SIGNIFICANCE OF COMPRESSION TESTS OF CONCRETE

by Inge Lyse*

1. INTRODUCTION

Most plain and reinforced concrete structures are designed on the principle that the effective concrete area shall be stressed in compression only. Consequently the compressive strength becomes a most important quality of the concrete and its accurate determination a most outstanding problem for the engineering profession. Ever since the first uses of concrete, attempts have been made to ascertain its compressive strengths. However, the problem of interpreting and correlating the secured results is far more difficult than it appears to a casual inspector, and the significance of the compression tests becomes a very difficult question to answer in definite terms. In the following pages the author will attempt to discuss some of the more important items bearing on the significance of the compressive strength and other related qualities of the concrete. The problem will be divided into two major groups, one discussing the significance of the compression test as a measure of the quality of the concrete in the structure, and the other one dealing with the compression test as a satisfactory test of the concrete giving quality of the ingredients used in the mix.

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* Research Associate Professor of Engineering Materials
Lehigh University, Bethlehem, Pennsylvania

2. METHODS OF TEST

While any method of test may be useful and valuable for pure research purposes, definite methods have to be established for the correlation of research and for practical application. In order to provide such correlation between research studies as well as between construction conditions, the American Society for Testing Materials has adopted standard methods of MAKING COMPRESSION TESTS OF CONCRETE (C39-27) and MAKING AND STORING COMPRESSION TEST SPECIMENS OF CONCRETE IN THE FIELD (C31-31). These standards state that the specimens shall be cylinders of diameter equal to one-half the length. For two-inch maximum size aggregates the cylinder shall be six by twelve inches, for greater than two-inch aggregates eight by sixteen inches. For mortars two by four-inch cylinders may be used. The molds shall preferably be of metal, have a machined metal base, and be oiled with heavy mineral oil before using. The specimens shall be capped with neat cement paste and removed from the molds 20 to 48 hours after molding. In testing the specimens the adjustable bearing block shall be placed on the top of the specimen and the load applied uniformly, without shock, until the maximum load has been reached.

The problem of correlating the results of tests of sample specimens with the strengths of the concrete structures is still before us, making the value of the tests more of a qualitative than of a quantitative nature. But even qualitative values must be compared on the same basis, namely the same methods of test. Definite methods should therefore be used in all testing of concrete specimens and even small deviations from the standards should be prohibited. Acceptance tests must be carried out in strict accordance with standard methods in order to be of any value to the owner and to the public.

3. TEST SAMPLES

Since testing to destruction cannot be carried out on actual structures, samples of the material in a structure are tested and used as bases for estimating its strength. These test samples must be so selected that they give a dependable picture of the quality of the material and at the same time lend themselves to simple test operations. For compressive strength tests cylindrical shaped specimens have been adopted in this country, while in Europe cubical specimens are used extensively. A 6 by 12-inch cylinder is the test specimen most generally used, but 3 by 6-inch cylinders are also much used in laboratory work. For mass concrete such as in dams, 18 by 36-inch cylinders are frequently used as control specimens. The shape and size of specimen are immaterial in themselves, since it is the correlation between test sample and actual structure which determines their value. If test specimens are made alongside the actual structure, a method which should be used in all control and acceptance tests, the fabrication and curing of the specimens should be as nearly as possible the same as that of the structure. Although the effect of such items as the direction of placing, types of molds, and method of compacting the mass are not clearly established, care should be taken that the conditions of the test specimen are as identical as possible with those of the structure. The method of placing must be the same for the specimen and for the structure if the test is to have any significance.

If samples are taken from the hardened concrete, they must be so prepared that they will represent the quality of the material in the structures. Cylindrical cores from pavements and structures are most easily obtainable and serve well for acceptance tests, provided the relation between core strength and actual strength of the structure is known. The cores should preferably be tested in the same direction as that in which the compressive stresses are applied in the structure. Valuable assistance in the correlation for size and shape of specimen is presented in a paper by H. F. Gonnerman*. He shows that for cylinders whose lengths vary from 0.5 to 4.0 times the diameter, the strengths vary from 1.78 to 0.9 times the strengths of cylinders whose lengths are twice the diameter. When the specimens

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* EFFECT OF SIZE AND SHAPE OF TEST SPECIMENS ON COMPRESSIVE STRENGTH OF CONCRETE by H. F. Gonnerman
Proceedings, A.S.T.M., Vol.25, 1925, Part II, p.237

have been cured for the age determined in the design of the structure, they should be tested to destruction in a reliable testing machine. The testing machine should be accurate to at least 0.5 per cent*, and the load should be applied at a given rate, generally specified to be about 0.05-inch per minute per foot of length, running idle, as applied to the head of the machine. The effect of the rate of application of load on the compressive strength of concrete has been studied by D.A.Abrams.+ He concludes that it is permissible to use fast speed for the application of load up to one-half or three-fourths of the strength, provided the specified slow rate is used for the remaining load. A spherical bearing block should be placed on the top of the specimen and the bearing surfaces of the specimen should be so prepared that an even distribution of stress on the total area is assured. The preparation of the bearing areas of the specimen is a very important factor in the securing of dependable results. The effect of end condition on the strength of concrete cylinders is reported by H. F. Gonnerman.'
He points out the importance of the capping material, the planeness of the bearing surfaces, the direction of the axis of the test specimen, and the position of the spherical bearing block.

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* A.S.T.M. Standard E4-27: STANDARD METHODS OF VERIFICATION OF TESTING MACHINES sets a tolerance of ±1 per cent for new machines and ±1-1/2 per cent for used machines.

\+ EFFECT OF RATE OF APPLICATION OF LOAD ON THE COMPRESSIVE STRENGTH OF CONCRETE by D. A. Abrams
Proceedings, A.S.T.M., Vol.17, 1917, Part II, p.364

' EFFECT OF END CONDITION OF CYLINDER ON COMPRESSIVE STRENGTH OF CONCRETE by H. F. Gonnerman
Proceedings, A.S.T.M., Vol.24, 1924, Part II, p.1036

The most commonly accepted methods of preparing the bearing surfaces are capping with neat cement, capping with sulphur or other compounds, and grinding. The strengths of the caps must be equal to or greater than the strengths of the concrete specimens, otherwise failure of the cap will cause failure of the specimen. Gonnerman's experiments showed that a convexity of the cap of only 0.01-inch reduced the strength as much as 35 per cent, and 0.05-inch convexity as much as 60 per cent.

It is generally accepted that a molded test specimen should have a diameter at least four times that of the largest size aggregate in the concrete. When the size of the aggregate is so large as to make it impractical to use this size specimen, the coarsest aggregate particles may be removed before the specimens are molded and smaller test specimens used. If the amount of coarse aggregate thus removed is sufficient to materially change the consistency of the concrete, smaller size coarse aggregate of the same kind should be added to the mix until the original consistency is restored. This procedure has been recommended by F. R. McMillan* and no doubt has considerable practical merit. It should be kept in mind, however, that the effect of the size of the specimen itself is an important item. Recent data seem to indicate that the strength of a 36 by 72-inch cylinder may be only about 80 per cent of strength of the 6 by 12-inch companion specimen'.

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* Proceedings, A.S.T.M., Vol.30, 1930, Part I, p.521

' Engineering News-Record, March 9, 1933, p.324

The temperature of the concrete specimen at time of test also seems to affect its compressive strength. Tests made at the University of California* indicated that the strengths at 25°F were 140 per cent, and at 130°F were 85 per cent of the strengths at 70°F for a 1:2:4 mix tested at 135 days.

4. SPECIMENS AND STRUCTURES

The compressive strength of the test specimen has no significance if it does not represent in some definite manner the strength of the actual structure. Consequently results of tests on specimens which are not made, cured, and subjected to loads in the same way as in the concrete in the structure, may often be more misleading than helpful. Too much emphasis cannot be placed upon the fact that the specimen must represent the material in the structure in previously established ratios if the results are to be depended upon for control or acceptance values. Since the relationship between the strengths of the specimen and the structure has not yet been definitely established for all cases, certain assumptions are necessary for the interpretation of the test results. As already pointed out, tests on very large specimens have indicated that the compressive strength of a great mass of concrete may be considerably lower than that indicated by a small test specimen. The recent extensive reinforced concrete column investigation showed'

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* Proceedings, American Concrete Institute, 1931, p.499

' REINFORCED CONCRETE COLUMN INVESTIGATION
Proceedings, American Concrete Institute, 1931, p.675

that the compressive strength in a column is about 85 per cent of the strength of the 6 by 12-in. control cylinders. On the other hand, the computed compressive strength at failure in the compression section of reinforced concrete beams and slabs, has been found to be considerably greater than the compressive strength of the standard test cylinders. For the ordinary straight line method of computation, the computed flexural compressive strength of concrete was found* to be about 50 per cent greater than that indicated by test cylinders. Assuming parabolic stress distribution in the compression portion of the beam, the computed strength of the concrete in the beam was very nearly equal to that of the control cylinder. The apparently greater strength of the concrete in flexure is therefore probably more due to the method of computation than to actual strength differences.

Repeated loadings in compression have indicated that the fatigue strength of concrete may be only 50 to 60 per cent of the strength obtained by ordinary direct testing to failure'. However, this problem has not yet been fully investigated.

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* COMPRESSIVE STRENGTH OF CONCRETE IN FLEXURE AS DETERMINED FROM TESTS OF REINFORCED BEAMS by W.A.Slater and Inge Lyse Proceedings, American Concrete Institute, 1930, p.831

' RESEARCHES IN CONCRETE by W. K. Hatt Purdue University Engineering Experiment Station Bulletin No. 24, 1925

Tests on the effect of sustained loads on the compressive strength of concrete* have shown that as long as the sustained load does not approach the ultimate strength, its effect on the strength is negligible. For ordinary working conditions the effect of the plastic flow which accompanies sustained load may be considered immaterial as far as compressive strength is concerned. However, when the sustained load approaches the ultimate load, the strength of the concrete will be reduced appreciably, that is, the maximum load a concrete structure can sustain indefinitely is considerably less than the strength obtained by ordinary testing methods.

If definite relations could be established between the strengths of all structural members and those of their test specimens, the test data would enable the designer to utilize the concrete material much more effectively than at present. Although we still lack some of these relations, the compressive strengths of test specimens are generally considered to reflect the actual strength of the concrete in place. Consequently the factor of safety, which more correctly should be called the factor of ignorance, must be greater for concrete than for materials for which these relationships are known more fully.

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* FLOW OF CONCRETE UNDER THE ACTION OF SUSTAINED LOADS
by R. E. Davis and H. E. Davis
Proceedings, American Concrete Institute, 1931, p.837

5. COMPRESSIVE STRENGTH AS A MEASURE OF OTHER QUALITIES OF CONCRETE

The compression test is a very simple one, requiring inexpensive specimens and only ordinary testing precautions. This test would be even more useful to the concrete industry if it would also reflect qualities other than the compressive strength. It has been shown that under ordinary conditions the factors which determine the compressive strength also determine many other qualities of the concrete. Keeping in mind the effect of the characteristics of the aggregates, the tensile and transverse strength of concrete, wear, and modulus of elasticity; the permeability, durability, and fire resistance are found to depend upon the cement concentration of the paste in much the same manner as the compressive strength.* Consequently the significance of the compressive strength reaches into nearly every other desirable quality of the concrete. One exception is the volume changes due to variations in moisture contents. In general, these volume changes are greatest, or most harmful, when the concrete has the highest compressive strength and other desirable qualities.

In using the compressive strength to indicate tensile and transverse strength or durability of concrete, the

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* RELATION BETWEEN QUALITY AND ECONOMY OF CONCRETE
by Inge Lyse
Proceedings, American Concrete Institute, 1933, p.325

importance of the effect of character of aggregates should be kept in mind. While the different characteristics of aggregates may not affect the compressive strength to any large extent, they may produce considerable differences in the tensile and transverse strength, due to effect of bond between aggregate and paste; and in durability and fire resistance due to lack of durability in the aggregates. The compressive strength alone gives sufficient information on the quality of concrete to be subjected only to loading conditions, as is the case for indoor portions of structures; but exposed concrete must also be tested by other means. For concrete exposed to weathering attacks, the quality of the material should also be judged by exposure tests. Recent investigations carried out at Lehigh University showed that different aggregates had a very marked effect upon the durability of concrete, though the compressive strength was only slightly affected. The realization of the limitation of the compression test is just as important as the knowledge of its significance.

6. COMPRESSIVE STRENGTH AS A QUALITY MEASURE OF THE INGREDIENTS IN THE CONCRETE

Since the quality of the concrete is the final measure of the usefulness of an aggregate, a cement, or an admixture, the compressive strength becomes an important test for the selection of these materials. The desired quality of the concrete may be produced with the use of a number of different materials and it is up to the designer to select those materials which produce the given quality at least cost. A less high grade aggregate in the proper cement paste may produce the required quality of concrete at less cost than will a high quality aggregate. Consequently the materials for concrete should be judged by their concrete product and not alone by tests of the individual ingredients. This applies to cement and admixtures as well as to aggregates. Thus the strength and durability tests of the concrete specimens become to a large extent, the measuring stick for the qualities of the materials as well as of the concrete in the structure.

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