EVALUATION OF CONCRETE IN THE BASEMAT
WATERFORD UNIT NO. 3

Robert E. Philleo, Consulting Engineer

It is apparent that there were several violations of specification requirements during the placing of the basemat. The purpose of this report is not to document specification violations but to evaluate their effect on the structural integrity and safety of the mat. It is based primarily on observations of the first three blocks placed (Blocks 6, 1, and 2). There were sufficient violations on these three blocks to cause a stop-work order to be issued. By the time work was resumed, control and supervision had been tightened.

Non-conformance with specifications was noted in the following areas

a. Air content outside permitted range
b. Slump outside permitted range
c. Concrete accepted when too long a period had elapsed afteradding cement to water
d. Inadequate mixing after adding retempering water
e. Too many mixer revolutions permitted
f. Number of mixer revolutions not recorded
g. Discrepancy in records of added water
h. Discrepancy in air content readings
i. Error in recording time of batching or discharging
j. Use of an unapproved concrete mix design
k. Deficiencies in curing in maintenance of both moisture and temperature
l. Concrete dropped vertically more than 5 feet
m. A variety of irregularities in Cadweld inspection including inspections before inspectors were certified, missing records, discrepancies in inspector initials, and activityby inspectors before eye examinations were on file
n. Waterstop inspectors not certified
o. Vertical cracks and rock pockets in vertical surfaces of hardened blocks
p. Incorrect testing frequency
q. Incorrect placement practices
r. Irregularities in placing and handling reinforcing steel

The impact of each is discussed below.

a. AIR CONTENT OUTSIDE PERMITTED RANGE

Probably the largest number of specification violations were concerned with air content measurements. For the 1-inch maximum aggregate size concrete used in the mat the specifications mandated that the air content should be between 3.5 and 6.5%. While entrained air improves workability in all concrete, it is actually needed only in those concretes exposed to freezing in a saturated condition. In the basemat, which will not be exposed to freezing, quality of concrete does not depend on the air content unless the air content becomes excessively high, in which case strength, density, and permeability are adversely affected. Most of the non-conforming air contents were on the low side. The highest value for which concrete was accepted was 7.0%. This half percent extra air has a negligible effect on structural integrity; the low air contents have no effect.

b. SLUMP OUTSIDE PERMITTED RANGE

Single-batch limits for slump were a minimum of 1 inch and a maximum of 5 inches. Portions of batches with slumps as high as 6.5 inches were placed. After the slump had been determined, the remainder of each non-conforming batch was rejected. It is likely that some untested batches with a slump this high were placed completely. The concrete was proportioned somewhat below the required water-cement ratio so that there was some leeway in adding retempering water. Thus, even in the high-slump batches it is unlikely that the maximum water-cement ratio was exceeded. Since the actual average strength exceeded the design strength of 4000 psi by a large margin (6128 psi in the case of Block 6 where the highest slumps were recorded), some violations of the limiting value could be tolerated without adverse effect. The mat has no adverse environmental exposure. High slump has a greater effect on placeability of the concrete than on its ultimate quality. Thus, the structural integrity of the mat was not impaired by inclusion of small amounts of mpoderately high-slump concrete. The inspection personnel are to be commended for diligently rejecting parts of batches of concrete after it was discovered that the slump was out of specification limits.

c. CONCRETE ACCEPTED WHEN TOO LONG A PERIOD HAD ELAPSED AFTER ADDING CEMENT TO WATER

The specifications required discharge of the concrete within 60 minutes after the cement and water were combined although, with the approval of the engineer, the time could be extended to as long as 90 minutes. Later the requirement was changed to permit dischargekup to 70 minutes if emptying a truck was started within 60 minutes. The concrete is usable as long as it remains workable. The rigid time limit is established at a conservative level in order to provide design information to the concrete supplier in designing the concrete plant and scheduling operations and to provide an easily enforced specification requirement to simplify inspection and acceptance. The two biggest violations noted on the first three blocks were 95 minutes and 71 minutes. It was reported that the concrete was still workable. Thus, there was no adverse effect on structural integrity.

d. INADEQUATE MIXING AFTER ADDING RETEMPERING WATER AT SITE

The specifications required 30 revolutions of the drum after water is added at the site. On Block 6 there were 8 batches on which the number of revolutions varied from 1 to 28. The value of 1 may be an error in recording since it is unlikely that a mixer would be started and stopped after one revolution. Some of these 8 batches, however, probably had greater within-batch variability than desired since it is unlikely that the added water became uniformly distributed. The vibration of concrete during placing tends to remove some of this variability. The surplus strength tolerates some variability. It is unlikely that there was any significant deleterious effect on the integrity of the mat.

e. TOO MANY MIXER REVOLUTIONS PERMITTED

The specifications limited each batch to 300 revolutions. Again, the workability of the concrete is the important factor. The arbitrary limit on revolutions is for the purpose of guidance to the concrete producer and simplification of specification enforcement. Two cubic yards were placed from the only truck in which overmixing was documented. The rest was rejected. The concrete accepted had been in the mixer only 35 minutes and was probably satisfactory. There should be no impact on structural integrity or safety.

f. NUMBER OF MIXER REVOLUTIONS NOT RECORDED

During the first day's placement in the mat there were 9 batches for which the numbers of revolutions of the mixer drums were not documented. In addition one batch was shown as being rejected on the batch record but accepted on the pump discharge record. Apparently there was some problem getting the records system in place. While this breakdown in record keeping is serious and formed part of the justification for the stop-work order, the concrete had beenin the mixer a reasonable period of time and had a reasonable slump. Fortunately, the winter weather is not conducive to premature stiffening. It is unlikely that there was any adverse effect on structural integrity.

g. DISCREPANCY IN RECORDS OF ADDED WATER

For one batch on the first day of placement the truck discharge record and pump discharge record show different quantities of added water. This again demonstrates inadequate record keeping, but since both figures were within the allowable limit, there was no adverse effect on structural integrity.

h. DISCREPANCY IN AIR CONTENT READINGS

For one batch on the first day of placement, air content was measured as 2.5% at the truck discharge and 4.8% at the pump discharge. For another the results were 3.3 and 3.9% respectively. This apparent increase is an unlikely occurence. Since either result produces satisfactory concrete for the application, although the first is outside the specification limit, the integrity of the concrete is unimpaired.

i. ERROR IN RECORDING TIME OF BATCHING OR DISCHARGING

One truck on the first day of placement was recorded as discharging 21 minutes before leaving the plant. One time was obviously in error. Since the concrete was satisfactory and the truck was in a sequence of trucks for which the batching and discharge times were reasonable, the concrete was accepted with no detrimental effect on the integrity of the structure.

j. USE OF AN UNAPPROVED CONCRETE MIX DESIGN

There are documented cases of mixes being adjusted and used before formal approval was received. Adjustments were made to improve workability. The only alleged such violation during placing of the first three blocks was one in which incorrect batch weights were cited; they were not adjusted for moisture in the aggregates. The adjusted weights conformed to an approved mix within permitted tolerances. There was, thus, no impact on structural integrity.

k. DEFICIENCIES IN CURING

Curing is particularly important in thin structures of concrete since they can dry out quickly and lose so much water that hydration of cement stops before the required strength is achieved. In a 12-foot thick mat losing moisture only from the top surface, all but the top 3 or 4 inches will maintain sufficient moisture to gain adequate strength even if there is no moist curing. Such structures should be cured so that the top surface, which receives all the wear, will be durable and resistant to abrasion. Otherwise there may be maintenance and operations problems if not safety problems. The maintenace of a temperature of 50F for 7 days is important for thin structural members whose support is to be removed early. In a 12-foot mass hydration of cement generates large amounts of heat. which raise the temperature far above levels needed for adequate strength gain. Cooling the top surface would actually be a good procedure for removing heat from the mass rapikly in ofder to minimize thermal cracking. Thus, the one documented example of a curing temperature of 37F had, if anything, a favorable effect on safety. The few cases in which moist curing could not be verified throughout the required time period had no effect on safety and probably a minimum effect on operation and maintenance problems since ambient weather conditions were not conducive to rapid drying.

l. CONCRETE DROPPED VERTICALLY MORE THAN 5 FEET

This requirement is intended primarily for dry large-aggregate concrete to prevent segregation which might occur when the large particles roll away from the rest of the concrete. It is much less important for 1-inch maximum aggregate size concrete of a consistency capable of being pumped. The few violations should have no effect on structural integrity.

m. IRREGULARITIES IN CADWELD INSPECTION

It is apparent that there was an administrative breakdown in the operation of the Cadweld inspection process. Such items as permitting inspectors to function before they were certified, discrepancies in initials, failure to have eye examinations on file, and incomplete records were noted. However, no significant number of deficient welds were noted in the basemat. Since all inspectors were ultimately found to be qualified, there appears to have been no technical breakdown paralleling the administrative breakdown. Safety does not appear to be an issue.

n. WATERSTOP INSPECTORS NOT CERTIFIED

Waterstops do not contribute to the safety of the basemat. For operational convenience they should be intact. In addition to administrative certificate problems there were technical problems in placing concrete around the waterstops. Since waterstops are in formed surfaces, the first half of each installation is subject to 100% inspection. All observed deficiencies were repaired. It cannot be said with complete assurance that the second half of each installation was carried out successfully since it is buried in concrete and cannot be inspected. It may be assumed that after first half troubles placing crews are more sensitive to the necessity of careeful placing techniques during the second half. After several years under hydrostatic head there are no known waterstop failures. There is no safety issue and problem no operational issue.

o. VERTIVCAL CRACKS AND ROCK POCKETS IN VERTICAL SURFACES OF HARDENED BLOCKS

The vertical cracks which formed early cannot be said to have resulted from a violation of specification requirements. They resulted from thermal contraction when the surface was put into tension as a result of a much higher temperature in the interior, which is produced by cement hydration. They were shallow and were successfully eliminated by jackhammers. Rock pockets are the result of inadequate consolidation adjacent to forms. They were properly patched. Neither phenemenom impacts safety.

p. INCORRECT TESTING FREQUENCY

Certain tests had a required frequency of once every 50 cubic yards, and some had a frequency of once every 150 cubic yards. The interpretation of records auditors was that no more than 50 (or 150) cubic yards should be placed between consecutive tests. When such was the case, a deficiency was noted. The most enlightened specification enforcement requires sampling on a random basis with the average rate equal to the specified rate but with considerable variation in the intervals between tests. Such a procedure eliminates judgment on the part of the inspector in selecting batches for sampling, eliminates any effect which may be occuring with a fixed frequency, and makes it impossible for the producer to anticipate when samples will be taken. The correct numbers of samples were taken on an overall basis. The fact that some intervals between samples exceeded the average specified interval should not be interpreted as a violation of the specifications.

q. INCORRECT PLACING PRACTICES

The approved placing procedure required the establishment and maintenance of 3-foot steps of concrete throughout each placement and the vertical insertion of vibrators at intervals of about 2 feet. Both were violated. The step placement is intended to minimize the area of exposed concrete and thus to minimize the probability of cold joints. The vibrator technique is intended to minimize the occurence of internal voids. Becauuse the first three blocks were placed in the winter, the cold joint hazard was minimal and the necessity for maintaining the step placement relatively unimportant. Proper vibrator technique is more important. However, concrete of pumpable consistency with a maximum aggregate size of 1 inch is very easy to place with relatively little vibration. The fact that rock pockets were evident on formed surfaces does not necessarily infer that internal voids are present. Formed surfaces, particularily in corners and around keyways, present special problems which frequently are not well handled by inexperienced crews. The reluctance to get the vibrator too close to the form causes incomplete consolidation. Available construction photographs suggest adequate consolidation away from the forms. While it cannot be said with assurance that the mat is free of internal voids, the very workable concrete and the number of vibrators in use make voids unlikely. A few small voids would have little effect on the performance of the mat. There should be no safety problem attributable to placing practices.

r. IRREGULARITIES IN PLACING AND HANDLING REINFORCING STEEL

Throughout the mat construction there were cases of nicks or bends in bars or misplaced bars. Except for minor nicks, adequate corrections were made. The only item noted during the first three blocks was an incident when a bar was struck by a sledgehammer to make room for a concrete-placing elephant trunk. The blows vibrated previously placed concrete. This was a single occurrence. Thereafter provision was made during placing of steel for insertion of elephant trunks. Mishandling of steel had no significant effect on structural integrity of the mat.

## CONCLUSION

The construction of the basemat was adequate to insure the safety of the structure. While there were several violations of specification requirements or missing records, none were of a nature which would impair structural integrity. Most of the violations or omissions pertained to provisions intended to preserve the workability of the concrete such as air content, slump, temperature, age of concrete at time of discharge, and number of revolutions of the mixer drum. Because the mat was placed during the winter and early spring when workability problems are not critical and because a large part of the concrete was passed through pumps, which constitute a good inspection tool for assessing workability, the lack of documentation of some of the backup workability data is relatively unimportant. For the same reason the concrete was easy to consolidate, and departure from ideal placing procedures should not prove significant. Failure to document moist curing is not significant because of the massiveness of the structure; and the occasional failure to maintain the required curing temperature was probably an advantage in removing heat from the structure. Irregularities in Cadweld inspection were administrative rather than technical, and errors in handling reinforcing steel were inconsequential. Waterstop problems apparently were adequately dealt with; but in any event they do not affect safety.

While more attention might have been paid to controlling temperature stresses resulting from cement hydration, there is sufficient reinforcinng steel in the mat to prevent safetuy-related problems associated with thermal cracking.

## ROBERT E. PHILLEO

Mr. Philleo was awarded his civil engineering degree from Carneigie Institute of Technology in 1946. Upon graduation he joined the staff of the Portland Cement Association as research engineer in the Research and Development Laboratories. His responsilities included conducting concrete research in the areas of air entrainment, non-destructive testing, and effect of high temperature on concrete. During this period he also was lecturer in mechanics at Northwestern University at Evanston, ILL. In 1958 Mr. Philleo moved to the office of the Chief of Engineers in Washington, D. C. At the time of his retirement he was Chief of the Structures Branch, where he was involved with the development of requirements and performance criteria for engineering materials for heavy construction and was in charge of structural design for Corps projects. A recognized authority on the mechanics of materials, Mr. Philleo has authored many technical papers on this subject.

Mr. Philleo is Past President of the American Concrete Institute and is a member of several Institute technical committees. He is a past member of the Board of Directors of the American Society for Testing and Materials and Past Chairman of Committee C-9 on Concrete and Concrete Aggregates. He serves on ASTM Committee C-1 on Cement, and is Chairman of the Sponsoring Sub-committee on Portland Cement. He authored the chapter on "Elastic Properties and Creep" in ASTM STP 169B, Significance of Tests and Properties of Concrete and Concrete-Making Materials. He serves as Chairman of the Concrete Section of the Transportation Research Board and on committees devoted to mechanical properties of concrete and basic research pertaining to portland cement and concrete.

In 1967 he delivered the Stanton Walker Lecture at the University of Maryland, and in 1982 the Crom Lecture at the University of Florida. He is co-author of the Concrete Construction Handbook, published by McGraw-Hill, and of the Handbook of Structural Concrete, published by Pitmann, and is a member of the Board of Editors of Cement and Concrete Research, an International Journal.

# RESUME

Robert E. Philleo
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Telephone: [redacted]

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## Experience

1978-1983 Chief, Structures Branch, Directorate of Civil Works, Office Chief of Engineers, Washington, D.C. Supervised structural design and concrete technology for the world's largest engineering organization. Structures designed included concrete gravity dams, an arch dam, navigation locks, powerhouses, and floodwalls. Concrete technology developments included selection of materials, mixture proportioning, and development of techniques for roller-compacted concrete dam construction. Directly supervised a staff of 14 in the Structural Engineering and Concrete Sections in preparation of guidance for and review of structural activities of 11 division offices and 36 district offices.

1970-1978 Chief, Concrete Branch, Directorate of Civil Works, Office Chief of Engineers, Washington, D.C. As top technical concrete expert for the nation's largest user of concrete, supervised the activities of 11 divisions, 36 district offices, 8 division laboratories, and one research laboratory in the field of concrete materials, mixture proportioning, construction supervision, and concrete research. Technical problems included prospecting for and evaluating materials in remote locations and special temperature studies for materials to be used in mass concrete dams and locks. Directly supervised a staff of 6 who prepare d manuals and guide specifications, reviewed field design memoranda, directed structural instrumentation programs, and managed a research program.

1958-1970 Chief, Research, Development, and Standards Section, Concrete Branch, Office Chief of Engineers, Washington, D.C. Prepared manuals and guide specifications for field guidance and provided technical supervision of a $500,000 annual concrete research program carried out at the Waterways Experiment Station in Mississippi. Represented Corps of Engineers on standards committees of American Concrete Institute and American Society for Testing and Materials.

1946-1958 Research Engineer, Portland Cement Association, Chicago, Illinois. Conducted research on non-destructive methods of test for concrete, mechanics of air entrainment, and behavior of concrete subjected to high temperature. Executed preliminary designs for world's most sophisticated structural fire test facilities.

1952-1956 Lecturer in Mechanics, Northwestern University, Evanston, Il linois. Taught evening courses in statics, dynamics, and strength of materials

1943-1946 U. S. Army. Enlisted man in combat engineer battalion in the European Theater of Operations.

## Professional Activities

Registered Professional Engineer, State of Maryland

American Concrete Institute
- President 1973-74
- Vice-president 1971-73
- Chairman, Technical Activities Committee 1968-71
- Chairman, Publications Committee 1981-
- Chairman, Committee 214 on Evaluation of Strength Tests of Concrete 1959-63
- Chairman, Committee 224 on Cracking 1964-67
- Secretary, Committee 221 on Aggregates 1958-65
- Member: Executive Committee, Board of Direction, Planning Committee, Committee 207 on Mass Concrete, Committee 209 on Creep and Shrinkage, Committee 306 on Cold Weather Concrete

American Society for Testing and Materials (ASTM)
- Board of Directors, Member 1977-81
- Committee C-9 on Concrete and Concrete Aggregates
  - Chairman 1974-80
  - Chairman, Subcommittee on Elastic and Inelastic Properties 1957-68
  - Chairman, Subcommittee on Fly Ash, Natural Pozzolans, and Slag 1981-
  - Member: Executive Subcommittee, Subcommittees on Evaluation of Data, Non-destructive testing, Accelerated Strength Testing
- Committee C-1 on Cement
  - Chairman, Subcommittee on Statistical Methods 1972-80
  - Chairman, Subcommittee on Portland Cement Specifications 1980-
- Committee E-11 on Statistical Methods
  - Member of Committee

Transportation Research Board
- Chairman, Concrete Section 1982-
- Chairman, Committee A2E03 on Mechanical Properties of Concrete 1958-62
- Member, Committee A2E06 on Basic Research Pertaining to Portland Cement and Concrete

Joint CEB-CIB-FIP-RILEM Commission on Statistical Quality Control of Concrete
- Member of Commission

International Building Commission (CIB)
- Member, American National Committee

US-USSR Joint Committee on Cooperation in Housing and Other Construction
- Leader, Project on Cement and Concrete

Cement and Concrete Research, an International Journal, published by Pergamon Press
- Member, Board of Editors

## Education

1940-43;46 Carnegie Institute of Technology (now Carnegie-Mellon University) Pittsburgh, Pennsylvania. BS in Civil Engineering in 1946; ranked second in class; managing editor of Carnegie Technical, award-winning magazine

## Honors

1943 Member: Tau Beta Pi, Phi Kappa Phi, Pi Delta Epsilon (journalism honorary)

1967 Stanton Walker Lecturer at University of Maryland

1971 Hon. Member of Chi Epsilon, Rutgers University Chapter

1973 Fellow, American Concrete Institute

1974 Dpartment of the Army Award for Meritorious Civilian Service

1978 Honorary Member, American Concrete Institute

1980 Arthur Anderson Award for Materials Science, American Concrete Institute

1982 Crom Lecturer, University of Florida

Guest lecturer at Purdue University, Kansas State University, Massachusetts Institute of Technology, University of California (Berkeley), Clarkson College for Technology

## Publications

"Comparison of results of three methods for determining Young's modulus of elasticity of concrete," ACI Journal, Jan. 1955.

"Some physical properties of concrete at high temperatures," ACI Journal, April 1958.

"Elastic Properties and Creep," ASTM STP 169A, Significance of Tests and Properties of Concrete and Concrete-Making Materials, 1966.

"The origin of strength of concrete," Highway Research Board Special Report 90, Structure of Portland Cement Paste and Concrete, 1966.

"The strength of concrete--a statistical view," Stanton Walker Lecture Series on the Materials Sciences, University of Maryland, 1967

"The origin of concrete strength," Journal of the Mexican Institute for Cement and Concrete, May-June 1967

Chapter 44, Cracking; Chapter 45, Surface Blemishes; Chapter 46, Cooling of Mass Concrete; Chapter 47, Grouting of Concrete. Concrete Construction Handbook. McGraw-Hill, 1st Edition 1968, 2nd Edition 1974.

"Volume change and crack control of concrete," Proceedings of ACI Canadian Capital Chapter Seminar, December 1968.

Editor, Causes, Mechanism, and Control of Cracking in Concrete, ACI SP-20, 1968.

"Crack control of concrete," Journal of the Mexican Institute for Cement and Concrete, Sep.-Oct. 1969.

"Summary: Designing for effects of creep, shrinkage, and temperature," ACI SP 27, 1971.

"Results of ACI Symposium on Creep, Shrinkage, and Temperature," Proceedings of IABSE Symppsium on the Design of Concrete Structures for Creep, Shrinkage, and Temperature Changes, 1971

"Lunatics, Liars, and Liability," Proceedings of ACI Atlantic Capter Seminar, February 1974. Also ACI Journal, Apr. 1976.

Series of President's Messages in ACI Journal:

- The absurd present, May 1973
- Our jolly good fellows, June 1973
- Lunatics at Babel, July 1973
- The day the pump ran dry, Aug. 1973
- Concrete Detente, Sep. 1973
- Heavy traffic and heavy hearts, Oct. 1973
- Winter blunderland, Nov. 1973
- Time to prime the pump again, Dec. 1973
- Corinthian constructors, Jan. 1974
- Potential energy, Feb. 1974
- In-place heresy, March 1974

"...Which the days never know," ACI Journal, May 1974.

"In-situ evaluation of concrete," Proceedings of ACI Canadian Capital Chapter Seminar, Dec. 1974

"Can research solve the designer's volume-change problem?" Transportation Research Record, 1975.

"Compressive strength as a means for controlling the quality of mass concrete," ACI SP 37, 1975.

"Systeme international d'unites, yes or no?" ACI Journal, July 1975.

"Establishing specification limits for materials," Cement, Concrete, and Aggregates, (ASTM), vol. 1, no. 2, 1979

"A need for in-situ testing of concrete," Concrete International, Sep. 1979

"Building materials and components," Soviet Housing and Urban Design, Proceedings of a conference conducted by the Woodrow Wilson International Center for Scholars, Published by Department of Housing and Urban Development, Dec. 1980.

"Increasing the usefulness of ACI 214," Concrete International, Sep. 1981

"Concrete in Russia," Concrete Products, March 1983

Chapter 27, "Concrete Production, Quality Control, and Evaluation in Service," Handbook of Structural Concrete, Pittman Books, Limited, 1983 (published in the United States by McGraw Hill).

"A method for analyzing void distribution in air-entrained concrete," Cement, Concrete, and Aggregates (ASTM), vol. 5, no. 2, 1983.

"Lightweight Concrete in Bridges," part of a symposium on Recent Developments in Lightweight Concrete presented at ACI convention in Los angeles, March 1983, scheduled to be published in 1984.

EVALUATION OF CONCRETE CONSTRUCTION ADEQUACY IN THE BASEMAT
WATERFORD UNIT NO. 3

Robert E. Philleo, Consulting Engineer

I was asked to review the inspection records accumulated during the placing of the basemat and to comment on the potential impact of construction deficiencies, if any, on the safety of the mat. I spent a week at the site examining records and the basemat itself.

It is apparent that there were several violations of specification requirements during the placing of the basemat. The purpose of this report is not to document specification violations but to evaluate their effect on the structural integrity and safety of the mat. It is based primarily on observations of the first three blocks placed (Blocks 6, 1, and 2). There were sufficient violations on these three blocks to cause a stop-work order to be issued. By the time work was resumed, control and supervision had been tightened.

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During the first day's placement in the mat there were 9 batches for which the numbers of revolutions of the mixer drums were not documented. In addition, one batch was shown as being rejected on the batch record but accepted on the pump discharge record. Apparently there was some problem getting the records system in place. While this breakdown in record keeping is serious and formed part of the justification for the stop-work order, the concrete had been in the mixer a reasonable period of time and had a reasonable slump. Fortunately the winter weather is not conducive to premature stiffening. An examination of weather records reveals that there was no temperature as high a 80F during the months of December and January and only one hour at 80F during February. It is unlikely that there was any adverse effect on structural integrity.

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For one batch on the first day of placement the truck discharge record and pump discharge record show different quantities of added water. This again demonstrates inadequate record keeping, but since both figures were within the allowable limit, there was no adverse effect on structural integrity.

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There are documented cases of mixes being adjusted and used before formal approval was received. Adjustments were made to improve workability. The only alleged such violation during placing of the first three blocks was one in which incorrect batch weights were cited; they were not adjusted for moisture in the aggregates. The adjusted weights conformed with an approved mix within permitted tolerances. There was, thus, no impact on structural integrity.

k. DEFICIENCIES IN CURING

Curing is particularly important in thin structures of concrete since they can dry out quickly and lose so much water that hydration of cement stops before the required streng.. is achieved. In a 12-foot thick mat losing moisture only from the top surface, all but the top 3 or 4 inches will maintain sufficient moisture to gain adequate strength even if there is no moist curing. Such structures should be cured so that the top surface, which receives all the wear, will be durable asnd resistant to abrasion. Otherwise there may be maintenance and operations problems if not safety problems. The maintenace of a temperature of 50F for 7 days is important for thin structural members whose support is to be removed early. In a 12-foot mass hydration of cement generates large amounts of heat which raise the temperature far above levels needed for adequate strength gain. Cooling the top surface would actually be a good procedure for removing heat from the mass rapidly in order to minimize thermal cracking. Thus, the one documented example of a curing temperature of 37F had, if anything, a favorable effect on safety. The few cases in which moist curing could not be verified throughout the required time period had no effect on safety and probably a minimum effect on operation and maintenance problems since ambient weather conditions were not conducive to rapid drying.

l. CONCRETE DROPPED VERTICALLY MORE THAN 5 FEET

This requirement is intended primarily for dry large-aggregate concrete to prevent segregation which might occur when the large particles roll away from the rest of the concrete. It is much less important for 1-inch maximum size aggregate concrete of a consistency capable of being pumped. The few violations should have no effect on structural integrity.

m. IRREGULARITIES IN CADWELD INSPECTION

It is apparent that there was an administrative breakdown in the operation of the Cadweld inspection process. Such items as permitting inspectors to function before they were certified, discrepancies in initials, failure to have eye examinations on file, and incomplete records were noted. However, no significant number of deficient welds were noted in the basemat. There appears to have been no technical breakdown paralleling the administrative breakdown. Safety does not appear to be an issue.

n. WATERSTOP INSPECTORS NOT CERTIFIED

Waterstops do not contribute to the safety of the basemat. For operational convenience they should be intact. In addition to administrative certificate problems there were technical problems in placing concrete around the waterstops. Since waterstops are in formed surfaces, the first half of each installation is subject to 100% inspection. All observed deficiencies were repaired. It cannot be said with complete assurance that the second half of each installation was carried out successfully since it is buried in concrete and cannot be inspected. It may be assumed that after first half troubles placing crews are more sensitive to the necessity for careful placing techniques during the second half. After several years under hydrostatic head there are no known waterstop failures. There is no safety issue and probably no operational issue.

o. VERTICAL CRACKS AND ROCK POCKETS IN VERTICAL SURFACES OF HARDENED BLOCKS

The vertical cracks which formed early cannot be said to have resulted from a violation of specification requirements. They resulted from thermal contraction when the surface was put into tension as a result of a much higher temperature in the interior, which is produced by cement hydration. They were shallow and were successfully eliminated by jackhammers. Rock pockets are the result of inadequate consolidation adjacent to forms. They were properly patched. Neither phenemenom impacts safety.

p. INCORRECT TESTING FREQUENCY

Certain tests had a required frequency of once every 50 cubic yards, and some had a frequency of once every 150 cubic yards. The interpretation of records auditors was that no more than 50 (or 150) cubic yards should be placed between consecutive tests. When such was the case, a deficiency was noted. The most enlightened specification enforcement requires sampling on a random basis with the average rate equal to the specified rate but with considerable variation in the intervals between tests. Such a procedure eliminates judgment on the part of the inspector in selecting batches for sampling, eliminates any effect which may be occuring with a fixed frequency, and makes it impossible for the producer to anticipate when samples will be taken. The correct numbers of samples were taken on an overall basis. The fact that some intervals between samples exceeded the average specified interval should not be interpreted as a violation of the specifications.

q. INCORRECT PLACING PRACTICES

The approved placing procedure required the establishment and maintenance of steps of concrete throughout each placement and the vertical insertion of vibrators at intervals of about 2 feet. Both were violated. The step placement is intended to minimize the area of exposed concrete and thus to minimize the probability of cold joints. The vibrator technique is intended to minimize the occurence of internal voids. Because the first three blocks were placed in the winter, the cold joint hazard was minimal and the necessity for maintaining the step placement relatively unimportant. Proper vibrator technique is more important. However, concrete of pumpable consistency with a maximum aggregate size of 1 inch is very easy to place with relatively little vibration. The fact that rock pockets were evident on formed surfaces does not necessarily mean that internal voids are present. Formed surfaces, particularily in corners and around keyways, present special problems which frequently are not well handled by inexperienced crews. The reluctance to get the vibrator too close to the form (the specifications specifically prohibited hitting the forms with the vibrator spud) causes incomplete consolidation at the form. Available construction photographs demonstrate the wide open forms with plenty of space betwen reinforcing bars, conditions which make for easy placing. While it cannot be said with assurance that the mat is totally free of internal voids, the very workable concrete and the number of vibrators in use make the existence of numerous voids, and especially the existence of significant voids, unlikely. A few small voids would have little effect on the performance of the mat. There should be no safety problem attributable to placing practices.

r. IRREGULARITIES IN PLACING AND HANDLING REINFORCING STEEL

Throughout the mat construction there were cases of nicks or bends in bars or misplaced bars. Except for minor nicks, adequate corrections were made. The only item noted during the first three blocks was an incident when a bar was struck by a sledgehammer to make room for a concrete-placing elephant trunk. The blows vibrated previously placed concrete. This was a single occurrence and, whatever its effect, would only affect a miniscule portion of the structure. Thereafter, provision was made during placing of steel for insertion of elephant trunks. Mishandling of steel had no significant effect on structural integrity of the mat.

## CONCLUSION

The construction of the basemat was adequate to insure the safety of the structure. While there were several violations of specification requirements or missing records, none were of a nature which would impair structural integrity. Most of the violations or omissions pertained to provisions intended to preserve the workability of the concrete, such as air content, slump, temperature, age of concrete at time of discharge, and number of revolutions of the mixer drum. Because the mat was placed during the winter and early spring when workability problems are not critical and because a large part of the concrete was passed through pumps, which constitute a good inspection tool for assessing workability, the lack of documentation of some of the backup workability data is relatively unimportant. For the same reason the concrete was easy to consolidate, and departure from ideal placing procedures should not prove significant. Failure to document moist curing is not significant because of the massiveness of the structure; and the occasional failure to maintain the required curing temperature was probably an advantage in removing heat from the structure. Irregularities in Cadweld inspection were administrative rather than technical, and errors in handling reinforcing steel were inconsequential. Waterstop problems apparently were adequately dealt with; but in any event they do not affect safety.

Strength of the concrete is well documented. It exceeds the design strength by a larger margin than required by American Concrete Institute standards. This fact and the fact that concrete was placed under favorable physical conditions and in favorable weather, neither of which were conducive to the development of cold joints or internal voids, testify to the safety of the structure insofar as it is affected by the construction process. Adequacy of design was not addressed in this investigation.

May 18, 1984

## ROBERT E. PHILLEO

Mr. Philleo was awarded his civil engineering degree from Carneigie Institute of Technology in 1946. Upon graduation he joined the staff of the Portland Cement Association as research engineer in the Research and Development Laboratories. His responsilities included conducting concrete research in the areas of air entrainment, non-destructive testing, and effect of high temperature on concrete. During this period he also was lecturer in mechanics at Northwestern University at Evanston, ILL. In 1958 Mr. Philleo moved to the office of the Chief of Engineers in Washington, D. C. At the time of his retirement he was Chief of the Structures Branch, where he was involved with the development of requirements and performance criteria for engineering materials for heavy construction and was in charge of structural design for Corps projects. A recognized authority on the mechanics of materials, Mr. Philleo has authored many technical papers on this subject.

Mr. Philleo is Past President of the American Concrete Institute and is a member of several Institute technical committees. He is a past member of the Board of Directors of the American Society for Testing and Materials and Past Chairman of Committee C-9 on Concrete and Concrete Aggregates. He serves on ASTM Committee C-1 on Cement, and is Chairman of the Sponsoring Sub-committee on Portland Cement. He authored the chapter on "Elastic Properties and Creep" in ASTM STP 169B, Significance of Tests and Properties of Concrete and Concrete-Making Materials. He serves as Chairman of the Concrete Section of the Transportation Research Board and on committees devoted to mechanical properties of concrete and basic research pertaining to portland cement and concrete.

In 1967 he delivered the Stanton Walker Lecture at the University of Maryland, and in 1982 the Crom Lecture at the University of Florida. He is co-author of the Concrete Construction Handbook, published by McGraw-Hill, and of the Handbook of Structural Concrete, published by Pitmann, and is a member of the Board of Editors of Cement and Concrete Research, an International Journal.

Enclosure 2

RESUME

Robert E. Philleo
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Telephone: [redacted]

Born: [redacted]

## Experience

1978-1983 Chief, Structures Branch, Directorate of Civil Works, Office Chief of Engineers, Washington, D.C. Supervised structural design and concrete technology for the world's largest engineering organization. Structures designed included concrete gravity dams, an arch dam, navigation locks, powerhouses, and floodwalls. Concrete technology developments included selection of materials, mixture proportioning, and development of techniques for roller-compacted concrete dam construction. Directly supervised a staff of 14 in the Structural Engineering and Concrete Sections in preparation of guidance for and review of structural activities of 11 division offices and 36 district offices.

1970-1978 Chief, Concrete Branch, Directorate of Civil Works, Office Chief of Engineers, Washington, D.C. As top technical concrete expert for the nation's largest user of concrete, supervised the activities of 11 divisions, 36 district offices, 8 division laboratories, and one research laboratory in the field of concrete materials, mixture proportioning, construction supervision, and concrete research. Technical problems included prospecting for and evaluating materials in remote locations and special temperature studies for materials to be used in mass concrete dams and locks. Directly supervised a staff of 6 who prepare d manuals and guide specifications, reviewed field design memoranda, directed structural instrumentation programs, and managed a research program.

1958-1970 Chief, Research, Development, and Standards Section, Concrete Branch, Office Chief of Engineers, Washington, D.C. Prepared manuals and guide specifications for field guidance and provided technical supervision of a $500,000 annual concrete research program carried out at the Waterways Experiment Station in Mississippi. Represented Corps of Engineers on standards committees of American Concrete Institute and American Society for Testing and Materials.

1946-1958 Research Engineer, Portland Cement Association, Chicago, Illinois. Conducted research on non-destructive methods of test for concrete, mechanics of air entrainment, and behavior of concrete subjected to high temperature. Executed preliminary designs for world's most sophisticated structural fire test facilities.

1952-1956 Lecturer in Mechanics, Northwestern University, Evanston, Il linois. Taught evening courses in statics, dynamics, and strength of materials

1943-1946 U. S. Army. Enlisted man in combat engineer battalion in the European Theater of Operations.

## Professional Activities

Registered Professional Engineer, State of Maryland

American Concrete Institute
- President 1973-74
- Vice-president 1971-73
- Chairman, Technical Activities Committee 1968-71
- Chairman, Publications Committee 1981-
- Chairman, Committee 214 on Evaluation of Strength Tests of Concrete 1959-63
- Chairman, Committee 224 on Cracking 1964-67
- Secretary, Committee 221 on Aggregates 1958-65
- Member: Executive Committee, Board of Direction, Planning Committee, Committee 207 on Mass Concrete, Committee 209 on Creep and Shrinkage, Committee 306 on Cold Weather Concrete

American Society for Testing and Materials (ASTM)
- Board of Directors, Member 1977-81
- Committee C-9 on Concrete and Concrete Aggregates
  - Chairman 1974-80
  - Chairman, Subcommittee on Elastic and Inelastic Properties 1957-68
  - Chairman, Subcommittee on Fly Ash, Natural Pozzolans, and Slag 1981-
  - Member: Executive Subcommittee, Subcommittees on Evaluation of Data, Non-destructive testing, Accelerated Strength Testing
- Committee C-1 on Cement
  - Chairman, Subcommittee on Statistical Methods 1972-80
  - Chairman, Subcommittee on Portland Cement Specifications 1980-
- Committee E-11 on Statistical Methods
  - Member of Committee

Transportation Research Board
- Chairman, Concrete Section 1982-
- Chairman, Committee A2E03 on Mechanical Properties of Concrete 1958-62
- Member, Committee A2E06 on Basic Research Pertaining to Portland Cement and Concrete

Joint CEB-CIB-FIP-RILEM Commission on Statistical Quality Control of Concrete
- Member of Commission

International Building Commission (CIB)
- Member, American National Committee

US-USSR Joint Committee on Cooperation in Housing and Other Construction
- Leader, Project on Cement and Concrete

<u>Cement and Concrete Research, an International Journal</u>, published by Pergamon Press
- Member, Board of Editors

## Education

1940-43;46 Carnegie Institute of Technology (now Carnegie-Mellon University) Pittsburgh, Pennsylvania. BS in Civil Engineering in 1946; ranked second in class; managing editor of Carnegie Technical, award-winning magazine

## Honors

1943 Member: Tau Beta Pi, Phi Kappa Phi, Pi Delta Epsilon (journalism honorary)

1967 Stanton Walker Lecturer at University of Maryland

1971 Hon. Member of Chi Epsilon, Rutgers University Chapter.

1973 Fellow, American Concrete Institute

1974 Dpartment of the Army Award for Meritorious Civilian Service

1978 Honorary Member, American Concrete Institute

1980 Arthur Anderson Award for Materials Science, American Concrete Institute

1982 Crom Lecturer, University of Florida

Guest lecturer at Purdue University, Kansas State University, Massachusetts Institute of Technology, University of California (Berkeley), Clarkson College for Technology

## Publications

"Comparison of results of three methods for determining Young's modulus of elasticity of concrete," ACI Journal, Jan. 1955.

"Some physical properties of concrete at high temperatures," ACI Journal, April 1958.

"Elastic Properties and Creep," ASTM STP 169A, Significance of Tests and Properties of Concrete and Concrete-Making Materials, 1966.

"The origin of strength of concrete," Highway Research Board Special Report 90, Structure of Portland Cement Paste and Concrete, 1966.

"The strength of concrete--a statistical view," Stanton Walker Lecture Series on the Materials Sciences, University of Maryland, 1967

"The origin of concrete strength," Journal of the Mexican Institute for Cement and Concrete, May-June 1967

Chapter 44, Cracking; Chapter 45, Surface Blemishes; Chapter 46, Cooling of Mass Concrete; Chapter 47, Grouting of Concrete. Concrete Construction Handbook. McGraw-Hill, 1st Edition 1968, 2nd Edition 1974

"Volume change and crack control of concrete," Proceedings of ACI Canadian Capital Chapter Seminar, December 1968.

Editor, Causes, Mechanism, and Control of Cracking in Concrete, ACI SP-20, 1968.

"Crack control of concrete," Journal of the Mexican Institute for Cement and Concrete, Sep.-Oct. 1969.

"Summary: Designing for effects of creep, shrinkage, and temperature," ACI SP 27, 1971.

"Results of ACI Symposium on Creep, Shrinkage, and Temperature," Proceedings of IABSE Sympposium on the Design of Concrete Structures for Creep, Shrinkage, and Temperature Changes, 1971

"Lunatics, Liars, and Liability," Proceedings of ACI Atlantic Capter Seminar, February 1974. Also ACI Journal, Apr. 1976.

Series of President's Messages in ACI Journal:

- The absurd present, May 1973
- Our jolly good fellows, June 1973
- Lunatics at Babel, July 1973
- The day the pump ran dry, Aug. 1973
- Concrete Detente, Sep. 1973
- Heavy traffic and heavy hearts, Oct. 1973
- Winter blunderland, Nov. 1973
- Time to prime the pump again, Dec. 1973
- Corinthian constructors, Jan. 1974
- Potential energy, Feb. 1974
- In-place heresy, March 1974

"...Which the days never know," ACI Journal, May 1974.

"In-situ evaluation of concrete," Proceedings of ACI Canadian Capital Chapter Seminar, Dec. 1974

"Can research solve the designer's volume-change problem?" Transportation Research Record, 1975.

"Compressive strength as a means for controlling the quality of mass concrete," ACI SP 37, 1975.

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"Establishing specification limits for materials," Cement, Concrete, and Aggregates, (ASTM), vol. 1, no. 2, 1979

"A need for in-situ testing of concrete," Concrete International, Sep. 1979

"Building materials and components," Soviet Housing and Urban Design, Proceedings of a conference conducted by the Woodrow Wilson International Center for Scholars, Published by Department of Housing and Urban Development, Dec. 1980.

"Increasing the usefulness of ACI 214," Concrete International, Sep. 1981

"Concrete in Russia," Concrete Products, March 1983

Chapter 27, "Concrete Production, Quality Control, and Evaluation in Service," Handbook of Structural Concrete, Pitman Books, Limited, 1983 (published in the United States by McGraw Hill).

"A method for analyzing void distribution in air-entrained concrete," Cement, Concrete, and Aggregates (ASTM), vol. 5, no. 2, 1983.

"Lightweight Concrete in Bridges," part of a symposium on Recent Developments in Lightweight Concrete presented at ACI convention in Los angeles, March 1983, scheduled to be published in 1984.