으로 되어 있다. 即, 몇個의 強度試驗의 平均値가 얼마以上 이어야 된다든가, 全部의 콘크리트가 얼마 以上의 壓縮強度를 갖어야 된다든가, 또는 콘크리트는 28日 壓縮強度 얼마를 낼 수 있도록 콘크리트 單位容積當 cement 를 몇 kg, 或은 몇 包袋를 使用해야 된다 든가로 規定되는 것이 普通으로 되여 있다.

그러나 이 方法만으로는 그 콘크리트의 實際의 安全率을 豫測할 수 없을뿐만 아니라 均質한 콘크리트를 얻는것을 期待할 수가 없을 것이다. 即 合理的인 示方이 되지 못 한다. 두말 할 것도 없이 우리는 現場에서 建築物設計者가 要求하는 強度의 콘크리트를 얻어야 될 것이고, 또 한편으로 그 強度가 골고루 되어야 할 것이다. 即 強度의 變化가 甚하지 않아야 될 것이다. 이것을 期待하기 爲하여 concrete 製造現場에서 統計學的 理論에 立脚한 品質管理를 行하는 것이다. 그렇게 하므로서 보다 合理的인 示方이 이루어지게 된다. 現在 美國에서는 콘크리트 工事의 큰 現場에서 concrete 生產 品質管理를 行하고 있는 것으로 안다. 그러면 如何한 理論에 立脚하여 現場에서 多量으로 concrete 를 生產할때에 그 品質을 管理하느냐 하는 것을 現在 美國에서 propose 되여 있는 案과 ASTM 에 規定되여 있는것을 中心으로 紹介하고 아울러 concrete 工事에서 強度에 關한 示方을 앞으로 이끄러, 나갈 方向을 提示하고저 한다.

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§ 1. Introduction.

In most manufacturing industries, quality control is being performed for the products in order to assure the quality of the products. To this end, statistical analysis is applied to evaluate the results of measured data of the products. Where large construction project is performed, statistical approach for evaluating the results of concrete test have been used in the design and construction of concrete structures.

How should the value of concrete strength

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which is reasonably considered as representing its real strength be estimated with the test results of field concrete ? True strength may not be obtained. Probable value of strength can be evaluated only by using probability theory. One objective of the compression tests of field concrete is to secure uniformity of concrete of designed strength and quality variation in strength of concrete may be caused by the lack of uniformity of ingredients of concrete as well as by inadequate proportioning, mixing, transporting, placing, and curing. When proper control is achieved and the test results are properly interpreted, consistent concrete of adequate quality can be produced. Although it may not be expected to make complete uniformity of concrete in field job, excessive variation of concrete strength should be interpreted as inadequate concrete control. A reduction in the cost of concrete may be obtained by improving control since the average strength of concrete can be adjusted more closely to sepcification requirements.

§ 2. Typical Specification Requirements.

The following are the examples of typical specifications related to compressive strength of concrete in the United States.

(1) The average of all the strength tests as well as the average of any five consecutive strength test, shall be equal to or greater than 3,000 psi, and not more than one test in ten shall have an average value less than 90 percent of the specified strength.

(2) Not more than one test in ten shall have an average strength less than 3,000 psi and the average of any three consecutive tests shall not be less than 3,000 psi.

(3) All concrete shall have compressive strength of 3,000 psi at 28 days.

(4) The proportions of cement, fine aggregate, coarse aggregate and water will be determined beforehand, so as to produce a workable plastic concrete having a minimum compressive strength of not less than 3,000psi at 28 days.

(5) The concrete shall have a minimum cement content of 6.5 bags per cubic yard and an anticipated compressive strength of 3,000 psi at 28 days.

(6) Concrete shall be proportioned to secure a minimum compressive strength of 3,000 psi at 28 days.

(7) The engineer shall determine from laboratory tests the proportions that will produce workable concrete having a compressive strength at 28 days of not less than 3,000 psi.

(8) Concrete proportioned in accordance with these specifications may be expected to develop 3,000 psi minimum compressive strength at 28 days.

There is another type of specification which designates no strength but requires various detailed proportions usually defining a definite cement content which is sufficient enough to cover the most inefficient operation.

The engineer who determines such proportions tries to get some definite strength.Thus it becomes not only wasteful but also encourages inefficiency in field works. Another disadvantages to this type of specification is that one can not assure the desired strength.

As long as concrete is used as a structural material, the designer has to use some assumed strength in his design. Therefore, strength of concrete should be specified in specifications, as being the best over-all measure of quality of concrete.

In minimum strength specifications, the designer can not know whether the factor of safety which he has specified has been increased, decreased, or left at the level he intended until the job is over and the test results are analyzed.

So that, minimum strength specifications mentioned above are not realistic, not generally met in practice, and tend to obscure the real safety factor.

§ 3. Factors Afecting Concrete Strength.

Strength of concrete may be affected by two fundamentally different factors.

(1) Differences in strength-producing properties of the concrete mixture.

(a) Changes in water-cement ratio caused by poor control of water, cement or excessive variation of moisture in aggregate.

(b) Variations in water requirement caused by aggregate grading or non-uniform materials.

(c) Variations in characteristics and properties of ingredients such as aggregates, cement, pozzolans and admixtures.

(d) Variations in transporting, placing, and compaction.

(e) Variations in temperature and curing.

(2) Differences in strength caused by discrepancy in tests.

(a) Inconsistent sampling procedure.

(b) Nonuniform fabrication techniques concerned with amount of compaction, excessive handling of sample or care of fresh cylinder.

(c) Change in curing which causes temperature variation and variable moisture.

(d) Poor testing procedures such as cylinder capping or compression tests.

Since the strength of concrete is goverened mainly by water-cement ratio, the first criterion for uniformity of producing concrete is a uniform water-cement ratio. Therefore, if the quantity of cement can be measured accurately, the water content to be used has to be controlled strictly. However, it should be considered that construction practices may cause variations in strength due to inadequate mixing, poor compaction, delays,and improper curing.Also,discrepancies in sampling, fabrication, curing, and testing of specimens may indicate variations in strength of concrete. Good testing method will reduce these variations and standard testing procedure should be established.

§ 4. Statistical Evaluation of the Test Results of Concrete Strength.

A sufficient number of tests of concrete strength sholud be prepared to determine the representing strength of concrete when statistical approach is used to evaluate the test results of concrete strength. Plotting each test value against its cumulative frequency of occurence, or probability that the number will(or will not) be equal or exceeded, cumulative polygon can be drawn. From this curve, one can learn many useful things, such as whether the test data indicate a trend, whether the test value are reliable, and what the average of future value should be so that none would be likely to be below a given minimum.

If one draw a curve which indicates frequency of occurence v.s. its value,frequency distribution curve may be obtained. The data of strength tests on controlled project may be assumed to fall into some pattern of the normal frequency distribution curve. If good control is performed, the curve will be tall and narrow. On the other hand, in the case of bad control, the curve

Standards of Concrete Control

Class of Operation	Coeff. of variation for different control standards			
	Excellent	Good	Fair	Poor
Over-all variations general construction	Below 10.0	10.0 to 15.0	15.0 to 20.0	above 20.0
Laboratory Control	Below 5.0	5.0 to 7.0	7.0 to 10.0	above 10.0
Within test variations Field Control	Below 4.0	4.0 to 5.0	5.0 to 6.0	above 6.0
Laboratory Control	Below 3.0	3.0 to 4.0	4.0 to 5.0	above 5.0

becomes low and wide. These facts imply that lower variation in strength indicates extremely uniform work and high variation, a poorly controlled job. In other words, the coefficient of variation, which is nondimensionalized value of variation obtained by dividing by mean value of the data, is smaller in the former instance than in the latter.

For practical comparisons, the conffificient of variation may be a more useful way of expression for measuring the dispersion of the test results of concrete strength than the standard deviation itself.

By setting up proper controls a plant can lower its variation and thus take advantages of the reduced average strength required to meet a given design strength.

The Burean of Reclamation in the United States found the average value of coefficient of variation to remain consistantly around 15 percent from its long term test results of concrete. ASTM also recommands that when no data are available, a coefficient of variation of 20 percent must be assumed for the ordinary average job.

Analysis of the concrete test data can be taken into account one further step in order to determine whether the average strength of the concrete is reasonably sufficient to assure attainment of the specified strength. If the average strength is considerably higher than required, cement may be wasted and consequently the cost of producing concrete is greater than it is needed. On the other hand, if the average strength is too low, the risk of failing to meet specified strength is too great.

According to ASTM C94—58, the risk factor is specified as "Not more than one test in ten shall have an average strength less than 90 percent of the specified strength."

Quality control chart have also been used by manufacturing industries as an aid to uniformity and efficiency in production. This methods are shown in the ASTM "Manual on Quality Control of Materials." These charts may also be utilized when concrete is produced continuously over long periods.

In order to evaluate the strength of field concrete based on statistical analysis, several factors which affect results of data must be taken into account. These are:

(1) Probability sampling

(2) Random sampling

(3) Carelessness of the inspector who makes several cylinder sets out of one batch instead of separate batches at different time during the day.

(4) Additional water or cement is permitted to be added to the sample after the sample is taken.

(5) Carelessness in the curing, capping, and testing procedures.

(6) A sufficient number of tests should be made to insure accurate representation of the concrete.

(7) Rejection of doubtful specimens.

§ 5. Criteria for Strength of Concrete Based on Statistical Analysis.

One may infer load carrying capacity of oncrete structure with the results of strength est of concrete. Compressive strength test data f specimens are, therefore, important in stablishing criteria. Since minimum strength eqiurements are impractical and unrealistic and ontrol of the pattern of results rather than ndividual values is the most appropriate basis or both specifications and the general ssessment of results, statistical concepts have uch significant value in concrete control. From iese concepts, there have been developed means o control variation.

To satisfy strength requirements, the average trength of concrete must be in excess of f_c'. he degree of excess strength depends on the xpected uniformity of concrete production and e allowable proportion of low tests. The equired average strength, f_{c_r}, for any design an be computed as fallows:

$$f_{c_r}=\frac{f_c'}{(1-tV)}$$

which,

f_{c_r}=required average strength

f_c'=specified design strength

t=A constant depending on the proportion of the tests that may fall below f_c' and the number of samples used to establishe V.

V=forecasted value of the coefficient of variation expressed as a fraction

Example (1)

For the data of

average strength $f_{c_r}=3,500$ psi

and standard deviation $\sigma=390$ psi,

if the probability of test results of concrete

$$P_r(f<f_c')\leqq\frac{1}{10}$$

is required, the specified design strength may be found as follows:

(t being 1.282 for $P_r\leqq\frac{1}{10}$ from table)

$$V=\frac{390}{3500}=11.1\%$$

$$f_c'=f_{c_r}(1-tV)$$

$$=3500(1-1.282\times0.111)=3000 \text{ psi}$$

Example (2)

If specified design strength $f_c'=2500$ psi,

forecasted value of the coefficient of variation

$V=15\%$,

and the probability of test results of concrete

$$P_r(f<f_c')\leqq\frac{1}{5}$$

are required, the average strength of concrete must be:

(t being 0.842 for $P_r\leqq\frac{1}{5}$ from table)

$$f_{c_r}=\frac{3000}{1-0.842\times0.15}=3430 \text{ psi}$$

§ 6. Conclusion.

From the above discussion, one may conclude the following.

(1) The present construction practices do not meet the requirements of a minimum strength specification.

(2) Statistical method offers a more realistic approach than the minimum strength specification, and has added benefits in fixing the factor of safety beforehand, reducing costs, reducing maintenance, and leads to easier contract administration.

(3) By using this approach, the designer knows beforehand what his probability of lows is going to be and consequently his factor of safety can be predicted.

(4) Statistical way of specifying concrete strength is actually safer than the minimum strength specifications.

(5) By this method, the real situation concrete strength in the field job is recognize and the analyzed value of concrete strengt may be taken as representing the strengt of whole concrete.

Value of t.

tσ

No. of samples minus 1	Percentage of tests falling within the limits $\bar{x} = t\sigma$							
	50	60	70	80	90	95	98	99
	Chances of falling below lower limit							
	2.5 in 10	2 in 10	1.5 in 10	1 in 10	1 in 20	1 in 40	1 in 100	1 in 200
1	1.000	1.376	1.963	3.078	6.314	12.706	31.821	63.65
2	0.816	1.061	1.386	1.886	2.920	4.303	6.965	9.92
3	0.766	0.978	1.250	1.638	2.353	3.182	4.541	5.84
4	0.741	0.914	1.190	1.533	2.132	2.776	3.747	4.60
5	0.727	0.929	1.156	1.476	2.015	2.571	3.365	4.03
6	0.718	0.906	1.134	1.440	1.943	2.447	3.143	3.70
7	0.711	0.896	1.119	1.415	1.895	2.365	2.998	3.49
8	0.706	0.889	1.108	1.397	1.860	2.306	2.896	3.35
9	0.703	0.883	1.100	1.383	1.833	2.262	2.821	3.25
10	0.700	0.879	1·093	1.372	1.812	2.228	2.764	3.16
15	0.691	0.866	1.074	1.341	1.753	2.131	2.602	2.94
20	0.687	0.860	1.064	1.325	1.725	2.086	2.528	2.84
25	0.684	0.856	1.058	1.316	1.708	2.060	2.485	2.78
30	0.683	0.854	1.055	1.310	1.697	2.042	2.457	2.75
∞	0.674	0.842	1.036	1.282	1.645	1.960	2.326	2.57

Other values of t for $n-1=\infty$

percentage within $\bar{x} = t\sigma$	chances of falling below lower limit	t
40	3 in 10	0.524
68.27	1 in 6.3	1.000
95.45	1 in 44	2.000
99.73	1 in 741	3.000

(6) The integrity of the design is better maintained than in minimum strength specifications.

(7) When this approach specifies to tie the required average to the coefficent of variation, contractor comes to watch his operation and call attention to irregularities before the inspector becomes aware of

them.

(8) Concrete quality will be improved and costs of producing concrete will be reduced in the long run with this specification.

(9) It is concluded that a probability of 10 to 20 percent of strength being below design strength provides better concrete than obtained currently under minimum strength specifications.

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