

**CORRESPONDENCE**  
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“ Quality Control of Concrete—Its Rational Basis and Economic Aspects ” †

by

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**Mr L. B. Mercer**, of Australia, observed that statistics, at most, could provide only an indication of the probable future general behaviour of concrete when it was assumed that there was no change from the original conditions under which the data were compiled. However, provided the variables involved were appreciated and the improbability of the above assumption was realized, then a knowledge of statistical procedure could furnish assistance in the determination of methods for control.<sup>31, 32, 33</sup> He suggested that perhaps the Paper did not sufficiently stress the importance of sampling and testing variables. Whilst appreciating that errors in testing did not influence the quality of the concrete or disturb the reliability of the structure from which such tests were taken, nevertheless they could indirectly influence both quality and economy through setting an incorrect “target” strength. Mr Mercer considered that quality control of concrete through statistical analysis should accordingly make separate provision for the variables of testing, which would be different for different laboratories and conditions; he further suggested that the cement variable should also be separated from the other factors involved in control of concrete production.

† Proc. Instn Civ. Engrs, Pt I, vol. 2, p. 311 (May 1953).

<sup>31</sup> L. B. Mercer, “Concrete Strength Variation—60 Contributory Causes.” *Building and Construction*, 28 March and 5 April, 1950.

<sup>32</sup> L. B. Mercer, “Concrete Quality Control—Fallacious Application of Statistical Analysis.” *Commonwealth Engineer*, December 1950.

<sup>33</sup> L. B. Mercer, “Concrete Mix Design.” Research Bulletin No. 2, Melbourne Technical College Press, 1953.

For instance, if  $V_c$  represented the coefficient of variation for the compression strength properties of the cement, excluding the cement testing variables;  $V_p$  represented the coefficient of variation for the plant and aggregate variables, including batching and mixing with control of variations in the water/cement ratio and workability; and  $V_t$  represented the coefficient of variation for the sampling and testing of concrete specimens, then  $V$ , the coefficient of variation for the complete concrete production and testing, was given by the formula:

$$V = \sqrt{(V_c)^2 + (V_p)^2 + (V_t)^2}$$

For example, if  $V_c$  varied from 4 per cent, in the case of a mixing plant drawing cement from one reliable factory, to 9 per cent where the cement was drawn from, say, several factories operating with different control limits;  $V_p$  varied from 7 per cent for concrete batching and mixing plants using uniform aggregate and equipped for accurate weigh-batching operations with strict control of the water, to 14 per cent for variable materials and indifferent control; and  $V_t$  varied from 4 per cent for strict concrete testing to 7 per cent for indifferent testing, then  $V$  might vary between:

$$V = \sqrt{(4)^2 + (7)^2 + (4)^2} = 9 \text{ per cent}$$

$$\text{and } V = \sqrt{(9)^2 + (14)^2 + (7)^2} = 18 \text{ per cent}$$

It was possible, on that basis, to provide for variations in the cement from time to time, to adjust for different plants operating under various conditions in several locations, and to modify the figures according to any changes in the efficiency of the testing laboratory. Provision could readily be made for major variations, such as a change in the type of cement or aggregate, by adjusting the "target" average.

The recommended procedure for the design of mixes was thus to determine  $V_c$ ,  $V_p$ , and  $V_t$ , experimentally, calculating  $V$  (overall coefficient) and checking for the complete concrete production operation by experiment. Changes in  $V_c$ ,  $V_p$ , and  $V_t$  would have to be anticipated, with the aid of experience and prior experimental knowledge, so that the modified  $V$  could be obtained and the "target" average adjusted accordingly. The average had also to be revised to provide allowance for radical changes in "level." Thus, if a change was made to a cement which gave 500 lb. per square inch variation in average strength under otherwise similar conditions to those upon which the original concrete average was based, then the original concrete "target" average had to be modified accordingly for such variation.

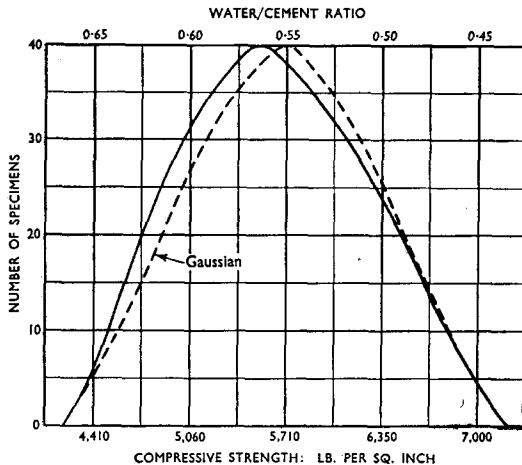
It was contended that it was possible, with the above amplified application of statistical analysis, to secure increased economy with safety.

Mr E. R. Giles noted that the Author had sought to show the desirability of sampling in such a way that variation in compressive strength of cubes could be attributed separately to "within batch" or "between batch" causes, in order that the means of achieving a more "economical

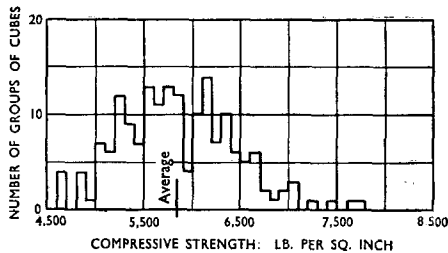
homogeneity" might be discovered. One had to bear in mind, however, that compressive strength was a complicated quality characteristic which itself was amenable to analysis, and which was not capable of interpretation to the degree of accuracy required for differentiation between the sources of variations unless a very large number of samples was taken for continuous checking. Yet, of the factors affecting the strength of cubes, only two were relevant to the strength of the concrete on the job, the cement strength and the water/cement ratio.

For the former, a probable value was obtainable direct, initially from the supplier and later from tests as the job proceeded. It would seem useful to measure the latter direct as well, since a continuous record of water/cement ratios would permit the calculation of a standard deviation for them—that would be difficult to infer from the cube results because the distribution of compressive strengths was not a Gaussian curve for a random distribution of water/cement ratios, as could be seen from *Fig. 6*. In that Figure, the broken line depicted a Gaussian distribution

*Fig. 6*



*Fig. 7*



about a water/cement ratio of 0.55, and the full line a distribution derived from it by interpreting the various ratios as strengths for a standard cement strength and plotting those strengths on a linear scale between the extremes of the Gaussian curve. Asymmetry of that kind was noticeable in *Fig. 7*, which was a histogram of 28-day strengths from a current contract covering about 80,000 cubic yards of concrete, and it was dependent to some extent on the strength level. Similarly, asymmetry could be observed in *Figs 45* and *46* of Airport Paper No. 1.<sup>34</sup>

A method of measuring water/cement ratio direct was given in B.S.1881 and could be used for continuous checking. Although the results of those tests would be themselves inaccurate they would have the virtue that the figure to which they approximated would be one which was strictly relevant to the problem in hand. The engineer could criticize himself on the basis of the result without having to bear in mind irrelevant factors which had served as a means of producing it. Mr Giles emphasized that, once a mix had been designed, the contractor was not aiming to produce a strength but to achieve consistent batching.

Did the Author consider that site control by the method outlined above would be preferable to the present method of control by cube samples in seeking the cause of lack of homogeneity ?

**The Author**, in reply, expressed his appreciation of Mr Mercer's valuable contribution.

As soon as the importance of variation in concrete strength on quality was realized, the next step was to analyse the different sources of the variation, and to determine which contribution was of the greatest influence ; reduction of that specific contribution could then lead to a reduction of the composite coefficient.

Mr Mercer had distinguished between the variations caused by cement, mixing-plant, and testing. Any one of them was a composite coefficient of variation, with several contributions, and by localizing one major component it was possible to obtain a great overall reduction of the variation.

The Author doubted whether  $V_c$ , as determined from test specimens of mortar, gave a true indication of the variation in concrete strength, which arose from variation in properties of the cement ; at least, that was the case when the mortar-specimens were manufactured using a standard sand with a very steep gradation curve.

The Author did not agree that specifications for the control of concrete quality should make special provision for errors of testing arising from the variation of laboratory conditions. For instance, the statistical analysis by which the most economical homogeneity was determined (see *Fig. 3*) might yield quite misleading results if the component of the standard deviation arising from testing errors had not been eliminated from the standard deviation by which the concrete was characterized.

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<sup>34</sup> See reference 2 in the Paper.

Mr Giles had questioned whether the Author considered that control of cement strength and water/cement ratio was preferable to control by cube samples when seeking the cause of lack of homogeneity.

In reply, the Author summarized his experience thus :—

- (1) Cube tests were of little value, first, because of the differences in mean strength and standard deviation between the cubes and the structure (*cf.* pp. 326–330 of the Paper) and secondly, because the results were at least one week delayed.
- (2) It was, therefore, natural, to attempt control of the qualities of the concrete components prior to mixing and the mixing proportions simultaneously with the mixing, so that corrections could be made whilst the mix was still in the mixer.

Mr Giles's suggestion was, therefore, a step in the right direction. The Author fully agreed to the earliest possible control of the cement quality, but he doubted whether control of the water/cement ratio was a sufficient supplement.

It should be emphasized that concrete strength was not governed by the water/cement ratio but by the water-plus-voids/cement ratio, which meant that the water/cement approximation held good only when the volume of voids was negligible, that was, when the workability corresponded to the method of compaction and that, therefore, also had to be controlled.

Experience showed beyond doubt that the compactness was not always satisfactory, and that was one of the reasons why the Author had recommended continuous control of the workability. The second reason was that the Author considered direct measurement of the water/cement ratio or the absolute water content very dubious and delaying, whereas indirect measurement of the water content via the workability or consistency measurements could be made more correctly and speedily.

This indirect measurement rested on the assumption of constant grading of all solids, discussed at length on pp. 330–331 of the Paper.

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