CORRELATION OF AIR VOID PARAMETERS OBTAINED BY LINEAR TRAVERSE WITH FREEZE-THAW DURABILITY

by

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(The opinions, findings, and conclusions expressed in this report are those of the author and not necessarily those of the sponsoring agencies.)

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SUMMARY

The correlations obtainable from comparisons of the various air void parameters with the freeze-thaw durability of concretes are listed. It is shown that correlations are no better when only small voids are used than when the total void content is used. It is concluded that for most concretes, (1) the void parameters required by ASTM C-457 produce sufficient information to delineate the character of the air void system, and (2) that parameters such as the specific surface for small voids only and the spacing factor for the proportional number of small voids add no useful information when the demarcation between large and small voids is at 1 mm diameter expressed on the plane of examination.

It is recommended (1) that any further research deal with the entire void distribution by using the chord length distributions, and (2) that the various kinds of concrete be tabulated separately.

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PREVIOUS WORK

Over many years a wide variety of concretes have been tested at the Research Council to determine characteristics of their air void system in the hardened state and their expected durability under cycles of freezing and thawing. The air void data have been collected by linear traverse according to ASTM C-457,[1] and during the microscopic examination, voids irregular in form or having a diameter exceeding 1 mm, as expressed on the plane surface of the slab, have been noted. Data on these large and irregular voids have been collected separately as well as part of the total number and volume of voids. The freeze-thaw tests have employed ASTM C-666 Procedure A,[2] which has been increased in severity by using a 2% sodium chloride solution instead of water around the specimens. For this procedure, the specimens are aged for two weeks in a moist room and for one week under ambient laboratory conditions between demolding and testing.

It has been considered desirable to consolidate the data obtained by the two methods, and in 1978 Howard Newlon, Jr. stated that they should be analyzed "to seek relationships among durability factors, weight loss, surface rating, and air void parameters".[3] In attempting such a correlation, M. A. Edwards[4] was able to establish relationships with the air void parametrical system and between the air voids in fresh concrete and the air void system in hardened concrete, but found no relationships between the freeze-thaw data and the air voids analyzed according to ASTM C-457.[1]

This lack of a good correlation between the linear traverse and freeze-thaw data is not surprising. Both of these methods are essentially destructive; therefore, the exact same specimen cannot be examined by both tests. The linear traverse examination requires a smoothly lapped surface for microscopic analysis. The specimen must be cut into a thin enough slab to fit both the lapping equipment and the linear traverse stage. This slab is lapped with successively finer abrasives to produce a surface as shown in Figure 1.

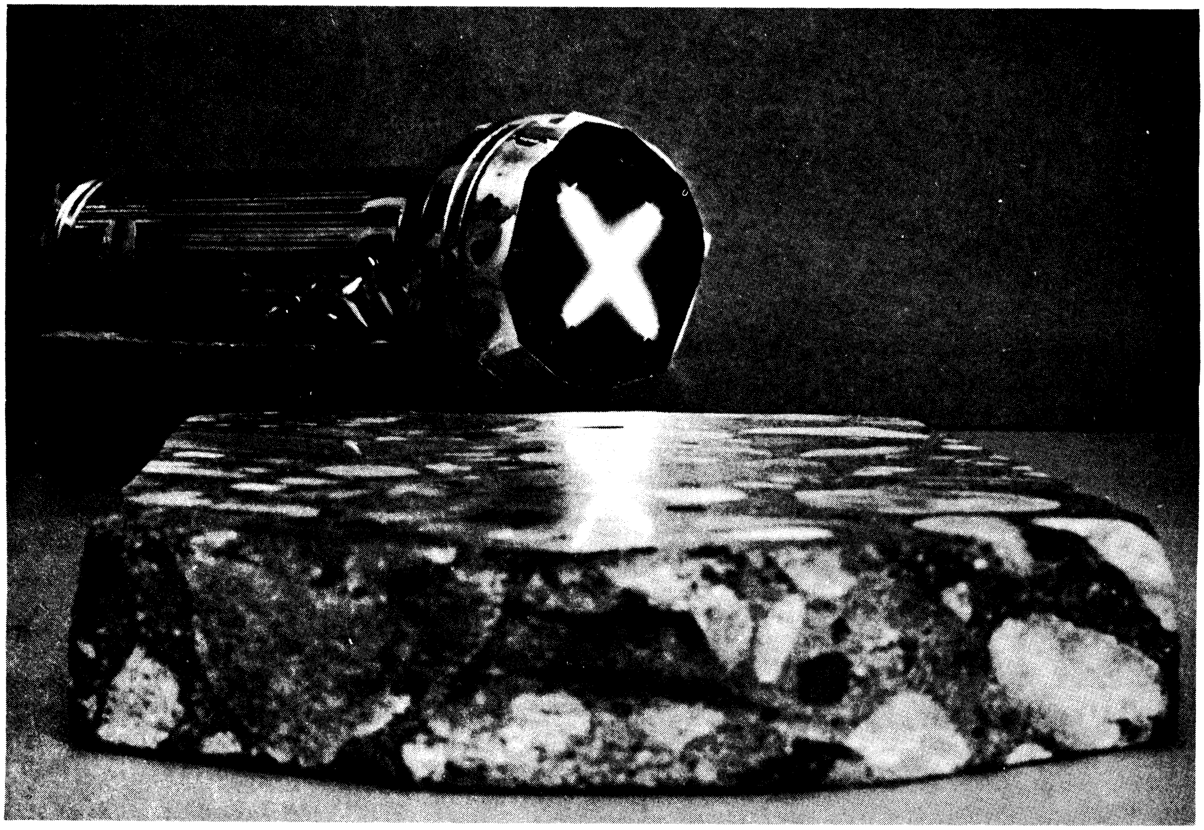

Figure 1. The ability to reflect a light image at a low angle indicates a sufficiently smooth surface.

The freeze-thaw procedures can cause severe deterioration of the concrete and usually produce cracks, secondary deposits, and a general weakening that make the concrete unsuitable for the fabrication of the smoothly lapped slab necessary for linear traverse. In the ordinary operations of the Council's laboratory, seldom is a freeze-thaw tested prism slabbed, lapped, and subjected to linear traverse analysis. At best, comparison tests are made on specimens from the same batch, and often in the case of concrete from the field two specimens are from different batches, or ready-mix trucks, and merely from the same bridge or pavement. The variability of concrete is well-known. It has been said that "no specimen of concrete is like any other specimen of concrete ... in fact a specimen of concrete is hardly like itself".[5]

For these reasons one cannot expect good correlations between different tests made on such specimens.

EFFECT OF AIR VOID SPACING ON DURABILITY

In 1958, Backstron et al. stated that a close spacing of air voids produces a high freeze-thaw resistance.[6] It has since been assumed that the small voids that occur closely packed are the major agent in the freeze-thaw resistance.[7,8] In 1980 a logical formula for calculating the spacing factor for small voids was devised,(9) and it was expected that such a formula would provide a good correlation between the voids and freeze-thaw resistance. The classical spacing factor (ASTM C-457) is calculated from a mean void size and distribution that includes all the large voids as well as the small voids. The larger voids have not been considered to provide protection against freeze-thaw deterioration, and they have been thought to be undesirable because of their adverse effect on strength. Thus, it was felt that a useful spacing factor should consider the small voids separately. As discussed by Walker,[9] the data obtainable from an ordinary linear traverse analysis which sorts the voids into only two sizes cannot reflect the true size distribution. Nevertheless, because the customary procedure has been to so divide the voids, the spacing factor for proportional number of small voids, $\bar{L}_s$, was devised and the concluding sentence of reference 9 states that "The collection of data necessary for examining this correlation (with freeze-thaw protection) is in progress at the Virginia Highway and Transportation Research Council."[9]

PRESENT WORK

The work reported here was not an effort to find good correlations, but rather to discern which correlations are better than others and which are of little or no apparent value.

Scope

Special consideration was given to the spacing factor for proportional number of small voids and of the specific surface calculated for small voids only. It was desirable to discover if these data are valuable and worth the time necessary to calculate and record them.

This present report presents the results of a study comparing the air void parameters as determined by linear traverse, ASTM C-457, with the durability factor and weight loss data obtained by use of test method ASTM C-666 Procedure A.

Procedures

The Council files were searched and test results for specimens that appeared to come from the same batch or from comparable field concretes were matched. The data were listed and computer cards were cut containing the test data from the two methods for each pair of specimens. At first 167 pairs were used, but as the calculations progressed it became obvious that some pairs were not truly representative of concrete in general. For example, 7 pairs from a laboratory study on internally sealed concrete were eliminated because, due to the unusual nature of the voids, the data gave negative correlations when positive ones were expected. Finally, 151 pairs were selected. Sixty-seven of these pairs were from field concrete and other miscellaneous sources, 50 were from an in-house study of superplasticizers, and 34 were a combined group from in-house studies of fly ash and kleenopor.

The following parameters were selected from each pair of specimens for the correlation.

From ASTM C-666 Procedure A — Freeze-thaw

Durability factor, DF
Weight loss, WL

From ASTM C-457 — Linear traverse for air system

Percent air — total	=	A_t
Percent air in small voids	=	A_s
No. of voids, mean, per inch traverse	=	V/in.
Specific surface, mean, as in ASTM C-457	=	SS_t
Specific surface, small voids only	=	SS_s
Spacing factor, mean, as in ASTM C-457	=	$\bar{L}_t$
Spacing factor, proportional, small voids only	=	$\bar{L}_s$

Each parameter of the air void system was compared with both the DF and WL. Within the groupings of 151 pairs (67 miscellaneous, 50 superplasticizers, and 34 fly ash and kleenopor) the following calculations were made by computer.

Sum of data for freeze-thaw

Sum of data for air system

Sum of squares of data for freeze-thaw

Sum of squares of data for air system

Sum of DF x each air void parameter

Sum of WL x each air void parameter

Figure 2 is given as an example of how the data were organized. The correlation coefficients, slope intercepts, and deviations about the curve produced were obtained with a programmable TI 58-C.

Results

The correlation coefficients obtained are shown as the heavy lines near the middle in Figures 3, 4, 5, 6 and 7. The confidence band was derived from Z ± 1.96 (standard deviation of Z), where $Z = 0.5 \ln \frac{1 + r}{1 - r}$, and r = correlation coefficient and using $1/(N-3)^{\frac{1}{2}}$ as standard deviation of Z. Thus for N = 151, $SD_Z = 0.821$; where r = 0.471, Z = 0.51135, Z - 1.96 (0.0821) = 0.35024, and Z + 1.96 (0.0821) = 0.6725. Therefore, the 95% confidence band for N = 151 and r = 0.471 is between r = 0.337 and r = 0.5866 as plotted for the correlation of the percent total air with the durability factor on Figure 3.

It can be seen that the confidence band becomes narrower as the N increases. The band is narrower at high correlations, and thus the portion above the coefficient determined is narrower than that below. The correlation of the air void parameters with DF was considerably better than with WL. The total group of 151 specimens was the only group of data that gave meaningful correlations with WL. The two groups from laboratory studies did not provide any correlations with WL that had a confidence rating of 95% or better. The group of 67 pairs of miscellaneous concrete provided no useful correlation with WL for A_t, A_s or V/in. There was minor evidence of a relationship between WL and SS_t, $\overline{L}_t$, and $\overline{L}_s$ for the mixed group. The WL data will not be presented for the smaller groupings.

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AKA = TOTAL AIR VOLUME
AKB = SMALL VOID VOLUME
V/IN= VOIDS PER INCH
SST = SPECIFIC SURFACE OF TOTAL SYSTEM
SSS = SPECIFIC SURFACE OF SMALL VOIDS
SFT = SPACING FACTOR OF TOTAL SYSTEM
SFP = SPACING FACTOR FOR PROPORTIONED SMALL VOIDS
WL  = WEIGHT LOSS,          DF  = DURABILITY FACTOR

 151 DATA POINTS
```

	MEAN	SUM	SUM OF SQUARES
AKA	5.684106	858.300000	5494.850000
AKB	3.771523	569.500000	2611.870000
V/IN	8.076821	1219.600000	13424.480000
SST	559.390728	84468.000000	55088140.000000
SSS	767.721854	115926.000000	101785632.000000
SFT	.009774	1.475878	.019489
SFP	.012121	1.830259	.030356
WL	3.964901	598.700000	8213.130000
DF	77.304636	11673.000000	1039591.000000

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SUM OF PRODUCT WL  X  AKA  =      2825.930000
SUM OF PRODUCT WL  X  AKB  =      1930.220000
SUM OF PRODUCT WL  X  V/IN =      3561.070000
SUM OF PRODUCT WL  X  SST  =    296428.500000
SUM OF PRODUCT WL  X  SSS  =    413866.200000
SUM OF PRODUCT WL  X  SFT  =         7.687246
SUM OF PRODUCT WL  X  SFP  =         9.285481

SUM OF PRODUCT DF  X  AKA  =     70687.200000
SUM OF PRODUCT DF  X  AKB  =     47894.600000
SUM OF PRODUCT DF  X  V/IN =    104935.600000
SUM OF PRODUCT DF  X  SST  =   6920504.000000
SUM OF PRODUCT DF  X  SSS  =   9275203.000000
SUM OF PRODUCT DF  X  SFT  =        98.865099
SUM OF PRODUCT DF  X  SFP  =       122.946123
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Figure 2. Computer printout of the sums of the data.

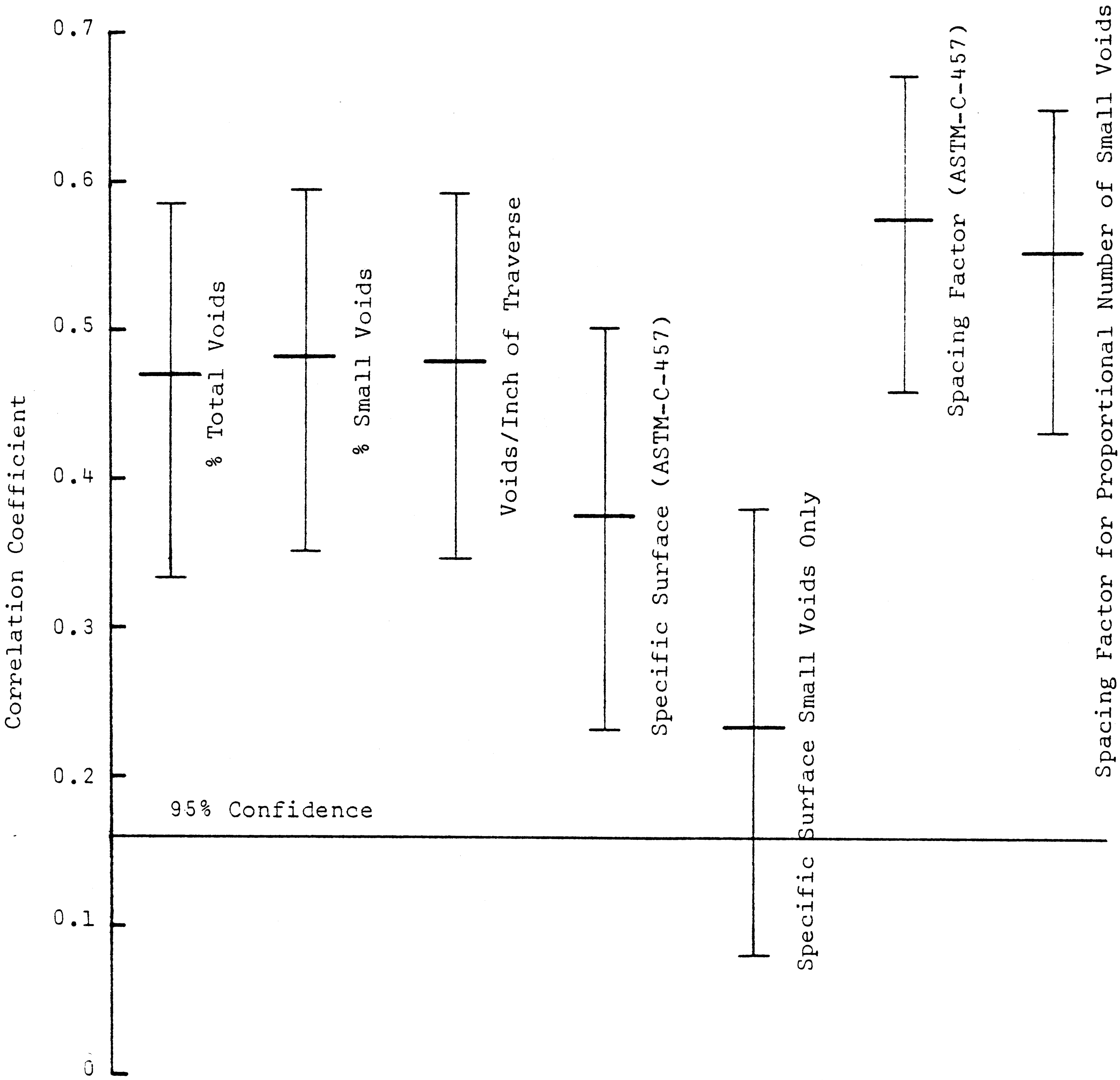

Figure 3. Correlation coefficient — durability factor versus parameters of air void system.
N = 151 95% Confidence Band
All pairs

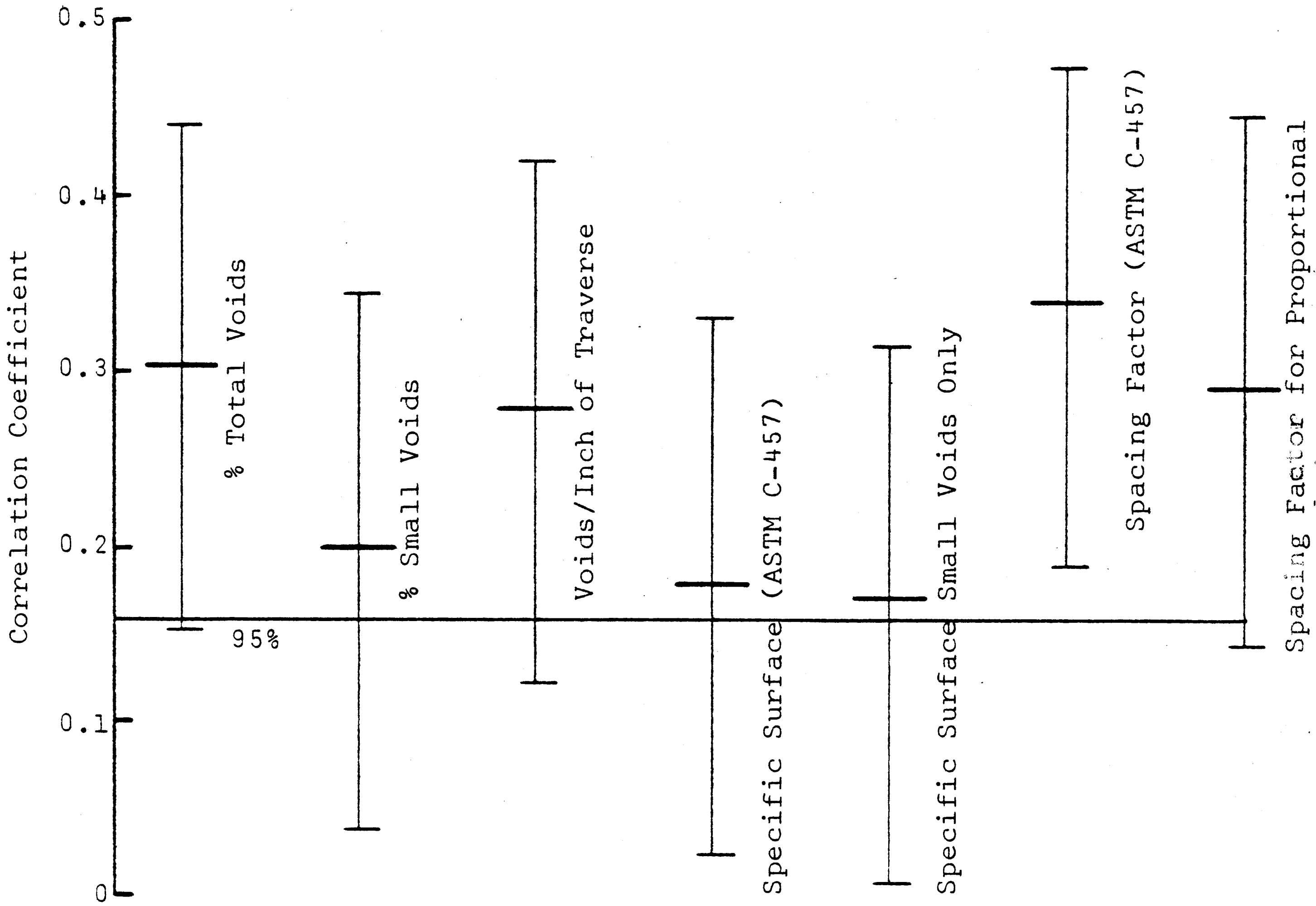

Figure 4. Correlation coefficient — weight loss versus parameters of air void system
N = 151 95% Confidence Band
All pairs

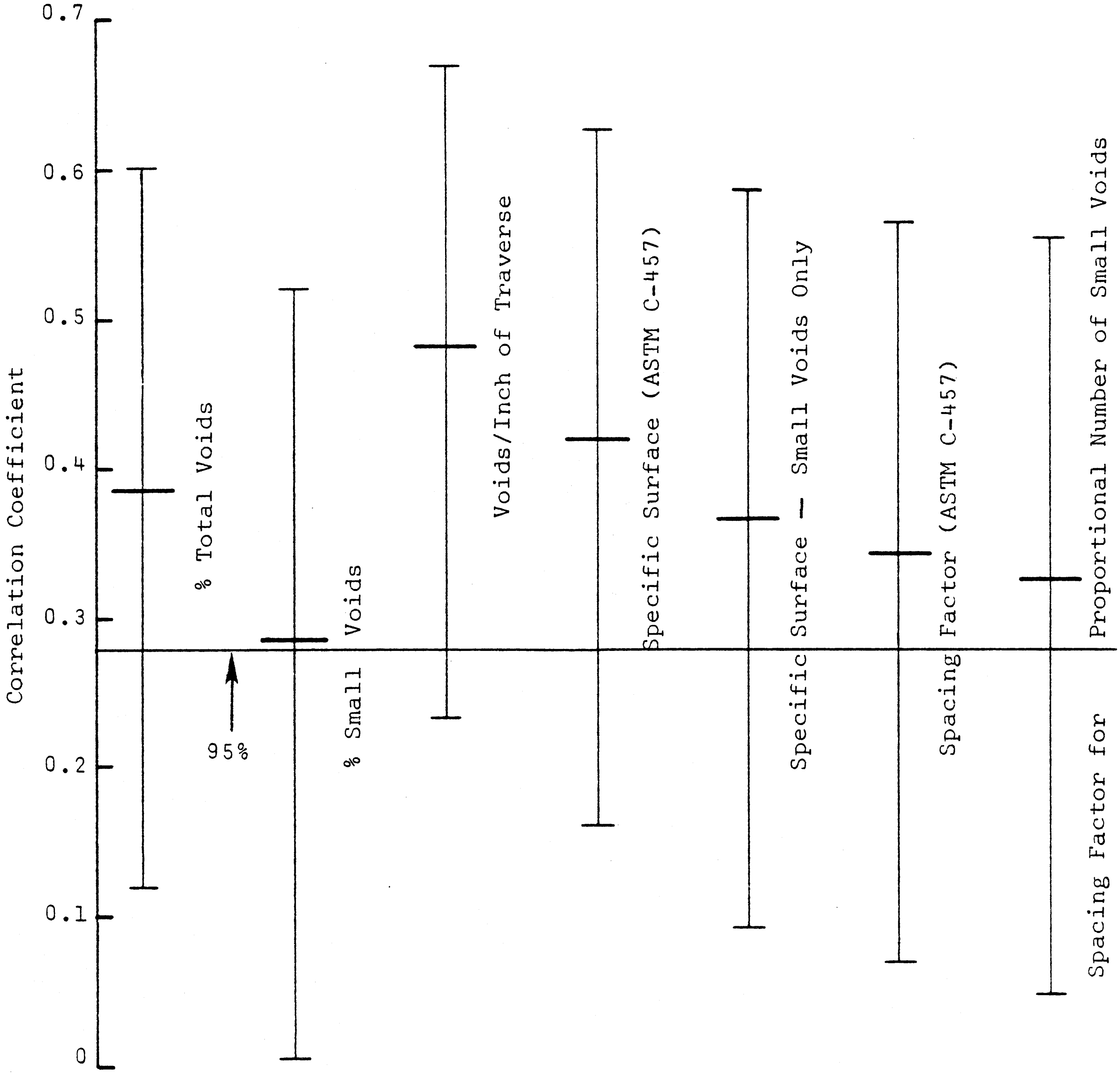

Figure 5. Correlation coefficient — durability factor versus parameters of air void system
N = 50 95% Confidence Band
Superplasticizer Project

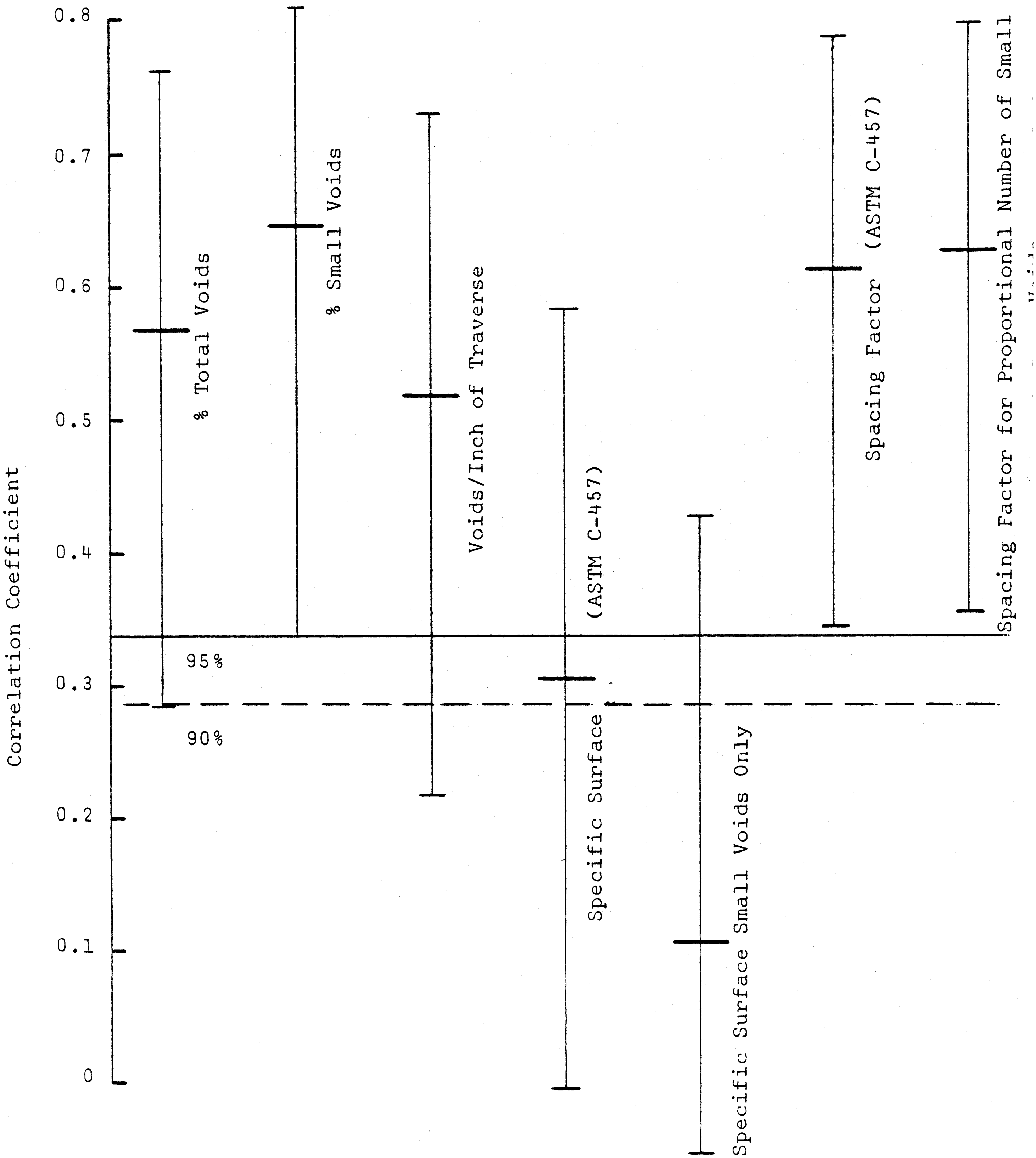

Figure 6. Correlation coefficient — durability factor versus parameters of air void system
N = 34 95% Confidence Band
Fly Ash and Kleenopor Projects

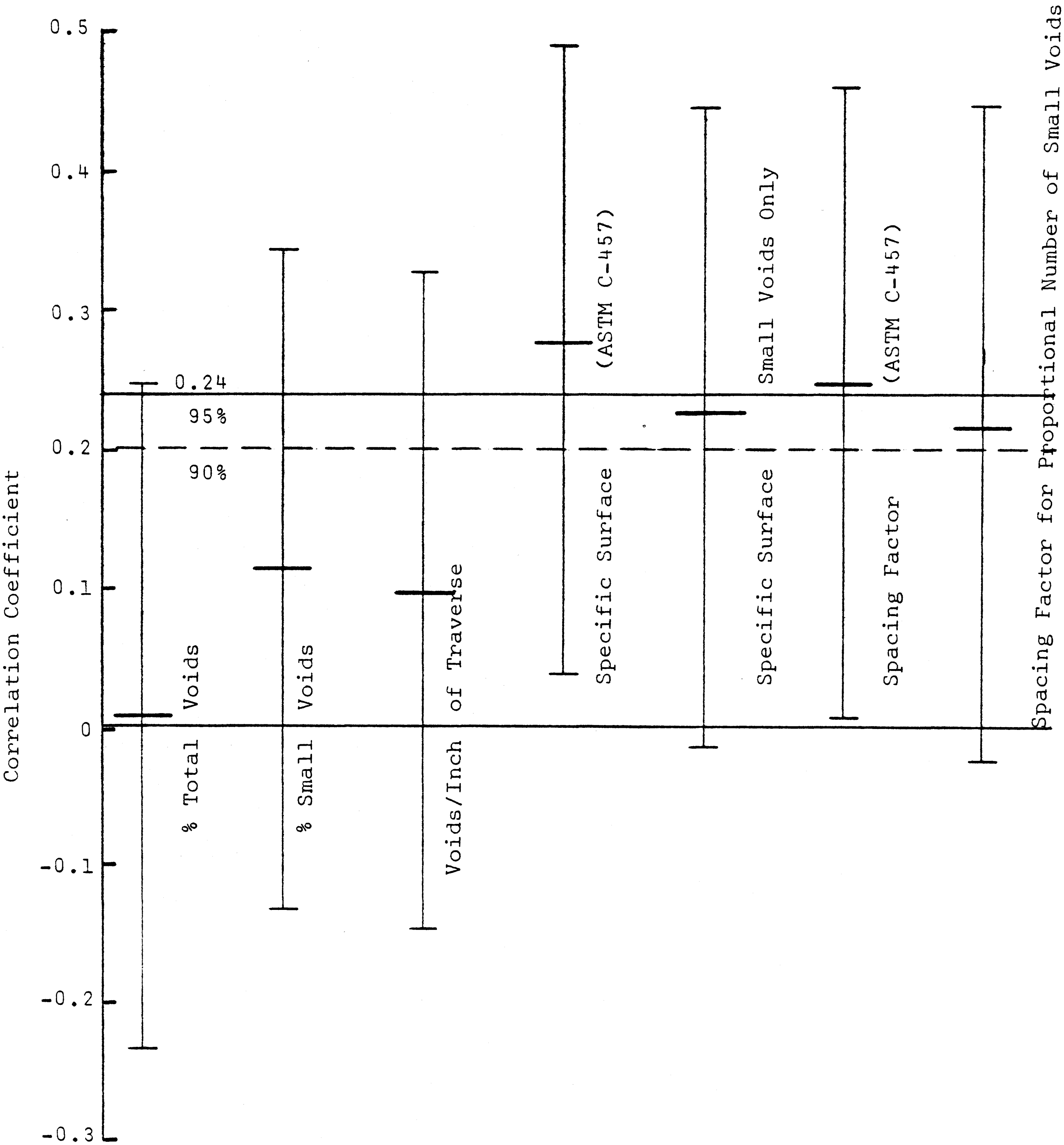

Figure 7. Correlation coefficient — durability factor versus parameters of air void system
N = 67 95% Confidence Band
Miscellaneous Group

From the illustrations of the correlations provided by these groupings of data pairs, the following observations can be made.

The laboratory groups and the total group of 151 show correlations between the air voids and DF at the 95% confidence level, except for the specific surfaces of the fly ash-kleenopor group. This lack is probably because of the very small size of some of the voids in the concretes in this group. The pairs from the miscellaneous concretes show much poorer correlations, but the SS_t and $\bar{L}_t$ correlations indicate a relationship at the 90% confidence level.

A_s does not consistently provide better correlations than A_t.

SS_s appears usually to provide less correlation than does SS_t.

$\bar{L}_s$ provides no better correlation than does $\bar{L}_t$.

The slopes of the curves generated for the 151 specimen group are illustrated in the Appendix.

From these results we may conclude that the calculations described in ASTM C-457 are sufficient for most concretes.

Discussion

The results showing that the calculations which emphasized the importance of small voids provide no better, and in some cases worse, correlations than the results from total voids are somewhat surprising in view of what had been generally thought concerning the importance of these voids for freeze-thaw protection. Perhaps a better correlation might be achieved if a different demarcation between sizes had been used. The results from the group of concretes from the study of superplasticizers can be interpreted to indicate that the larger voids provide some freeze-thaw protection. Voids of just 1 mm size are common in such concretes. Contrary results from the miscellaneous groups, where consolidation may be more of a problem, indicate the value of determining the percentage small voids; no correlation could be determined with total voids. Thus, it appears that different parameters may be more valuable than others in different kinds of concrete.

RECOMMENDATIONS

It is recommended that when the demarcation between large and small voids is a 1.0 mm diameter expressed on the plane of examination, the calculations for SS_s and $\bar{L}_s$ be discontinued as a waste of time. The same information appears to be available with a slightly better correlation in SS_t and in the classical spacing factor, $\overline{L}$, of ASTM C-457.

It is further recommended that any study attempting to provide more information concerning the correlations between freeze-thaw data and air void systems be concerned with the entire void size distribution. This might be achieved by a graphical analysis of the chord length distribution.

Because of the differences found between the various groups of concrete used in the work reported here, it is recommended that any further such study be confined to one type of concrete.

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ACKNOWLEDGEMENTS

The extensive collection and calculation of data and file searching accomplished by Christopher Hughes in preparation for this correlation are gratefully acknowledged. Philip Harris has been most helpful and patient in doing the computer work. Howard Newlon's encouragement has been a great aid, as has been the leadership of Harry E. Brown.

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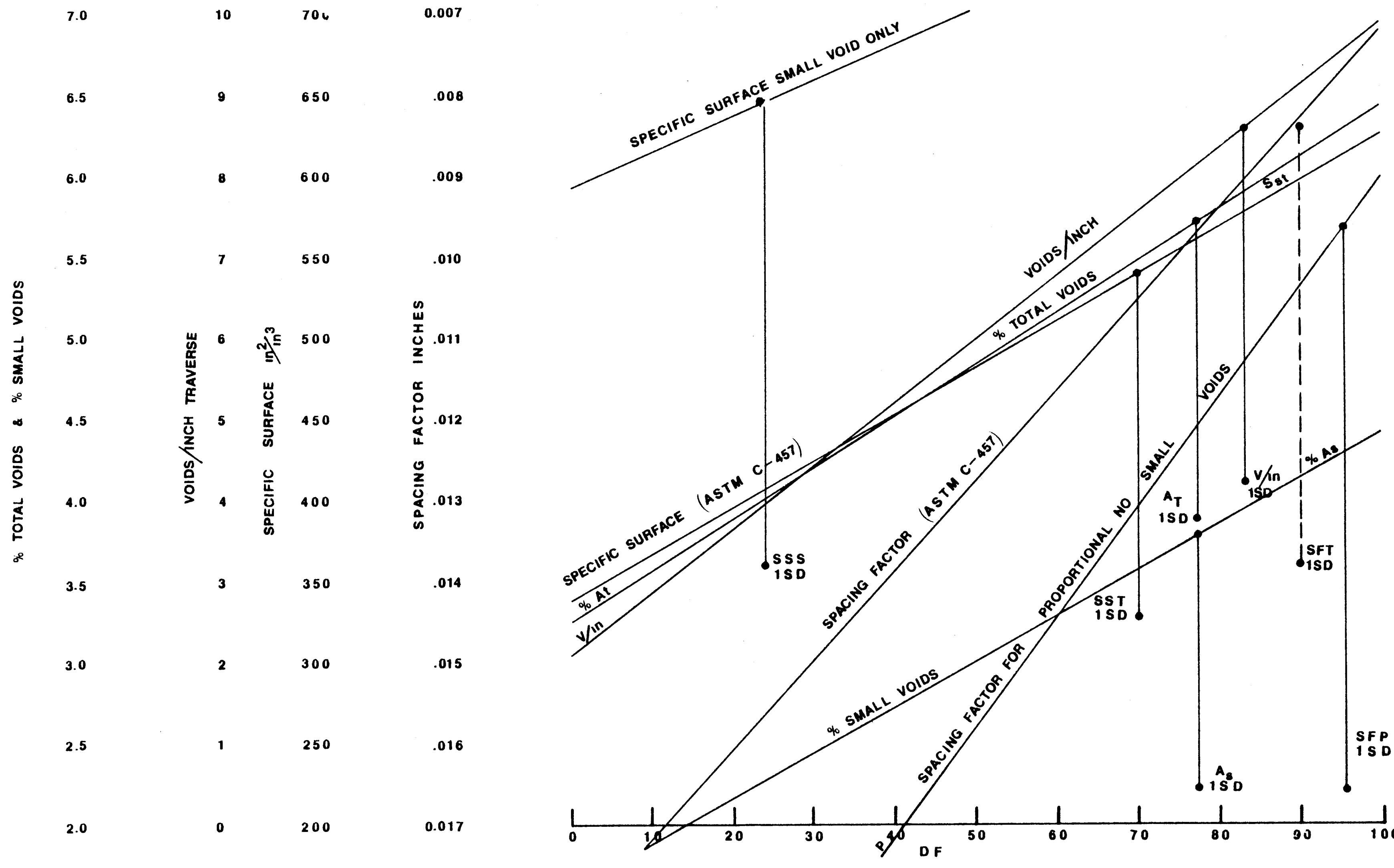
APPENDIX

GRAPH SHOWING RELATIONSHIP OF THE SLOPES OF THE AIR VOID PARAMETERS VERSUS DURABILITY FACTOR FOR SET OF ALL 151 PAIRS



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