SP 100-1

Reflections on Concrete Durability and on International Conferences on Concrete Durability

by K. and B. Mather

Synopsis: The Organizing Committee for this conference requested that we make some remarks and prepare some comments for inclusion in the *Proceedings*. These words are intended as a basis for the former and to serve as the latter. We observe that: Concrete is international, it is made locally, it has infinite variability, it can be made to be very uniform, and it can be made to last as long as you want it to. An unsolved problem is assessment of the nature and severity of the exposure, so that requirements can be graduated according to severity. Only when this problem is solved will we be able to stamp out specification overkill.

The Organizing Committee also suggested we furnish biographical data and bibliographic data. The standard material accompanying this publication should suffice for the former. An appendix of selected items is provided for the latter purpose.

Keywords: concrete durability; concretes; exposure; specifications; variability

ACI Honorary Member Katharine Mather, a resident of Clinton, Mississippi, retired from the Waterways Experiment Station, Vicksburg, Mississippi, in 1982 after 40 years of service with the U.S. Army Corps of Engineers. Mrs. Mather received the Anderson Award in 1982, and the Wason Medal in 1955. She has served on the ACI Board of Direction, and is a member of numerous technical committees. She is also an honorary member of ASTM and is a fellow of the Mineralogical Society of America.

Bryant Mather is Chief, Structures Laboratory, Waterways Experiment Station, U.S. Army Corps of Engineers, Vicksburg, Miss., and has been with the Corps since 1941. He is an Honorary Member and a past president of ACI and is a member of several technical committees. He is currently chairman of Committee 116, Notation and Nomenclature. His awards and honors include ACI's Henry C. Turner Medal in recognition of "his many years in improving the quality of concrete work...and for his vigorous personal efforts both inside and outside of that assignment."

INTRODUCTION

During the 44th Annual Meeting of the Highway Research Board (HRB) in 1965, Committee MC-B6 on Basic Research Pertaining to Portland Cement, of which Bill Dolch was Chairman and Katharine Mather was a member, put on the T. C. Powers Symposium on Structure of Portland Cement Paste and Concrete, under the cognizance of the HRB Concrete Division of which Bryant Mather was chairman. Special Report 90, the proceedings of that meeting, is a landmark that all serious workers should have access to and know.

The idea that anyone would put on a "Mather Symposium," in some way analogous to the Powers Symposium, was one that never occurred to either of us and one we found incredible when John Scanlon told us he was going to do it unless we seriously objected. As can be seen, we didn't. I might point out that we have here a "Conference," not a "Symposium." There is a story, once published in the ASTM Bulletin, about how a senior research scientist of a large corporation visited the Chief Executive Officer to request money to support a symposium and the CEO said "What is a symposium?" Whereupon they turned to a dictionary and found, to the dismay of the scientist: "Symposium, fr. Gr. 'symposion' a drinking party..." At that point the CEO said "I approve, nobody needs a drinking party more than you research types." We expect that those of you who desire to participate in a drinking party will not leave Atlanta unsatisfied!

The Organizing Committee has asked that we prepare some comments to go in the Proceedings and to serve as the basis of remarks that we are asked to make on the final day of the conference. In view of all that the Organizing Committee has put into making the conference a successful contribution to "durable" concrete and to all of us who have said, in one way or another, that "concrete need not deteriorate," it is with gratitude that we try to comply with its request.

This Conference has again demonstrated a number of fundamental truths and relationships, most of which are quite well known to most of those who participated--especially those more than forty years old. Among them are the following:

Concrete is international and may well be or become intergalactic. Concrete is made everywhere that people build. Concrete is of interest to those who build regardless of their language, their national heritage, their climate, or their cultural heritage. Concrete is like air to breath, water to drink, earth to grow plants in; it provides for all what Dick Gaynor's 1976 National Ready Mixed Concrete Association's U.S. Bicentennial bumper sticker said: "Concrete - the Foundation of America" and which can be expanded to "Concrete - the Foundation of Civilization."

Concrete is made locally. The mixing water, with negligible exceptions (perhaps when concrete is made on the moon); the aggregates usually; the cement often, is or is made from one or more locally available natural raw materials, in various degrees of processing.

Concrete has infinite variability. The varieties of concrete that are intentionally produced are more numerous than the known varieties of natural sedimentary rocks. Concretes have been--and will be--required to be produced having unit masses from as low as 160 kg/m^3 (10 lb mass per ft^3) to as high as 4800 kg/m^3 (300 lb mass per ft^3); that have unconfined compressive strengths from as low as 0.35 MPa (50 psi) to as high as 275 MPa (40,000 psi); that are of any color--white, black, pink, turquoise, chartreuse, or as one Corps of Engineers' officer demanded: "sand tan"; we await the demand for "olive drab."

Concrete can be made to be very uniform. ACI Committee 214 was organized in 1946. It told concrete makers and users how to use strength tests to measure uniformity of concrete as produced. It is still doing it. In 1979, ASTM Standard Method C 917 for Evaluation of Cement Strength Uniformity was adopted. For many years ASTM Specification C 33 has put rather restrictive limits on uniformity of grading of fine aggregate in terms of fineness modulus. There are uniformity requirements on pozzolans given in ASTM Specification C 618.

Concrete can be made to last as long as you want it to. Even as some relatively fragile sedimentary rocks exist that have survived some hundreds of millions of years, so there are concretes that, if they remain in relatively mild environments, could last forever or at least as close to "forever" as we can measure. The duration of the life of a concrete with its relevant properties not sufficiently degraded so as to impair or jeopardize its ability to serve its intended purpose, is not usually a function of the absolute level of any universally relevant property of the concrete such as slump, unit mass, strength, modulus of elasticity, or color but is almost always a function of the interaction of some property or properties, the required levels of which depend on the severity of the environment to which the concrete will be exposed in service. One need not worry much about resistance to freezing and thawing in the tropics, except in facilities using refrigeration; or at the poles, except in facilities using intermittent heating. One need not worry about acid attack, abrasion attack, sulfate attack, attack by burrowing molluscs, or any of the myriad hazards described by Kleinlogel, Biczok, or others except where they exist and impact the concrete of interest. And where these potentially destructive influences can be and are brought to bear on the concrete, if their action and its intensity and duration are properly anticipated, the concrete can be rendered adequately resistant so as to merit the designation "Durable," even when as demanded of us by the Nuclear Regulatory Commission, "durable" means not significantly degraded for many centuries or in some cases hundreds of centuries.

The message we have decided to leave with you at this time is (a) that concrete need not deteriorate and (b) that knowledge exists by the use of which concrete can be caused to exist in any of the environments of service for which it may be reasonably proposed with tolerable degradation during its intended service life, if precautions to limit degradation appropriate to the environmental severity are taken.

The Unsolved Problem - The important matter is to know how properly to assess the nature and severity of the environment of service; to get a reasonable estimate of intended service life; to get a reasonable assessment of how much degradation is tolerable structurally and, when relevant, aesthetically. One must then, from these and known relationships of environmental influences and concrete composition and constitution, have procedures and criteria by which to select materials, proportions, and construction practices that will, with reasonable probability of success and compliance with the owner's budget for the work, give concrete that will not deteriorate.

Most of the raw material of knowledge to do this exists, some in relatively quite refined states. But the manner in which this knowledge is used in an attempt to make it an effective tool for makers and users of concrete is primitive. Today we talk about reactive vs non-reactive aggregate and high-alkali vs not high-alkali cement as if all structures, in all environments, involving all ambient temperatures and temperature ranges, in all degrees of moistness from "it rains on the average every 12 years" to the tidal zone in Mombasa, as if all the precautions and restrictions must be taken at 100 percent of the degree we ever need anywhere, everywhere we need to do anything at all. There is no relaxation of the 0.60 percent Na_2O limit on cement as a function of environmental severity, reactivity of aggregate, or anticipated level of permeability of concrete. An aggregate is either reactive--or not; if not, nothing need be done, no precautions taken; if "reactive," then the precautions must be taken without reference to degree of reactivity or degree of severity of exposure.

Today we talk about need for resistance to freezing and thawing. If the concrete will ever likely freeze when any of the spaces in it that can hold freezable water are more than 91 percent full, we need air-entrainment, sound aggregate, and protection until moderate maturity is achieved. And, "air-entrainment" means an air content that will give an air-void system with an $\bar{L}$, a bubble spacing factor, less than 0.2 mm (0.008 in.) regardless of whether we have one or one hundred cycles of freezing and thawing per year and regardless of whether the rate of freezing is fast or slow or whether the minimum temperature achieved 10 mm below the exposed concrete surface is minus 5 C or minus 50 C. This topic was elegantly explored by Treval Powers years ago and was brought back to us this week by Bob Philleo.

We have decided to refer to these sorts of approaches as "specification overkill." It involves, much of the time, paying more than needs to be paid to buy a level of protection that, in many cases, can't ever be needed and from which no good can ever be derived. "Ever" in the preceding sentence means not more often than once in a million years. Today we have computers that can be run by most bright junior high school scientists that could be used to take the knowledge that does exist and derive from it reasonable criteria for matching degree of precautions needed or degree of restriction required of the contractor in his exercise of choice among materials, proportions, and practices; so that only limited precautions and light restrictions are called for when the nature and intensity of the anticipated environmental hazards and insults the concrete must resist are slight or of short duration in time. We can then reserve the levels of precautions we now take for all levels of severity for those cases where the hazard is really very severe and protection is needed for a very long time. We might well, by so limiting these requirements in their applicability, be able to increase their degree of protection so as further to minimize the probability that they will be less effective than needed.

Our challenge to all of you therefore is: Since Concrete Need Not Deteriorate, Insure that it Doesn't, but do so without raising the cost more than necessary; stamp out specification overkill.

APPENDIX

We have selected from the approximately 500 titles in our respective and joint lists of publications the following for the reasons stated.

Mather, Bryant. 1945. "Effect of Type of Test Specimen on Apparent Compressive Strength of Concrete," Proc., ASTM, Vol 45, pp 802-812. Results of tests of 2375 specimens, drilled cores, molded cylinders, modified cubes suggested that factors relating specimen types varied with strength level.

Mather, Katharine. 1947. "Relation of Absorption and Sulfate Test Results on Concrete Sands," American Society for Testing and Materials Bulletin, No. 144 (January 1947), pp 26-31. Test data on samples of 409 sands showed a high correlation of the performance test value and the property test value but this cannot be used as an acceptance criterion for a specific material.

Mather, Bryant. 1948. "Petrographic Identification of Reactive Constituents in Concrete Aggregates," Proc., ASTM, Vol 48, pp 1120-1125. A description of criteria for recognizing opal, chalcedony, tridymite, cristobalite, acid and intermediate volcanic glass in samples of aggregate.

Mather, Katharine and Bryant Mather. 1950. "Methods of Petrographic Examination of Aggregates for Concrete," Proceedings, American Society for Testing and Materials, Vol 50, pp 1288-1313. Also 1950 Preprint, No. 76, 25 pp. The description of the techniques and procedures that became ASTM C 295-54.

Mather, Bryant. 1952. "Cracking of Concrete in the Tuscaloosa Lock," Proc., Hwy Res. Bd., Vol 31, pp 218-233. A report on an extensive investigation primarily by Katharine Mather of what turned out to be the Corps of Engineers' first major example of alkali-silica reaction in a structure in service.

Mather, Katharine. 1953. "Applications of light microscopy in concrete research," Symposium on Light Microscopy, American Society for Testing and Materials Special Technical Publication No. 143, pp 51-70. A review of the development, since 1882, and state-of-the-art including some previously unpublished results of research on mass concrete, selected for the ASTM Sanford E. Thompson Award for 1953.

Kennedy, Thomas B. and Katharine Mather. 1953. "Correlation between laboratory accelerated freezing and thawing and weathering at Treat Island, Maine," Jour. American Concrete Institute, Proceedings Title 50-9, Vol 50, pp 141-172. Also WES Bulletin, 1954. Authors' closure to discussion, ibid (December 1954), pp 172-15 to 172-20. A major attempt to relate laboratory test data to field test data to performance in service. Selected for the ACI Wason Medal for Materials Research for 1955.

Mather, Bryant. 1957. "Laboratory Tests of Portland Blast-Furnance Slag Cements," Jour. ACI, proc., Vol 54, pp 205-232. A report on a study of samples of the product at all six of the plants making portland blast-furnace slag cement in the U.S.A. in 1952.

Mather, Bryant and Katharine Mather. 1958. The Butterflies of Mississippi, Tulane Studies in Zoology, Vol 6, No. 2, New Orleans, La., pp 63-109, 6 figures. Supplements 1, 2, 3 have been published in the Jour. Lepid. Soc. 13:71-72, 1959; 30:197-200, 1976; and 39:134-138, 1985. Recorded occurrence in Mississippi of 150 species of butterflies; increased from 83 to 122 to 144 to 150.

Pepper, Leonard and Bryant Mather. 1959. "Effectiveness of Mineral Admixtures in Preventing Excessive Expansion of Concrete Due to Alkali-Aggregate Reaction," Am. Soc. Testing Mats., Proc. 59, pp 1178-1203. Based on the Waterways Experiment Station Technical Report 6-841 (1958) showed that the amount of pozzolan or slag required to be introduced into a high-alkali cement-reactive aggregate mortar mixture to reduce expansion by 75 percent ranged from 10 to 45 percent and varied as fineness, silica solubility, and silica content changed. Selected for the 1961 ASTM Sanford E. Thompson Award.

Mather, Katharine. 1965. High-Strength, High-Density Concrete, WES MP 6-698, 10 pp; also Journal, Amer. Conc. Inst., Proceedings, Vol 62, No. 8, pp 951-962; reprinted on pp 1587-1596 of ACI SP-34, 1972, Concrete for Nuclear Reactors. Concrete having unit weights of 225-235 lb/ft^3 made using each of two sorts of iron ore (magnetite and ilmenite) as high-density aggregate and having water-cement ratios of 0.30 and 0.35 by mass developed strengths of 10,000 to 12,000 psi. Concrete can be simultaneously high-strength and high density.

Mather, Bryant. 1968. "Stronger Concrete," in A Symposium on Concrete Strength, Highway Research Record No. 210, NAS-NAE-NRC Publication 1553, pp 1-28. A state-of-the-art review based on one prepared for the Air Force listing reports of concrete having 10,000-psi strength and higher and factors affecting production of such concrete.

Mather, Bryant. 1968. "Field and Laboratory Studies of the Sulfate Resistance of Concrete," in Performance of Concrete - Resistance of Concrete to Sulphate and Other Environmental Conditions - A Symposium in Honour of Thorbergur Thorvaldson, Canadian Building Series, No. 2, University of Toronto Press, pp 66-76. A review of the chemical reactions involved in sulfate attack and an attempt to relate results of chemical analysis and calculated phase composition of cements to field and laboratory test results.

Mather, Bryant. 1969. "Deterioration of Concrete in Eisenhower Lock," Trans., Ninth International Congress on Large Dams, Vol VI, pp 427-429, Paris. A report to the international dam building

community that for as severe an exposure as the St. Lawrence Seaway having very sound aggregate and a proper air-void system is not enough; it is also necessary that a degree of maturity be achieved before concrete can, with impunity, be allowed to freeze while critically saturated.

Mather, Bryant. 1969. "Sulfate Soundness, Sulfate Attack, and Expansive Cement in Concrete," in Proceedings, RILEM International Symposium on Concrete Durability, Technical University, Prague, Czechoslovakia, pp C-209 to C-220. A discussion of relations and differences among the phenomenology of the "sulfate" test to predict frost effects; sulfate attack on concrete; and the use of expansive cement. The concept of "crystal growth pressure" is questioned.

Mather, Bryant. 1969. Research on Concrete, Stanton Walker Lecture Series on the Materials Sciences, Lecture No. 7, University of Maryland (National Sand and Gravel Assn., National Ready Mixed Concrete Assn., Washington, D.C.), 15 pp. A review of topics for and benefits of concrete research in which it was concluded that "As humanity tries to cope with the exponential increase in population, pavements, and pollution, research on concrete has an increasingly important role to play in providing the knowledge that will permit society to provide pavements--and other concrete structures--for people and reduce pollution."

Mather, Bryant. 1970. "Portland Cement Concrete, Research, Testing and Performance," ASTM Journal of Materials, Vol 5, No. 4, pp 830-841, December. The 1970 ASTM Edgar Marburg Lecture. It included: "I believe that the next two major areas for development, innovation, and improvement in specifications for portland cement will be to provide assurance (1) of greater uniformity of behavior and (2) that the cement will perform more uniformly in concrete with the selected kinds of admixtures with which it is used."

Mather, Bryant. 1974. "Use of Concrete of Low Portland Cement Content in Combination with Pozzolans and Other Admixtures in Construction of Concrete Dams," Jour. Amer. Conc. Inst. Proc., Vol 71, pp 589-599, December 1974, and Author's Closure, Jour. Amer. Conc. Inst. Proc., Vol 72, pp 296-297, June 1975. "Mass concrete having appropriate levels of relevant properties for the construction of dams may be produced with portland-cement contents as low as 60 lb per cu yd (36 kg/m^3) and with a water content of less than 80 lb per cu yd (48 kg/m^3)."

Mather, Bryant. 1976. "How Soon is Soon Enough?" Journal American Concrete Institute, Proceedings, Vol 73, No. 3, pp 147-150. The time to be sure that what is in a batch of concrete is correct is when it is batched, not later; the time to be reassured is when the batch is dumped and tested for slump and air content; the final check is when the accelerated cured specimen is tested at an age of 24 hr.

Mather, Katharine. 1978. "Petrographic Examination" in Significance of Tests and Properties of Concrete and Concrete-Making Materials, ASTM STP 169-B, pp 132-145. This revision of the state-of-the-art article that was in STP 169 (1955) and 169-A (1966) deals with concrete and closes with the remark by St. Paul as quoted in Epistle to the Hebrews, Chapter 11, Verse 3: "Things which are seen"--concrete and mortar--"were not made of things which do appear"--to the eye and to the light microscope. This paper, together with the others in the volume, shared the ASTM Dudley Medal.

Mather, Bryant. 1979. "Concrete Need Not Deteriorate," Concrete International, ACI, Vol 1, No. 9, pp 32-37. It needn't.

Mather, Bryant. 1980. "Use Less Cement," Concrete International, Vol 2, No. 10, pp 22-24. How to save energy and make better concrete provided the concrete has the needed levels of relevant properties.

Mather, Katharine. 1981. "Condition of Concrete in Martin Dam After 50 Years of Service," Cement, Concrete, and Aggregates, ASTM, Vol 3, No. 1, pp 53-63. A case history of concrete in a structure with extensive evidence of alkali-silica reaction but which appears to be ready to serve its owner successfully for another half century.

Mather, Katharine. 1981. "Factors Affecting Sulfate Resistance of Mortars," Proceedings of the 7th International Congress on the Chemistry of Cement, Paris, Vol IV, pp 580-585; also WES MP SL-80-17, 18 pp. (CTIAC Report No. 44.) Summarizes recent work showing that some pozzolans are very effective in preventing expansions of mortar made with sulfate susceptible cements, others are not. The ones found effective were silica fume and volcanic glass. The ones found less effective or, in some cases, harmful were fly ashes. A tendency for lignite fly ash to be worse was noted.

Mather, Katharine. 1985. "Preservation Technology: Evaluating Concrete in Structures," Concrete International, Vol 7, No. 10, pages 33-41. This paper prepared and presented at the ACI Convention in Boston in 1975 was intended primarily to share concrete technology with architectural and historic preservation technologists.

Mather, Bryant. 1986. "Selecting Relevant Levels of Quality," Concrete International, Vol 8, No. 3, ACI pp 30-36. Presented at the Abdun-Nur/Cordon Symposium on Quality Concrete in Construction, the intent was to suggest that achieving a given level of quality in concrete in construction is not enough. Also needed are relevant and appropriate criteria for selecting the levels of quality to be achieved.

SP 100-2

Benefits from International Interaction in Concrete Research and Development

by G. Idorn, P. Nerenst, and E. Poulsen

ABSTRACT

The importance for a small European country of early contact with the powerful American research after World War II is described with emphasis on the integration of learning from the behavior of field concrete and from theoretical exploration of the basic nature of concrete.

The tutorial and exchange contributions by K. and B. Mather are discussed, especially about their system approach to investigations of field concrete and their dedication to the development of research and testing.

A survey of the changing conditions for concrete technology and research is outlined, and in conclusion more integration of structural analyses and materials research are recommended.

Keywords: concrete durability; concrete technology; field tests; petrography; research; tests

INTRODUCTION

The story of how contacts were established between the American cement and concrete research and Denmark after World War II is a display of long-term profitable returns for a small country from modest, but dedicated investments in cooperation and exchange.

Denmark, like other European countries, faced after 1945 a serious housing shortage, excessive unemployment rates and exhausted serviceability of marine and infrastructure works, but there was also insatiable desires among young engineers to regain and renew past potentials for technology development and international contacts.

The Danish civil-engineering education with a strong basis in applied sciences and in cement and concrete technology had traditions for continuous updating of news from international research and engineering innovations, primarily through the late Professor E. Suenson's pioneering efforts in teaching, and his own, personal engineering for the development of building design and construction with concrete.