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"Concrete and the Resident Engineer." †

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Mr. T. N. C. Bulman considered that another title for the Paper might have been more apt, because the resident engineer's work on site with respect to concrete was mostly in connexion with those matters which the Author expressly omitted (p. 63).

The physical analysis of sand and stone by sieve was a simple matter, as the Author stated, but what advantage was gained by such method? Mr. Bulman had not access to the books cited, and so was not aware whether concrete of greater strength, or better in other useful qualities, was obtained by the method; the figures given in Table III were too few to be conclusive, and against them he wished to cite some of his own for 4 : 2 : 1 concrete, cast in the winter, which averaged a compressive strength of 3,100 lb. per square inch over a range from 1,750 lb. to 4,800 lb. per square inch for periods varying between 7 and 28 days. That concrete was in a reinforced-concrete reservoir which under test showed a loss of water equal to 0.1 per cent. per week, which could be due to evaporation: therefore he was not convinced that the Author's refined method of grading could give practical advantages.

† Journal Inst. C.E., vol. 17 (1941-42), p. 62 (Nov. 1941).

With regard to the bulking of sand due to moisture, he suggested that the method, on the Author's own showing, broke down. Was it not probable that the water-content varied from day to day and from place to place in the sand heap? Had the Author or anyone else carried out the necessarily numerous tests to ascertain whether that was the case? If it were found to be so, then Mr. Bulman suggested that re-proportioning of the mixture at frequent intervals became an impracticable necessity, or else an arbitrary method of varying the sand content had to be applied, as it was at present, in the everyday mixing of concrete; the man who handled the mixer had to be able to apply some judgement in adding slightly to the sand-content for wet sand, and then add enough water to make the mix to the consistency which the resident engineer desired. Concrete-mixer driving was really a more skilled occupation than was usually recognized.

Modern methods of concreting had not yet eliminated losses of finer materials in mixing, transport, and deposition. That fact was generally countered by a small admixture of sand and cement above that which was theoretically necessary. Mr. Bulman doubted whether the Author's method would escape from the need for that small addition, and so precise proportioning was upset.

In the Report of the Research Committee of the Institution for the years 1935-36 and 1936-37, it was stated (p. 13), that, "With regard to aggregate grading, it appears that from strength considerations the grading is unimportant if the concrete can be well consolidated with the required water/cement ratio. . . . Generally speaking, with vibration-compacting, the grading can with advantage be rather coarser than would be used with hand compacting." Thus the deposition of the concrete could not be ignored when proportioning the mixture.

The Paper formed a definite contribution to the art of concreting and Mr. Bulman's remarks, which were meant to be constructive, were based upon his view that much needed to be done to improve methods of mixing, deposition, and curing, before any further refinement of grading would be of value in the field.

Mr. H. M. Gibb observed that in the Author's description of the method of arriving at the grading of the mix a rather misleading reference was given to the water/cement ratio. In his Introduction (p. 62), the Author had stated that his object was to "produce a workable concrete of maximum strength and density, etc." and on p. 63 he specified that the ratio of fine material to coarse should be fixed from time to time so as to give a dense workable concrete with the minimum water/cement ratio. On p. 71, however, under "Bulking of Sand and Water/Cement Ratio," he mentioned a water/cement ratio of 0.6, but did not state how he arrived at that value.

In that arbitrary method of choosing the water/cement ratio, no mention was later made of whether or not the mix was workable. It

would appear from that method of using *Fig. 6* that 0.6 was the universally best ratio for all mixes and conditions; but that was not the proper interpretation of *Fig. 6*. If the mix were to give a crushing strength of 4,800 lb. per square inch, at 28 days, then from *Fig. 6* a water/cement ratio of 0.6 was suitable. If the resultant mix was too stiff and unworkable in placing, then the quantity of sand and aggregate should be reduced, or alternatively more cement and water should be added until it was workable; thus a richer mix was required in both cases. If, on the other hand, the mix was leaner and a crushing strength of 3,000 lb. per square inch at 28 days was required, then from *Fig. 6* a water/cement ratio of 0.9 would give the required strength.

The Author had stated also (p. 71) that "the importance of maintaining the correct water/cement ratio cannot be over-emphasized, as the curves on *Fig. 6* show how quickly the strength falls off above and below the optimum ratio of approximately 0.6." *Fig. 6* showed the reduction in strength when excess water was added, but it also showed the much more serious reduction when there was too little water in the mix; for instance, taking the 6-months curve, the strength at 0.6 ratio was 100 per cent. and a 0.8 ratio gave a strength of 94 per cent., but a 0.4 ratio gave a strength of only 37 per cent. Therefore there was greater loss in strength with too little water in the concrete than with too much. At the end of a year the concrete with a little more water (not excess) than the best water/cement ratio would be almost equally strong, whereas it was certain that the concrete mix with too little water would never attain its full strength or density.

Fig. 6 gave the result of a series of laboratory tests to ascertain the effect upon the strength of the cement paste of varying the water/cement ratio. A ratio of 0.6 gave the best results, but that was dependent upon the resultant workability. If too lean a mix were used the mix would be too stiff and unworkable and sufficient cement and water would require to be added and would eventually make it a richer mix. The water/cement ratio and the proportions of the mix for workability were interdependent and could not both be fixed without experiment and with a view to the crushing strength required (see *Fig. 6*). It appeared, therefore, that the first thing to do was to determine the water/cement ratio required in relation to the crushing strength required at 28 days and then to ascertain whether it produced a workable mix. If 0.6 were the best ratio for 1 : 1 : 2 concrete it could not also be equally suitable for 1 : 3 : 6 concrete with three times the sand and aggregate.

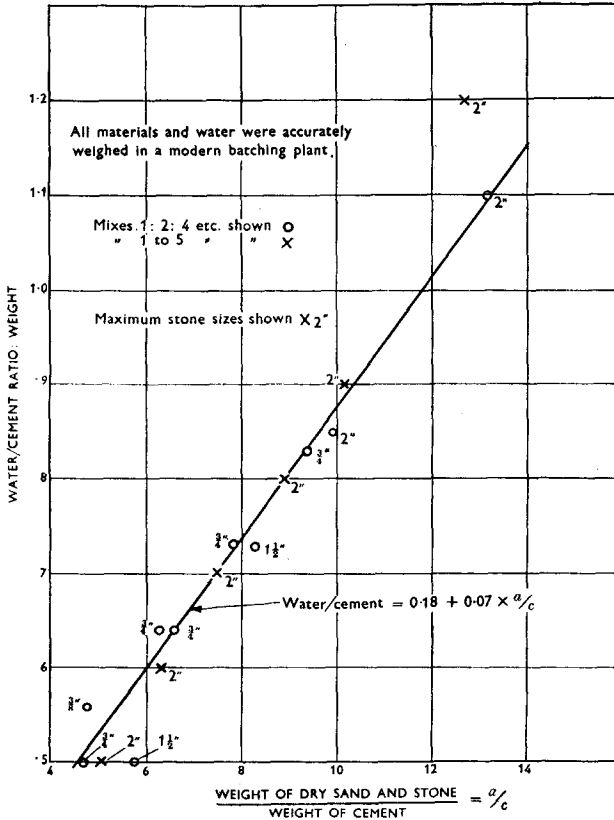
The results plotted on *Fig. 7*, were obtained from a modern batching-plant, where every item was carefully weighed. They showed how the water/cement ratio, to obtain a workable concrete, increased with the leaner mixes.

The water/cement (w/c) ratio had been plotted relative to the ratio of the weight of dry sand and stone to that of the cement (a/c). The water/

cement ratio ranged from 0.5 for an a/c ratio of 4.6, to 1.1 for an a/c ratio of 13.2.

In the equation it would appear that the neat cement required 18 per cent., and that the aggregates absorbed 7 per cent. of their weight of water.

Fig. 7.



The quantity of water required in a concrete mix varied with the following conditions:—

1. As the proportions of sand and stone to the cement increased the water/cement ratio also increased; a lean mix required more water than a rich mix.
2. A mix with a fine sand required a higher water/cement ratio than one with a coarse sand.
3. The greater the ratio of sand to stone, the more water would be required.

4. A mix with a maximum stone of $\frac{3}{8}$ inch would require more water than one with 2-inch maximum stone.
5. A slightly higher water/cement ratio was required for crushed aggregate than for waterworn sand and gravel.
6. A mix poured in precast units and vibrated would require a smaller water/cement ratio than one not vibrated in place.
7. If the mix were deficient in cement, sand, or fines, the addition of water did not produce workability, but a stony watery mix which segregated.
8. There should be enough water in the mix to give suitable workability to get it into place by spading, and that should be the determining factor. Workability should vary with the class of work, from slabs and mass walls to intricate reinforced work. Too little water to obtain those conditions would result in a serious deficiency in the strength of the concrete.

In the example cited by the Author on p. 69, the concrete mix consisted of 112 lb. of cement, 200 lb. of dry sand, and 490 lb. of stone, and the ratio of dry sand and stone to cement was 690 lb. to 112 lb., or 6.15. According to *Fig. 7*, a suitable water/cement ratio would be about 0.61, so that, provided the sand and stone were similar to those from which *Fig. 7* had been plotted, the value of 0.6, used on page 71, would be suitable.

In reinforced-concrete work, if the concrete was not workable enough to get into close contact with all the reinforcing-bars, stirrups, etc., the bond strength between the steel and the concrete would be affected and the structural strength of the member would be seriously deficient. The steel bars would not be fully protected against corrosion or the leakage of water or damp into the steel from the outside.

It was not possible, with a mix that was too dry, to make concrete of maximum density and not porous which would be satisfactory for resisting water-pressure without leakage. In many cases watertightness was much more important than maximum strength. In mass concrete work the stresses which the concrete had to resist eventually were usually much below the maximum stress it could withstand with a generous factor of safety; and a slight increase in the water (without excess) to get the material satisfactorily into position was better, as the reduction in strength at six months or one year was very small, whereas with too little water it was serious.

The Author had drawn attention to the bulking of the sand when moist, and *Fig. 5* showed that the increase in bulk due to moisture might amount to 37 per cent. If the sand were measured by volume, it might therefore amount to only 73 per cent. of the quantity required, and that method might result in a serious shortage of sand and fines and produce a mix which was harsh and could not be made workable. In that case, the

remedy was to increase the content of sand. Specifications should state the volume of the sand to be used after bulking had been allowed for.

Mr. T. R. Grigson observed that the Author's suggestions for the production of a dense and strong concrete were very interesting; but whilst he fully appreciated that the Resident Engineer should have a thorough knowledge of the manufacture of concrete, he rather wondered whether the work to which the Author had referred was not likely to add to his already onerous duties.

There was no question that aggregates were equally as important in the production of good concrete as the cement, yet if the latter could be supplied to a certain standard without continual tests being made, there was no reason why the aggregates should not be delivered to whatever grading was required and so relieve the Resident Engineer of the rather tedious work of checking almost every load.

The remedy lay entirely in the hands of the engineer responsible for the scheme, and if he would but specify that the aggregates should conform to certain requirements as to grading, and that all materials should be proportioned by means of suitable batching plant, the procedure as outlined by the Author would not be necessary. In that way the unsatisfactory and haphazard method of gauging by loose volume, which was far too common in Great Britain, would be avoided, the quality of the concrete would be improved considerably, and the work could be carried out on economical and scientific lines.

Mr. C. A. Risbridget observed that the Author had made a substantial contribution towards the development of the manufacture of concrete to the exact science which it would eventually become.

Much had been done to that end by the work of Professor D. A. Abrams and Professor H. N. Walsh on the "fineness modulus" method of proportioning aggregates, but it was doubtful whether their publications had as yet so wide a publicity among engineers (especially the younger ones) in Great Britain as had a Paper in the Institution Journal.

The advantage of the method lay in the fact that the suitability of the various available aggregates for the manufacture of concrete could be ascertained from their individual grading analyses, the determination of which was simple and inexpensive in comparison with the alternative method of selection involving the making of several trial mixes, the casting of test-cubes, and their testing for watertightness and strength.

If the engineer was restricted, on grounds of economy, and had little or no opportunity to select materials, the advantages of the method, although they certainly existed, might not be so immediately impressive when by long use of other methods he was satisfied from his test results that he was getting good concrete. Good results had been obtained by proportioning from measurement of voids, although that method could be demonstrated to be rationally unsound when used to make a selection from several available aggregates.

Another somewhat analogous method involved the experimental determination of the proportions of two or more grades of coarse aggregates required to produce their densest dry mixture. To that mixture was added the minimum quantity of the fine aggregate which would produce, with the specified cement-content and limited water/cement ratio, a concrete of the required degree of workability.

Mr. Risbridger had had an opportunity of testing the grading of three classes of concrete proportioned by the last-mentioned method, and in each case the result was in close agreement with the grading of the mix as designed by the "grading analysis" method.

There was, however, no doubt that the analytical method was the most convenient, both in design and in the subsequent control of the mix.

It was becoming increasingly evident that more reliance was being placed upon the proper proportioning of aggregates to increase the watertightness and strength of concrete, a result far too often obtained by making a wasteful increase of the cement-content compensate for faulty grading.

It was reasonable to suppose that with wider recognition of the important part played by correct grading a demand would arise from engineers for more rigid control of quarries, and the day should not be far distant when a request that concrete aggregates should be accompanied by certified grading analyses would occasion no more surprise than did the demand that a cement test-sheet should accompany any reasonably large consignment of cement. The proximity of that day was dependent upon a more general adoption of close control of concrete on works.

In the Author's specification of the coarse aggregate, the requirement that "the delivery must be uniform and not the product of several different quarries," might lead to the supposition that he hoped to obtain uniformity by drawing from the one quarry only. In his introduction and in *Figs. 1* and *2*, he showed that he was under no such delusion, and as he had stated, it was the fact that for various reasons the composition varied from load to load. Consequently, on large jobs, Mr. Risbridger favoured the use of three or more different sizes of aggregate from separate bins, as offering a more ready means of correcting any departure from the desired grading of the mix, more especially when concrete was proportioned at the mixer by a batch weighing-machine, which facilitated measurement, and of which very reliable makes were on the market. In order to obtain the requisite sizes of aggregate, it might be necessary to deal with more than one quarry, and the wisdom of specifying that the coarse aggregate should be from one quarry was questionable.

The Author had chosen for his practical grading curves those of Taylor, Thompson, and Smulski for a general-purpose concrete. Some variations from that curve would be desirable to meet certain cases, and in general a curve lying (within limits) below the practical curve would produce a more watertight concrete, provided that adequate means of

consolidation were adopted, whilst curves lying above the practical curve would give a concrete of greater workability, with corresponding decrease in strength and density.

When calculating the proportions of the various aggregates required to produce a mix of the desired grading, it would be found helpful, in estimating the adjustments to be made in the weight of individual constituents, if, for each, values representing the percentages *retained on each sieve* were calculated and set down next to the values of the percentages passing each sieve.

Thus, referring to the Author's "Example III", on p. 75, the addition to the mix sheet of the extra columns 8, 10, 11, and 12 shown in the following Table would reveal at once which particular sizes of stone were deficient or in excess :

Analysis.			No. 56.		No. 57.							
	14		30		56							
	Cement.		Sand A.		1½—¾ inch stone.		Mix.		Specified type grading.		Divergence from specification.	
	X	Y	X	Y	X	Y	Passed.	Retained.	Passed.	Retained.	Passed.	Retained.
1½ inch	14	100	30	100	56	100	100	Nil	100	Nil	Nil	Nil
1 "	14	100	30	100	30	53	74	26	77	23	-3	+3
¾ "	14	100	30	100	18	32	62	12	65	12	-3	Nil
½ "	14	100	29	98	—	—	43	19	47	18	-4	+1
⅓ "	14	100	27	90	—	—	41	2	38	9	+3	-7
No. 7	14	100	24	81	—	—	38	3	32	6	+6	-3
No. 14	14	100	16	55	—	—	30	8	26	6	+4	+2
No. 25	14	100	12	40	—	—	26	4	21	5	+5	-1
No. 52	14	100	8	27	—	—	22	4	17	4	+5	Nil
No. 100	14	100	3	9	—	—	17	5	15	2	+2	+3
								17		15		+2
								100		100	Col. 7	Col. 8
											Less	Less
											Col. 9	Col. 10
Column	1	2	3	4	5	6	7	8	9	10	11	12

From column 12 it was obvious that the final mix contained rather too much stone bigger than 1 inch and was deficient in stones of sizes between $\frac{3}{16}$ inch and $\frac{3}{8}$ inch, and in those between No. 7 size and $\frac{3}{16}$ inch. Mr. Risbridger considered that the addition of columns 8, 10, 11 and 12 indicated more clearly the nature of the mixture than did figures showing percentages passing sieves, and facilitated the necessary corrections to be made to adjust the differences, provided that similar columns indicating percentages retained were added to the analysis sheets of the individual constituents.

In the particular example considered, it was obvious that the deficiency in the $\frac{3}{8}$ inch size stones could not be made good without increasing the

already excessive "fines," as the No. 57 analysis showed that the $1\frac{1}{2}$ - $\frac{3}{8}$ -inch aggregate contained no $\frac{3}{16}$ -inch stone, whilst analysis No. 56 revealed that the sand contained only 8 per cent. of that size.

That example afforded a useful illustration of the desirability of making up the mix on the job from at least three different sizes of aggregate; for had there been an additional aggregate of size $\frac{3}{4}$ -inch to $\frac{3}{16}$ -inch it was probable that the three aggregates could have been combined to give a mix corresponding exactly with that specified, as in fact had been done in Example 6, although a coarser sand was used therein.

It was admitted that in Example 7, complete agreement had been achieved using only sand and one other size of aggregate; but in that case the sand contained a considerable proportion of stone of $\frac{3}{8}$ inch and $\frac{3}{16}$ inch sizes, which were rather large sizes to be found in aggregate classified as sand, and might have been specially pre-mixed to give the necessary qualities to combine ideally with the larger aggregate. Perhaps the Author would be able to confirm or refute that assumption.

If the "Percentage Retained" columns were added to the Table in Example 4, it would be seen that the adjustment of the mix had led to a result in which there was an excess of the largest and smallest sizes, and a deficiency of middles, which would give a concrete of rather easy workability, at the expense of density and strength. It would have been very useful and convenient had the Author been able to add to each example some particulars as to the nature, workability, density, etc., of the concrete resulting therefrom.

The Author was fortunate in having at his command, as shown in the Appendix, materials having a specific gravity as high as 2.9. That explained the very high weight per cubic foot (160 lb.) resulting from concrete graded to his curve No. 2, whilst those resulting from curves 5 and 6 were on the low side when such dense aggregate was used. Those low results were, however, to be expected from the positions of the grading curves of the mix from which the concrete was made, namely, above the practical curve in *Fig. 4*, and from the fact that the density of concrete—other things being equal—decreased with decrease in the maximum size of stone used.

The Author, in reply, observed that in writing the Paper he had wished to draw the Resident Engineer's attention to the more recent developments in the proportioning of concrete mixes and to emphasize that the proper control of the mix was becoming a larger and more important part of his work. The publication of recent Codes of Practice setting out various grades of concrete and allowing higher working stresses on "high-grade" concrete made it appear that the Resident Engineer would have to consider more fully the problem of obtaining a more rigid control, in order to ensure the maintenance of the higher standard. Therefore he could not agree with Mr. Bulman that the title of the Paper was not apt, or that the Resident Engineer was more concerned with other matters. A little more work was entailed, but he did not see how that could be avoided,

or who was to be responsible for the concrete if it did not come under the Resident Engineer's supervision. If, as Mr. Grigson had suggested, the aggregate could be obtained already graded, the work on the site would be reduced, and attention would need to be given only to the bulking of sand and to the water-content, as set out on page 71.

The Author agreed that the figures given in Table III were too few to be conclusive. He had no doubt that the 4 : 2 : 1 concrete was just as good, but he would like to know how Mr. Bulman would have proceeded if his 4 : 2 : 1 concrete had not been to his satisfaction and how he had satisfied himself that the required strength was produced with the minimum quantity of cement.

Sand certainly did vary from day to day in moisture-content and bulk, and the Author had tested it daily for many months and had made the necessary adjustment to the quantities of sand and water to maintain the mix uniform. That work might be rather monotonous, but it did not occupy more than 15 minutes each day. He agreed that the mixer-driver's work called for considerable skill, and he thought that every Resident Engineer had had occasion to value a man who showed an aptitude for that work.

With regard to mix sheets, Mr. Risbridger's additional columns were very interesting and certainly revealed the excesses and deficiencies very clearly, but after those sheets had been used a few times it would be found that the allowances could be made easily and rapidly by inspection. Three different sizes of aggregate were very much to be desired, and made grading easier. The three sizes could be the product of different quarries, as Mr. Risbridger had suggested, but in the specification clause quoted it was assumed, for simplicity, that only one size of stone ($1\frac{1}{2}$ — $\frac{3}{8}$ inch) was being supplied, as was usual on most jobs.

Mr. Risbridger's other method of proportioning was very interesting, especially as the results were in good agreement with the grading curves.

The Author agreed that the sands used for the tests referred to in the Paper were rather coarser than was usual. They were as found in the district and were not artificially pre-mixed. The sand shown in Example 4 was even coarser than the one referred to by Mr. Risbridger ; but a coarse sand was not a disadvantage where grading was concerned, provided the stone used was suitable. The more conventional limit of $\frac{3}{4}$ inch for the fine aggregate was presumably fixed by the fact that sand was more often of that size, but from the requirements of grading the delineation between sand and stone was purely arbitrary.

The Author was in full agreement with Mr. Gibb's interesting and instructive remarks on the water/cement ratio. If he had been guilty of creating the impression that he thought that ratio was unimportant it was merely because he was considering grading as his main subject. He fully realized that in a short Paper every aspect of the problem could not be dealt with completely.