reduction in the total water content of the freshly mixed concrete is advantageous. In fact, it is reasonably certain that in instances where bleeding has been reported as decreased by the addition of fines to the sand or a better grading of the sand, that the real reduction in bleeding was secured by a reduction of the total water in the concrete; the increased workability of the concrete by the improved grading of the aggregate making this possible. Mr. Powers' paper indicates that the addition of fine sand (unless of a fineness comparable to cement) would have a negligible effect upon the bleeding tendency of the concrete, except as it might decrease the water required for workability.

Tests by Gruenwold* indicate that where enough such fine sand has been added to retain the water and really decrease the bleeding tendency, the resulting concrete shows decreased durability.

The finer the cement is ground the lower the bleeding rate and the bleeding capacity for a given water content of the concrete. This characteristic of a concrete made with a finely ground cement is probably of some advantage in certain types of construction. The author is of the opinion that it also offers serious objections in many instances. These objections will be discussed later.

Certain admixtures in concrete or in a cement are effective in reducing the bleeding tendency.

Most of these admixtures are of the type which cause the incorporation of air in the cement water paste. This air is very effective in promoting workability and reducing the amount of water and paste required for a given consistency. Any reduction in bleeding secured by reducing the total water in the concrete is desirable. It should, however, be pointed out that the properties which make possible this reduction in water content may also reduce the compressive strength of the concrete. A balance between these features should be secured in the design of the mix.

There are practical limits to the possible reduction in total water content of a given mix. The necessity for handling and placing the concrete will frequently result in a higher bleeding rate than seems desirable. This is particularly likely to occur where rather deep sections of concrete are being placed. When this occurs the reduction in the bleeding rate by the use of admixtures or finely ground cements may possibly be desirable. Again it should be pointed out, however, that if these admixtures or cements with high water retentive capacities are used, precautions must be taken to prevent the use of excessive quantities of water and also to see that the placing and finishing

*"Lean Concrete Mixes"—Ernest Gruenwold, A. S. T. M. Proc., Vol. 39, 1939.

processes do not result in incorporating in the upper layer of concrete the excess water coming up from the lower layers. Where cements or admixtures with high water retentive capacity are used this excessive water will not be evidenced by the accumulation of free water on top of the concrete. Where possible, the water on top of the concrete in deep sections should be removed or compensation made in the succeeding batches of concrete to allow for the excess water, bleeding from the portions below.

USES OF BLEEDING

Most of the preceding discussion was concerned with the objectional features of bleeding and how these might be controlled. We should, at the same time, recognize that for most of our plastic concrete some bleeding is required. In thin horizontal slabs and in pavement construction, the appearance of free water on the top of the concrete is frequently used as a guide for the required amount of water to be added to the mix. The top of the concrete must be wet to permit ordinary finishing procedure on thin slabs and in concrete pavement construction. When, due to low water content, or to cement and aggregate characteristics having low bleeding rates, the top of the pavement does not show some free water, it is customary in most construction practices to increase the basic water content of the mix. The author has noted this in many instances where high-early-strength cements were being used. The low bleeding rate of concretes made with such cements frequently requires the addition of considerable quantities of water to the mix, far above the requirements for workability in placing, so that the surface would not be too sticky and difficult to finish by the ordinary procedure. Frequently engineers think of this kind of concrete as having set up too fast and are inclined to blame this characteristic on the fact that high-early-strength cement sets too rapidly. This is not the case; such surfaces sometimes are very sticky and almost dry, while the mass as a whole is of a jelly-like consistency. Increases in water content of as high as one gallon per bag of cement have been noted in some instances where finely ground, high-early-strength cement was being used.

Let us consider the significance of cement fineness on the bleeding rate of a concrete. Take as an example the same concrete mix used by Mr. Powers (Page 63, PCA Bulletin 2). In this example he used cement 14502—a typical modern cement with fineness of 1860 sq. cm./grm. (see table, p. 34, Bulletin 2).

Using this cement, it is found that this concrete has a bleeding rate of $Q = 35 \times 10^{6-}$ cm./sec., and a slump of 4.7 in.; the water content was approximately 4.6 gal. per sack.

Now replace cement No. 14502 with No. 14560, a cement ground to what was no doubt a satisfactory fineness with the standard practice of 20 years ago. The cement has a specific surface of 1085 sq. cm./grm. By means of equations 226 and 14 of Bulletin No. 2, using exactly the same quantities of cement, water and aggregates, it will be found that the bleeding rate is: $Q = 167 \times 10^{-6}$ cm./sec. —more than 4.5 times the bleeding rate of the first concrete. Similarly, computing the bleeding rate, if cement K20 (a high-early-strength cement of 2540 specific surface area) were used, one would secure a value of $Q = 12.4 \times 10^{-6}$ cm./sec., only one-third of the bleeding rate of a normal cement, one-fourteenth that of the old-fashioned cement. To bring the high-early-strength cement concrete up to the same rate of bleeding as the normal cement would require 28 per cent more water, an increase of about 9 gallons per cubic yard. To produce concrete made with this finely ground cement with the same bleeding rate as the old-fashioned cement would require 74 per cent more water, an increase of more than 20 gallons per cubic yard. This would obviously produce a mix of such consistency that bad segregation would result, and the equation would not apply. Practically, it would not be possible to produce a concrete using such finely ground cement that would have the same characteristics as when the coarse ground cement was used.

To try to produce concrete with the old-fashioned cement with a bleeding rate of only 35×10^{-6} cm./sec. (that shown by the typical modern cement) would require a reduction in water content of more than 25 per cent. The resultant mix would not be usable if the original concrete with cement No. 14502 was a suitable mix.

In one instance, in the laboratory where a concrete pavement mix was being placed with three different cements, it was found that using the same aggregates to produce the same bleeding rate and apparent wetness of surface for finishing would require for Cement "A" at 3-in. slump, 4.8 gal. of water per sack; Cement "B" required 5.8 gal. of water per sack, and Cement "C," a finely ground high-early-strength cement, required 6.9 gal. of water per sack to give the same apparent finishing characteristics.

Concrete pavement placed with cements having high water retentive capacity and low bleeding rates may be badly abused if the engineer does not recognize that he always requires some bleeding, and that concrete which does not bleed may be very defective if enough water is added to make it bleed in accordance with his ideas of the desired wetness of surface. Where a concrete in thin slabs bleeds so slowly that a wetness of surface for finishing is not secured, water should be added by means of a fine spray. This condition is not commonly met with except in warm weather on drying days, or where unusually fine cements or admixtures are being used. Failure to recognize these conditions when they have developed has led to the construction of much inferior concrete. The surface characteristics of some sands tends to the development of premature bridging and a consequent checking of the bleeding rate. Some of these sands may require water varying from 10 to 20 per cent in excess of that required with other sands using the same cement. When such sands are combined with cements or admixtures producing concrete with high water retentive capacity the concrete is likely to be badly abused.

To reduce the bleeding rate of concrete by any means other than the reduction in the total water content of the concrete is a hazardous procedure. Cement and concrete technicians have gradually introduced into use cements and aggregates having distinctly different characteristics from those of not many years ago. We have not warned the ordinary user of these changing characteristics of the concrete when these cements are used. In most instances the average contractor or builder, and alas, too many engineers, are still using the criterion of 20 years ago for the proper consistency and wetness of surface for a concrete mixture. The result is that many engineers and builders think they are using much drier concrete than they used in their earlier experiences, when as a matter of fact, they have increased the water content considerably. Concrete is deserving of much more careful and thorough study than it has had during recent years. We have had very exhaustive (or exhausting) studies of cement, sand, stone, and the design of concrete mixtures but little thorough study of the real characteristics of a concrete mixture. Mr. Powers' paper leads the way toward such a critical study.

DENSITY

Another item on which we engineers have been consistently inconsistent is related to the density of concrete.

The density of concrete has frequently been used as a measure of concrete quality. Generally, the assumption is made that the quality improves with higher density. While all concrete technicians recognize that the densest concrete is never a rich mixture, those who speak most frequently of density think of the terms as being in agreement; that is, that density implies a rich mix. Most engineers have thought of density in terms of the maximum density for a given arbitrary quantity of cement, sand and stone. The maximum density for a fixed mix can be achieved only with the proper water content which is usually considerably less than is being used. Thus it can be seen that our concept of high density and related durability has really been a concept of low water content. The author believes that experience with such concretes and such variations in density has given rise to the vogue for the worship of dense concrete. When we recognize that most of the value of increased density in a mix of fixed proportions is due to decreased water content per unit volume of concrete we are not so surprised when we find that the use of admixtures in the concrete or in the cement, which incorporate air in the paste thus reducing the density of the concrete, usually give a remarkable increase in the resistance of such concrete to freezing and thawing. The incorporation of a small quantity of air in this paste promotes workability and plasticity more effectively than the incorporation of the same amount of water would have done. The result is that for the same workability the total water content has been materially decreased with the resultant increase in resistance to the disintegrating effect of freezing and thawing.

Without question, the resistance of this concrete to disintegration is further increased by the presence of these air voids. It is common knowledge that a low saturation coefficient in most masonry materials increases their resistance to disintegration by frost action. Presumably this increased resistance is due to the fact that as water freezes and pressure tends to develop, it is crowded into these small air voids without the development of destructive forces. While experimental data confirming this explanation of the increased resistance of concretes made with treated cements which do incorporate these air voids is still lacking, one would expect our experience with other types of materials to be repeated in this case. Observations of such concrete after a service of many years, and innumerable laboratory tests confirm the advantages of such concrete; the disadvantages of lowered density and consequent small loss in strength being more than offset by the gain due to decreased water content per unit volume and lowered saturation coefficient.

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Discussion of a Paper by C. H. Scholer:

Consistent Inconsistencies in the Consistency of Concrete*

BY ERNST GRUENWALD AND C. H. FORESMAN

BY MR. GRUENWALD†

Professor Scholer's observations coincide very closely with our own experience. His paper provides a valuable link between laboratory research and field practice. Laboratory tests make it possible to study the fundamentals of concrete under a given set of conditions, but it is difficult to reproduce the wide range of field conditions, particularly as regards placing and finishing. The paper offers a definite contribution on the problems of segregation and bleeding.

Contrary to the accepted belief that bleeding is undesirable, Professor Scholer presents the viewpoint that to some extent bleeding is a necessary and desirable property of concrete. His remarks refer in the main to paving concrete, where the presence of free water is necessary to expedite finishing, which usually starts shortly after the concrete is deposited.

We know that the fineness of the cement affects bleeding, and Professor Scholer's remarks on finely ground cements and high early strength cements bear directly on this point.

As we see the problem, there is a difference in the character of bleeding. In mixes lacking in fines, water alone comes to the surface. This water can be removed and this type of bleeding will generally not lead to an increase in the water ratio of the concrete near the surface. When mixes become more plastic, either through an increase in cement

*ACI JOURNAL, Apr. 1941; *Proceedings* V. 37, p. 537.
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content or use of finely ground cements with a higher water retentive capacity, the manipulation of concrete will bring mortar, rather than water to the top. This mortar has a high water ratio, as well as a high cement content and after hardening may easily separate and produce scaling in service. This type of mortar bleeding can be avoided in the field by the precautions suggested by Professor Scholer, such as low water ratio and minimum manipulation while the concrete still is in a plastic state. However, present field operations are geared to rapid progress and in general the temptation will be to improve the finishing characteristics by adding more water, especially when extremely fine cements are used.

That raises this question: should not the Tentative Cement Specifications which now contain a minimum fineness requirement, also perhaps require maximum limits of fineness for the different types of cement? And if so, what should these limits be?

Our experience with high-early-strength cements during the last 14 years has indicated that in mixes of moderate cement content, these cements will produce a more plastic concrete and still bleed sufficiently to facilitate finishing operations. It is only in the richer mixes, containing more than 6½ bags cement that this troublesome and objectionable stickiness appears which leads to the addition of water in order to promote finishing operations on the job. This is particularly true when cements of extremely high finenesses are used.

So far as finer cements are concerned, laboratory results and field experience are sometimes at variance. In the laboratory an increase in cement fineness is usually accompanied by greater strengths and somewhat increased durability. In the field, however, under present practices of manipulation and finishing, these advantages often fail to materialize. The reason lies primarily in a misconception as to workability. In the field, workability is usually judged by the slump test, but this test does not indicate true workability, particularly with the finer cements, such as high-early-strength cements, which produce a more plastic and cohesive concrete. It will be found that for equal slumps, fine cements produce concrete of greater mobility and placeability than coarse cements. This suggests the use of lower slumps with fine cements, and thus by maintaining normal water ratios the value of high-early-strength cements can be fully realized in the field.

Professor Scholer's paper is timely and helpful, and the application of his recommendations in the field should lead to better and more lasting concrete.

BY MR. FORESMAN*

I wonder if Mr. Scholer enjoyed writing his paper on "Consistent Inconsistencies . . ." as much as I enjoyed reading it. The cement finishers could do no less than present him with a life membership in their union. Anyone who presents a gang of cement finishers with a nice "bloody" concrete that requires them to sit peacefully by for hours before they can begin their work and then provides a nice film of laitance for them to trowel easily to a beautifully smooth surface is certainly deserving of their deepest gratitude. Oh, yes, this concrete is also to be put through a process of segregation immediately as it is placed so that the finisher is assured that he will encounter no difficulties whatever in his eighteen hours of—collecting his wages. So much for fun—with apologies.

Seriously, Mr. Scholer's paper provides plenty of food for thought. A discussion of the actual subject matter can be limited to a few brief comments: First, a properly designed mix does not bleed excessively and it does not need artificial segregation, other than that produced by adequate screeding, to provide a surface that can be floated and finished. Second, Mr. Scholer in his condemnation of "density" has shown at least one way of obtaining a good dense cement paste, which is the basis of durability. By providing incorporated air for lubrication he reduces the total water and provides a more dense paste. It is possible that the air incorporated in the mix could be replaced with a hard, durable mineral. The result would be much the same. Water would be displaced and the cement paste would be more dense and more durable.

In connection with that troublesome phenomenon known as "bleeding" (and not discounting the value of the work of Mr. Powers, Mr. Sprague and others), has it not occurred to anyone that the retention of water in a concrete mix depends mainly on the surface tension of the mixing liquid (usually water) and the surface area of the cement and aggregate? Suppose we state it this way: "Other conditions being the same, the bleeding of a concrete mix varies inversely with the specific surface area of the combined cement and aggregate." It is also true that, given a constant specific surface area, etc., the amount of bleeding can be varied by changing the surface tension of the mixing liquid. Mr. Powers mentions sodium chloride. Calcium chloride will also reduce bleeding. Both of these are soluble salts and increase the surface tension of the mixing liquid. The use of soluble salts is somewhat risky because they are generally active chemically. With the

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exception of calcium chloride, the action of which is fairly well known, any active chemical would be subject to a rather long and involved series of tests before its use could be considered. On the other hand many inert mineral flours can be safely used. Any job where the strength and durability of the concrete is of importance should have preliminary tests made of the concrete produced by the materials proposed to be used and materials considered for control of bleeding should be investigated in these tests. Materials other than those which are entirely inert may be used when the user has reliable information concerning the action when blended with portland cement.

I would like to call attention to two points which are not contained in the subject matter of Mr. Scholer's paper but which are emphasized by his discussion. The first of these is the multiplicity of meaning attached to the various terms used in connection with concrete. As an example let us take the word "density." The term can be applied to the specific gravity of the individual aggregate particles. We have again, the density of the mass of aggregate particles. This is strictly a function of the grading and shape of the aggregate particles. Then there is the apparent density of the cement paste (reduced by Mr. Scholer through incorporation of air). The actual density of the paste surrounding Mr. Scholer's air bubbles or particles of aggregate is something else again. Finally, the density of the mass of the concrete which is a combination of all the other densities. What does one mean by density? Concrete terminology may not be worse than that applied to other subjects but it is certainly in need of revision and simplification.

The other point brought out by Mr. Scholer's discussion is the appalling lack of ordinary intelligence in much of the design and control of concrete mixtures. If the hit-or-miss methods used in concrete work were applied to the manufacture of steel I wonder what would happen to some of our skyscrapers and bridges. It may be complimentary to concrete as a building material that it has stood up at all but the methods used certainly do not reflect much glory on the intelligence of the engineers who use it.

I do not quarrel with any person's idea of what the composition of a batch of concrete should be. I may think he is wrong and certainly he is entitled to think I am wrong but there can be no question that the concrete in any section of a structure that acts as a unit should be uniform. Current specifications and present methods of design and control do not make for that uniformity. To illustrate: The current A.S.T.M. specification for 1½-in. to No. 4 aggregate sets up the following limiting percentages passing the sieves listed:

2-in.	100
1½-in.	95-100
¾-in.	35-70
⅜-in.	10-30
No. 4	0-5

Material complying with this specification may have 65 per cent between ½ and ¾-in. or it may have only 25 per cent. These extremes represent totally different gradings and if fixed quantities of material are maintained in the mix a wide difference in the void content of the combined aggregate will obtain. Any increase in the void content of the combined aggregate simply means more water to maintain the proper consistency. The result is obvious, yet how many engineers or architects require (or permit) adjustment or redesign of the mix to take care of variation of the grading of aggregates within the specification.

Specifications for concrete aggregates have been and will continue to be dependent on what the aggregate industry is able to produce with the equipment available. Grading limits must be fairly wide but it does not follow that primary variations are acceptable in the final product—concrete. It is the function of the concrete engineer to adjust variations to his needs—not accept them as inevitable. An examination of specifications and procedures for the manufacture of concrete will show, however, that this last is just exactly what the concrete industry has done and continues to do. The Joint Committee in Paragraph 305 of its report sets up certain suggested mixes. The only reference to what is desired in the grading of the combined aggregates is a foot note that the amount of sand may have to be varied to secure proper workability. The variations in the original aggregate are accepted as inevitable in the final product.

The gradation of the combined aggregates is an elementary, but important problem in the manufacture of concrete. The treatment of this one problem under the accepted methods of the design and control of concrete mixtures is a fair indication of the brand of intelligence used in that focal point of all of the knowledge we have of concrete. Mix design is not a matter of so many pounds of this and so many pounds of that; it is the considered application of knowledge of concrete and its ingredients to the requirements of the product.

Mr. Scholer discusses density, bleeding and segregation. I am inclined to disagree with him to some extent but neither he nor I will be able to obtain the desired results by accepting what Mother Nature provides and letting it go at that. Cements differ and aggregates differ. Many cements produce results that are desirable in some cases