DISCUSSION ON DURABILITY TESTS OF CERTAIN PORTLAND CEMENTS

(Report of Committee on Durability of Concrete as Affected by Cement, Proceedings, Highway Research Board, Vol 16)

MR IRA PAUL, *New York State Department of Public Works* While I agree in principle with the cooperators in this series of laboratory tests on portland cements, that the higher lime cements are more resistant to the action of freezing and thawing, I fail to see just how this test checks up the service records rendered by these cements Some cements similar in composition to those listed in this series that did not show up so well in the laboratory freezing and thawing tests have given us better service in concrete pavements than those that did We have some very outstanding examples of excellent old concrete pavements with cements such as is indicated by sample No 8, and some rather poor ones constructed at a later date as represented by samples No 1, No 10, and No 4

In a paper presented by Professor Lyse, of Lehigh University, before the American Concrete Institute in February, 1935, on, "The Effect of Brand and Type of Cement on Strength and Durability of Concrete," 18 commercial portland cements were considered The composition of the cements used by him were similar in general with such cements as No 1, No 2, No 4, and No 10, as represented in this cooperative series tests, in which the ratio of $\frac{CaO}{SiO_2+Fe_2O_3+Al_2O_3}$ ranges between 2 04 and 2 3 Some of the conclusions drawn by Professor Lyse are rather interesting and read as follows

1 "The durability of concrete containing different cements show considerable variation" (Durability as was measured by the number of cycles of freezing and thawing required to disintegrate the concrete until a loss in weight of 25 percent resulted)

2 "There was no consistent relationship between strength and durability of concrete containing different cements"

3 "No definite relationship could be found between strength and durability of concrete and the chemical compounds for different cements"

4 "The variation in strength and durability of these different cements was probably due more to the method of manufacture of the cement than to any other cause"

To me the most interesting conclusion is the last one quoted.

In all the physical tests I have made on portland cements in mortars or concrete—be it for strength, absorption, permeability, volume changes, or freezing and thawing, I have been unable to tie up any of these tests with the quality of the cement I do not believe we shall get very far in our search of the factors affecting the durability of concrete until we have a better understanding of what determines the quality of the most important constituent in concrete, namely, the cement

The quality of the cement is tied up with its manufacture Our main difficulty has been to evolve a laboratory control method, which will correlate the quality with the manufacture of the cement Several attempts have been made to determine the quality along chemical lines on the basis of oxide analysis, compound composition, and ratios While these attempts have been met with some favor, there have come to our attention several discrepancies, because of erroneous assumptions and other qualifying conditions in manufacture

An investigation is now under way by the American Society for Testing Materials Committee C-1 to check up the value of a "water test" I developed on portland cements, which I believe is related to the process of manufacture

In this connection I might state that cements No 1, No 4 and No 10 of this cooperative series, which had low resistance in the Merriman Sulphate test, showed rather heavy flocs in my "water test" The other samples in this series showed very little or no floc formation in the "water test" Both the Merriman Test and my floc test are chemical tests, and measure not only its sulphate resistant properties but the chemical stability of the cement A cement that is chemically stable is the type which in the long run will give more satisfactory service

MR P H BATES, *National Bureau of Standards* This discussion will cover only that part of the Committee's report which deals with the acknowledged purpose of the tests, namely, the effect of cement compositions on the resistance of the cements to freezing and thawing and "certain other influences" The Committee is to be congratulated on having been able to draw so many conclusions from the data aside from those bearing on the avowed purpose of the research

The data so far as the discussion relating to cement composition is concerned are presented largely in Figures 7, 7A, 9 and 10 These were prepared from the original results as given in certain tables But the graphs just cited and used as a basis for the conclusions are based on certain averages It is the use of these averages that leads one to question the legitimacy and correctness of all of the conclusions made regarding compositional effects If one will consider Figure 6, he can see the "individual" data which were used in some of the averaging He will see that one laboratory has found that freezing and thawing under certain conditions at one age disintegrates the modulus of rupture specimens, while another laboratory carrying out the same (?) tests—but in its own manner—found that the strength ratio was reduced but 0 05, that in another case the ratio was reduced 0 81 according to one laboratory and increased 0 11 by another At three months after 300 cycles, laboratory CU has an average ratio for all cements of 1 04, while laboratory PCA had an average of 0 53 In other words, on the average one laboratory found that the cements were improved by freezing and thawing while another laboratory found the strength was reduced about one-half In spite of such a great spread of results, as one can very readily see in Figure 6, the reader is asked to accept conclusions based upon the question of a procedure of deducing trends from such nonconcordant results

But if the reader does accept these, it is difficult to see how he can accept the statement that Figure 7 indicates a trend showing that an increase of C_3S or the ratio of the percentage of lime to the sum of the percentages of silica, iron oxide, and alumina give better resistance Neither this figure nor any of the figures cited by the Committee as showing trends indicating relations between composition and strength show anything significant other than that there are no trends If in Figures 7, 7A, 9 and 10 one will omit Cements 9 and 10, and in Figure 10 the 14-day results, then it is only possible to deduce that compositional changes have no effect on freezing and thawing results As plotted, for instance, in Figure 9 Cement 8 on the left and Cement 11 on the right (omitting Cements 9 and 10) having the extremes in composition, have so nearly the same strength relations that it would almost take microscopical examination to see wherein there were any differences

Further, the other seven cements lie so nearly on a line joining these two extremes that one is doubly surprised at the Committee's conclusions

Among the "certain other influences" stated as the purpose under "Scope," there was apparently intended some studies of sulphate resistance The Committee with the same broadmindedness that characterized its freezing and thawing procedure, permitted each laboratory to carry out the sulphate tests in whatever manner the laboratory felt inclined to do Hence, four laboratories used three different test procedures Our attention is directed to the fact that "the effect of sulphate solutions was observable on Cements 1 and 10 in which the computed C_3A contents were 14 4 and 12 percent, respectively " Our observations show us that laboratory WU in one set of specimens found Cement 1 was barely adversely affected by the sulphates, while the specimens of Cement 10 were actually improved In another set of specimens the same laboratory found both cements decidely adversely affected But we are curious if the Committee intended us to observe such different deportment in its cryptic statement, "the effect of sulphate solutions was observable " The summary of the SO_3 results would lead one to believe that the Committee connected adverse sulphate resistance with high C_3A content However, laboratory NYSH found Cement 3 with but 1 0 percent C_3A (the least of all the cements) no better than Cement 8 with 7 1 percent and inferior to Cements 5, 6 and 9 with 9 9, 6 6 and 5 1 percent C_3A, respectively. Laboratory WU found Cement 3 (1 percent C_3A) no better than Cement 5 (9 9 percent C_3A) and inferior to Cement 2 (11 4 C_3A) in one set of tests and no better than Cements 5 and 11 (5 2 C_3A) and inferior to Cement 9 (5 1 C_3A) in another It seems that with such contradictory results it is rather difficult to find any relation between the content of assumed C_3A and the sulphate resistance The Committee might have called attention to the fact that Cement 9, found to be the poorest by nearly all tests in its resistance to freezing and thawing, was exceeded by none in its ability to resist sulphate action, while Cement 10, found almost uniformly to be the best in its resistance to freezing and thawing, was about the poorest in its resistance to sulphate action

We hope we will not be considered presumptuous if we suggest that the Committee might have discarded all of its summary and used in its place the following brief statement.

After having carefully studied the data obtained at the several laboratories, your Committee finds itself embarrassed, indeed, it should say more properly, chagrined Having set out "to ascertain the relative resistance to freezing and thawing and to certain other influences of several commercial cements differing in composition," your Committee so much lost sight of its objective that it permitted so many variables to be introduced by allowing each of the cooperating laboratories to follow its own test procedure, that no adequate "findings" can be derived as to the effect of varying compositions on freezing and thawing and "the certain other influences "

PROF C H SCHOLER, *Kansas State College:* Mr Bates' discussion is indeed very interesting I know of no more exhilarating experience than to listen to Mr Bates critically discuss a report The care with which he has studied this report to pick out its weak places and inconsistencies merits the appreciation of the Project Committee Had it not been an important and worthwhile report, I do not believe that Mr Bates would have gone to the trouble to even comment upon it

Mr Bates particularly objects to the conclusions drawn by the Project Committee relating to cement composition, and presented in Figures 7, 7A, 9, and 10 The Project Committee, in present-

ing the results of this series of tests, as shown in the graphs of Fig 9 and Fig 6, was unquestionably in error in attempting to arrive at the presentation of these results by means of one grand average A reference to Table 10 which shows relative flexural strengths of 1 2 mortars after freezing and thawing at various test periods and varying number of cycles by the various test periods and varying number of cycles by the various cooperating laboratories, will show that without exception, the results from two laboratories are such as to indicate that up to that time the method of test used in that laboratory was not severe enough to be of any significance as indicating the relative durability of the cements If you will observe the relative ratings of these cements at the conclusion of the various test cycles you will note that a variation of 4 or 5 percent between cements is about as high a variation as is shown These variations are no larger than would be expected by the individual specimens of the same cement In dealing with the general problem of durability and resistance to freezing and thawing, small variations in the apparent loss of strength are of no significance whatever So, in general, the results shown by laboratories B P R and C U, and to a considerable extent W U do not show enough discrimination between the various cements to make it worth while to attempt to draw any conclusions The inclusion of the data from these laboratories in the grand average tends to somewhat becloud the issue, but in spite of what Mr Bates says, it has not changed the general line-up as to the relative durability of the cements as shown in the summary of the tables. The variations as shown by these laboratories were so small that any conclusions to be drawn, together with the results from laboratory K S C, would merely be a report of the results secured at the latter institution This is a weakness in the report which the keen eye of Mr Bates did not discover or else was so considerate of the Project Committee's feelings that he did not wish to cause them the embarrassment of realizing that after all, their summary report was largely based on the findings from two laboratories only, P S H and K S. C

If you will refer to that portion of Figure 7 which reports upon the results of the loss from all laboratories, all ages, and all cycles, and refer to Mr Bates' statement that these data indicate that there are no trends, you will note that he has been deceived by a very common ruse in presenting data by graphs By merely enlarging the vertical scale of this figure you are impressed by the strong conclusions that might be drawn from these data

The same thing may be said of Figure 7A in which it will be noted that by changing the vertical scale, a very definite slope will be given to all lines, confirming the conclusions of the Committee

It is the writer's opinion that tests of this type should be interpreted in rather a broad, general way, and for this purpose I prepared a table showing the rating of the different cements at the conclusion of different test periods as determined by laboratory K S C This is then combined into an average rating for the complete period, and this in turn combined with the rating secured by P S. H and P C A These three laboratories being the only ones whose results showed sufficient separation between the various cements and consistent enough results that it might be feasible to try to average them together I have then taken these results and plotted these ratings on the basis of 1 to 10 in descending order against the tri-calcium silicate content of the cement, and against the lime ratio to the other oxides with the results shown on Figure 1 I have then

combined the results of the three laboratories and placed them on the same graph with the results from laboratory K S C You will notice the very excellent correlation shown by this graph to the conclusions drawn by the Committee If we were to eliminate one cement from this study, and Mr Bates has suggested that it is perfectly proper to eliminate two in order to conclusively prove your point, the correlation would be almost perfect It is the writer's personal opinion that we are not justified in going to the extreme refinement shown by this graph, that perhaps it would have been perfectly proper to combine the values shown by the high-lime cements, the medium lime cements, and the low-lime cements into three points and again there would be the same unmistakable trend of the data as shown in Figures 7 and 7A

From the inception of the program, Dr Bates was very critical of the fact that the Project Committee had not specified a rigid fixed method for the conduct of the test I am referring to freezing and thawing The writer was equally strong in the contention that probably the most significant facts in the study would be brought out by this variation in the method The conclusions as brought out by the Project Committee amply justify this contention As so frequently happens, the by-products of the investigation are more important than the original information it was sought to attain

PROF M O WITHEY, *University of Wisconsin* Just before coming to this meeting we measured and inspected the mortar prisms which were made of the various cements used in this program of tests and which have been half immersed, tops up, in pans of water out of doors during the past three winters at Madison, Wisconsin Records from two recording thermometers, one of which recorded air temperatures and the other the temperature within a 6 by 12-in cylinder, indicate that these prisms have received approximately 80 cycles of freezing and thawing during this exposure The data from these expansion tests have been inserted in a revision of Table 34 of the Appendix to the Committee Report They show that the 1 2

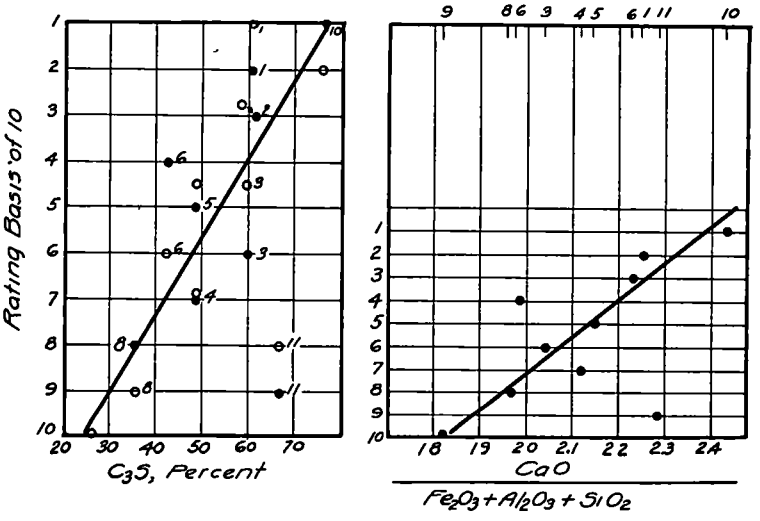

Figure 1

mortar prisms of cements 3, 6, 9 and 11 all of which had low ratios of Al_2O_3/Fe_2O_3 and medium to high contents of Fe_2O_3 and computed C_4AF have expanded much more than the other 1 2 mortars in this program Most of this expansion occurred during the past winter Several of these specimens have expanded over 0 2 percent Certain specimens of cements 9 and 11 expanded so much more on the bottoms than on the tops that the resultant bowing can be easily seen Checking and crazing on the surfaces was also more marked on the 1 2 specimens of these cements than on those of the other cements in the program

The large expansions for mortars of these cements are in agreement with the losses in strengths of similar mortars (Table 9) obtained at the laboratory of the Pennsylvania State Highway Department in the freezing and thawing tests which were conducted on specimens partially immersed during freezing and which we thawed in air This striking agreement in behavior indicates the desirability of partial immersion during freezing followed by thawing in air in making accelerated freezing and thawing tests

The expansion measurements of the 1 4½ mortar prisms of cements 3, 6, 9 or 11 show no excessively high expansions The 1 4½ mortar prisms of cement 4 have expanded materially and disintegrated considerably on the top surfaces and some of the corners of prisms of cements 1, 9 and 10 have crumbled away The maximum individual expansion of the 1 4½ mortar specimens was 0 2 percent, which was less than half of the maximums recorded for specimens of cements 9 and 11 in the 1 2 mortar specimens

MR R B GAGE, *New Jersey Highway Department* What proof do you have that any specimens are made up of the same density Note that density decreased in the properties of the concrete

PROFESSOR WITHEY I have no figures beyond the density figures presented here, but there have been computations made They are shown in the appendix of the report

MR L C MEDER, *California Division of Highways* It has been established through years of work in performing arbitrary tests that only by close standardization of details is it possible to obtain similar results Recently, in correspondence with several laboratories for advice in drawing up purchase specifications for such equipment, this laboratory learned that there were almost as many types of equipment and methods of testing as there were laboratories making such tests We admire the Committee's courage in publishing results that are so wide in range, but wonder if its object was not to emphasize the fact that if any reliance is to be put in the freezing and thawing tests, that test must be standardized

It is apparent that laboratory KSC got greater strength loss after the freezing and thawing cycles than did the other laboratories This laboratory had the most rapid freezing cycle, and the fastest thawing Since the test is designed as an accelerated test, the method giving results in the shortest time is the most satisfactory, if it can be proved that such results correlate with action obtained from natural weathering conditions

We do not feel that one is justified in drawing conclusions when they are drawn from results so inconsistent—to be explicit, laboratory BPR reports a ratio of 1 11 while laboratory PCA reports a ratio of 0 19 on the same cement under the same conditions There are a great number of such inconsistencies throughout the results that tend to cast a reason-

able doubt upon the value of the averages

Even if such averages are accepted, the resulting curves do not show a great difference in durability Were Cement 9, which is not a commercially-manufactured cement, eliminated, the resulting curve would be so flat that the influence of C_3S would be almost negligible

The results obtained in the sulphate test show considerably more uniformity between the laboratories involved All agree that Cement 4 with 16 percent of C_3A is the least durable The comparison that laboratory WU draws between 1 2 mortars and 1 4½ mortars bears out further data we have proving that leaner mixes are the less durable

Two of the laboratories used the Merriman Slab Test for evaluating the cements, and obtained somewhat similar results It has been found that the Merriman Test is not always accurate in such determinations It further appears that the total aluminates rather than the C_3A content are more of a factor determining durability when such a test is made in complete immersion in solutions of pure salts

For several years this laboratory has been conducting a comprehensive series of tests to determine the durability of cements exposed to aggressive solutions, and it has been found that certain calculated compounds contribute greatly to the action of a cement under definite conditions of test, but if the conditions are changed, other factors enter giving different results It is our opinion that not only the hypothetical compounds influence the characteristics of a cement, but also certain intangible factors introduced in raw materials and manufacturing processes

We feel that the paper under discussion, instead of closing the tests, should be considered more of a preliminary paper, and open the way for a test with those variables removed which do so much to cast a doubt on the results set forth in the present paper

Mr M Hirschthal, *Delaware, Lackawanna and Western Railway* The writer has found the following points of criticism of the various details of the report

Tests. There are eight types of tests included in the program With more attention to coordination to obtain concordant results and fewer types of tests more valuable results might have been obtained

Procedure· Statement as to age of specimen comparable to parallel ones subjected to freezing and thawing would indicate that the additional time for latter process was not included in age of untreated specimens Such additional time is referred to, in Tables 14 and 15 Was there interpolation of results?

Freezing and Thawing Tests· Variations in equipment and methods do not make for comparable results

Strength Tests Variation in methods here also I call attention to the fact that there is an A S T M standard for compression tests on portions of concrete beams, etc

Data Strength ratios in table do not show strengths of untreated specimens at corresponding age as referred to above

Summary or Results Conclusions unjustified by reason of lack of uniformity of equipment and of methods

(4) Quantitative tests for this purpose are necessary

Relative Resistance of Cements

(2) and (4) are not measures of durability

(5) is inconclusive because of variations

Tables

(3) shows wide variations and inconsistent except Cement No 4

(4) variations in mixing, curing, methods of loading, methods of freezing and various other tests

(8) K S C consistently low throughout

(9) K S C consistently low throughout

(10) K S C consistently low throughout

(11) shows very wide variations for individual cements

(13) no bearing on durability shown

(14) and (15) referred to above

While the conclusions arrived at from the tests seem reasonable, to my mind they are not fully justified because of the fact that they are drawn from results of different laboratories using different methods, different equipment, etc For instance, there is noted a variation in making specimens and obtaining constant consistency in the various laboratories, there is varying equipment for freezing and thawing and variation in times of freezing and thawing, yet the conclusion on this subject is based on tests from laboratories with slow freezing apparatus compared with those from laboratories with fast freezing apparatus It is to be noted also that an examination of the table shows that results from K S C are invariably appreciably lower than those of the other laboratories without any explanation for this condition

Moreover, it is questionable whether freezing and thawing tests are the whole answer to the question of durabilty of concrete or cement

MR H S MATTIMORE, *Committee Closure* In reply to Mr Paul the Committee would say that it is difficult to prove from service records the value of a cement unless *all conditions other than the cement are maintained constant* The Committee agrees with Mr Paul's statement that the strength and durability of concrete are closely related to the method of manufacture of the cement and that we need better control in manufacture If Mr Paul's floc test can be used to determine the durability of concrete made of a given cement, it will indeed be a blessing However, he submitted no substantiating data and the Committee has thus far received none from any source

The Committee well appreciates the variability of the results obtained due to the differences in procedures adopted in the tests made in the different laboratories Indeed, in formulating its program the variations in rates of freezing and in methods of thawing were to a large extent anticipated The Committee fails to share the chagrin so caustically expressed by Mr Bates in the last paragraph of his criticism It is the feeling of the Project Committee that this paragraph is out of place in this discussion From the nature of the program and the data secured it is not logical to omit the effects of the different methods used in conducting these tests The Committee's study of the data indicates that the "slow" rates of freezing accompanied by thawing in water used in three of the cooperating laboratories had small effect on the mortars made of any of the cements Nevertheless, the Committee *presented these data* It did not omit them Furthermore, the Committee asks those interested to examine carefully (1) the trends (in relations of lime ratio and the computed C_3S contents of the cements to the losses in compressive strength shown in Figures 8 and 9, (2) the data on rating of cements according to strengths shown in Tables 24 and 26 (Appendix), and (3) the ratings according to expansion and loss in weight, Tables 29 and 31 (Appendix) before they reject the Committee's conclusions relative to the relation of these quantities to the lime ratio and to computed C_3S

The Committee also wishes to call attention to the similarity in the trend of the expansion data from the tests of the 1 2 mortar specimens exposed to the weather for 3 years at the University of

Wisconsin and the trend exhibited in losses in strengths at the P S II and K S C laboratories during the accelerated freezing and thawing tests of the program

Commenting on two written criticisms presented by Mr Hirschthal, and Mr Meder, their main objection is to some of the findings given in the summary of results in the report, in that they do not feel that in all cases these findings of the Committee are justified from the data in the published report

One statement of some importance is made in the report under Summary of Results—"The data obtained from these tests is too voluminous to report in full in the printed Proceedings" Special reference is made to this as it is quite probable that if all of this data were available to all interested parties, as was the case with the Committee, in interpreting the findings, they would be in a better position to see the viewpoint of the Committee

Variations do exist in results secured from different laboratories This is noted in the published report, and has its effect on the averages, but the Committee thought it advisable to present findings from the averages rather than individual results At the same time the printed report furnishes data enough for those interested so that individual conclusion could be made independent of any findings of the Committee

We feel that the Committee really accomplished something in the results obtained on freezing and thawing as reported by the different laboratories The apparatus used by each laboratory was fully described giving the full information regarding time of freezing and thawing These data compared with the results secured should furnish excellent information for a possible standardization of the freezing and thawing tests Such standardization we all realize is vital at this time, in that, many reports are being submitted regarding the effect of the various cycles of freezing and thawing with little or no data accompanying them regarding the efficiency of the equipment

It is further hoped by the Committee that those interested will make an effort to study the additional tables in the appendix, which can be obtained through the Highway Research Board, and the Committee also solicits further comment so that the full value of the report can be obtained