Manual of Aggregate and Concrete Testing[1]

INTRODUCTION

This manual is intended to supplement, not in any way to supersede, the various ASTM test methods for sampling and testing aggregate and freshly mixed and hardened portland-cement concrete. The manual was prepared by Committee C09 on Concrete and Concrete Aggregates and has been accepted by the Society for publication as information only. The manual is not a part of the ASTM methods. Comments and suggestions on the manual will be welcomed by Committee C09.

Many specifications for aggregates and concrete are based on the results of ASTM methods of testing and therefore strict adherence to the requirements of the test methods is important. Improper use of test procedures can result in inaccurate data and mistaken conclusions about aggregate and concrete quality. Accordingly, this manual directs attention to many of the factors that might affect the results of the tests.

This manual does not purport to address all of the safety concerns, if any, associated with its use. It is the responsibility of the user of these standards to establish appropriate safety and health practices and determine the applicability of regulatory limitations prior to use.

The subjects covered in the manual appear in the following order:

[1] This manual is under the jurisdiction of the ASTM Committee C09 on Concrete and Concrete Aggregates and is the direct responsibility of Subcommittee C09.97 on Manual of Testing.

Published as information, October 1965; revised 1967, 1969, 1977, 1978, 1983, 1987, 1989, 1991, 1992, 1994, 1996, 1998, 1999, 2000, 2001, 2002, 2003, 2004, 2005, 2006, 2007, 2008, 2009, and 2013.

1. AVAILABILITY OF STANDARDS

Copies of the current *Annual Book of ASTM Standards*, Vol 04.02—Concrete and Mineral Aggregates, should be readily available to all laboratory workers and inspectors in the field. Vol 04.01—Cement; Lime; Gypsum contains the Manual on Cement Testing which includes valuable information on procedures and apparatus. New editions of ASTM standards should be reviewed promptly for changes so that procedures can be kept current.[1]

1.1 Construction specifications may refer to ASTM standards either with or without the year designation. If the year designation is given, the standard bearing that designation should be used. If the year designation is not given, normally the standard in effect at the time the bidding documents are issued is the one which is used unless the job specifications state otherwise. Sometimes the job specifications might state that the standard in effect at the time bids are received, or the contract is awarded, or the current standard should be used. Job specifications should be checked to determine that the correct standard is used, should there be differences. Unfortunately, sometimes job specifications refer to ASTM standards that are obsolete and several years out of date. It is possible in some such cases that the specification writer might wish to use an older standard because of some provision it contains that does not appear in later editions.

2. QUALIFICATION OF PERSONNEL AND LABORATORY EVALUATION

There is increasing emphasis and a requirement in many cases by building codes, political jurisdictions and job specifications that personnel, laboratories, and plants which test, inspect, or produce materials or do construction work be approved, registered, licensed, inspected, certified, or accredited in various ways.

2.1 ASTM Specification E 329, for Use in the Evaluation of Agencies Engaged in Construction Inspection and/or Testing,[2] and Practice C 1077, for Testing Concrete and Concrete Aggregate for Use in Construction and Criteria for Laboratory Evaluation,[2] identify and define the duties, responsibilities and requirements for personnel and equipment used in the testing and inspection of concrete and related materials.

2.2 The Cement and Concrete Reference Laboratory (CCRL),[3] under the sponsorship of ASTM Committees C01 and C09, and administered by ASTM and National Institute of Standards and Technology (NIST), formerly the National Bureau of Standards, has a laboratory inspection service (for details of this service, see Section 7) for concrete and concrete aggregates. CCRL also has a proficiency sample program for concrete, cement and pozzolans. Identical samples of material are issued to participating laboratories who test the material and report the results to CCRL. These results are statistically analyzed and a final report issued to the participating laboratories including a rating of their results as compared to all other laboratories returning data. A similar reference sample program exists for aggregates. This program, conducted by an organization jointly administered by the Highway Subcommittee on materials of the American Association of State Highway and Transportation Officials (AASHTO) and NIST, is called the AASHTO Materials Reference Laboratory (AMRL).[4]

2.3 The Standard Practice for Laboratories Testing Concrete and Concrete Aggregates for Use in Construction and Criteria

[2] For referenced ASTM standards, visit the ASTM website, www.astm.org, or contact ASTM Customer Service at service@astm.org. For *Annual Book of ASTM Standards* volume information, refer to the standard's Document Summary page on the ASTM website.

[3] CCRL, National Institute of Standards and Technology, 100 Bureau Drive, Stop 8618, Gaithersburg, MD 20899-8618, www.ccrl.us.

[4] AMRL, National Institute of Standards and Technology, 100 Bureau Drive, Stop 8619, Gaithersburg, MD 20899-8619, www.amrl.net.

for Laboratory Evaluation (C1077) requires the use of an evaluation authority. A number of evaluation authorities for concrete testing laboratories exist. To assist the laboratory in locating an evaluation authority the following list of organizations is provided. The list is merely a collection of organizations willing to provide this service and is not an endorsement of any particular organization. Others not listed may be able to provide this service. The Cement and Concrete Reference Laboratory (CCRL)[3]; the AASHTO Accreditation Program (AAP)[4], the National Voluntary Accreditation Program (NVLAP),[5] the Construction Materials Engineering Council (CMEC),[6] the American Association for Laboratory Accreditation (A_2LA),[7] WACEL, an Association of Engineering Laboratories, Inspection Agencies and Building Official (WACEL),[8] Washington Association of Building Officials (WABO),[9] and International Accreditation Service (IAS)[10] all offer the evaluation authority service for concrete and concrete aggregate testing laboratories mentioned in the practice.

2.4 A number of technician certification programs also exist. These include the following: National Institute for Certification in Engineering Technologies (NICET),[11] American Concrete Institute (ACI),[12] Portland Cement Association (PCA),[13] the Precast/Prestressed Concrete Institute (PCI),[14] WACEL,[8] WABO,[9] and International Code Council (ICC).[15]

2.5 Other programs offer inspections, accreditation, and/or certifications. National Ready Mixed Concrete Association (NRMCA)[16] offers an inspection and certification program of concrete plants and trucks. IAS[10] offers accreditation for Fabricator Inspection Program for Precast/Prestressed Concrete Plants and for IBC Special Inspection Agencies. PCI[14] offers a plant certification program for manufacturers of precast/prestressed concrete. WABO[9] offers "Special Inspection Agency" accreditation to concrete special inspection agencies and "Plant/Fabricator" certifications to precast/prestressed concrete manufacturers.

3. SAMPLES

Although this manual is primarily concerned with testing, some brief remarks about sampling are necessary. Sampling is discussed in more detail in later Sections and in *ASTM STP 169 B, Significance of Tests and Properties of Concrete and Concrete Making Materials*. No amount of testing will yield correct answers if the samples are carelessly taken and do not represent the material sampled. It is better not to test a material improperly sampled because erroneous conclusions can be drawn from the test results. In any sampling system there are perhaps four stages, each of which requires careful attention and planning: (*1*) selection of a sampling plan which will provide the greatest amount of information at the least cost; (*2*) physical selection or gathering of samples in accordance with predetermined procedures for the preselected locations; (*3*) testing; and (*4*) analysis of the data obtained. The first and last of these four items are those that are most often neglected. Practice D 75, Sampling Aggregates,[2] and Practice C 172, Sampling Freshly Mixed Concrete,[2] provide information needed to obtain the samples, but do not discuss the problem of developing a specific sampling plan. Strictly speaking, there is no such thing as a representative sample. All materials are subject to periodic variation. Different shipments, lots, truck loads, car loads, or batches from a given supply will vary to some extent. In addition, the material comprising any of the specific units will seldom be precisely homogeneous. However, a successful sampling plan can establish the average characteristic of the material and determine the nature and extent of variability. As data become available it is possible to detect trends and decide if changes in production procedures or processes are required to deliver materials of acceptable quality with reasonably low percentages of defective or substandard material. Prior to starting of construction, a statistical or probability sampling plan should be developed and instructions furnished to inspectors. Since the amount and nature of the variations may be unknown, it will be necessary to take samples more frequently at the start. Later, after patterns are revealed, it should be possible to decrease sampling frequency unless or until excessive variation develops. Inspectors must take samples in the manner, at the time, and from the location specified in the sampling plan if conclusions based on the data are to be of value. The purpose of statistical sampling is to obtain results typical of the lot. Samples should not be biased by procedures that intentionally select either the best or poorest materials. Representative samples upon which the acceptance or rejection of a material is based should be taken by the purchaser's authorized agent.

3.1 The fundamentals of probability sampling have been set forth by ASTM Committee E11. The coal and ore industries, who have many problems similar to those found in the aggregate field, have developed practical approaches that can be adapted to the concrete field. The following references are useful:

(1) ASTM Practice E 105, for Probability Sampling of Materials[2]

(2) ASTM Practice E 122, for Choice of Sample Size to Estimate the Average Quality of a Lot or Process[2]

(3) ASTM Practice E 141, for Acceptance of Evidence Based on the Results of Probability Sampling[2]

(4) Bicking, C. A." Bibliography on Sampling of Raw Materials and Products in Bulk," Technical Association of the Pulp and Paper Industry, Vol 47, No. 5, May 1964

(5) Symposium on Bulk Sampling, ASTM STP 242, Am. Soc. Testing Mats., ASTTA, 1958

(6) Symposium on Coal Sampling, ASTM STP 162, Am. Soc. Testing Mats., ASTTA, March 1955

[5] NVLAP, National Institute of Standards and Technology, 100 Bureau Drive, Stop 2140, Gaithersburg, MD 20899-2140, www.nist.gov/nvlap.
[6] CMEC, 850 Courtland St., Suite B1, Orlando FL 32804, www.cmec.org.
[7] A_2LA, 5301 Buckeystown Pike Suite 350, Frederick, MD 21704, www.a2la.org.
[8] WACEL, 7900 Wisconsin Avenue, Suite 305, Bethesda, MD 20814, www.wacel.org.
[9] WABO, P.O.Box 7310, Olympia, WA 98507-7310, www.wabo.org.
[10] IAS, 5360 Workman Mill Road, Whittier, CA 90601, www.iasonline.org.
[11] NICET, 1420 King Street, Alexandria, VA, www.nicet.org.
[12] ACI, PO Box 9094, Farmington Hills, MI 48333-9094, www.aci-int.org.
[13] PCA, 5420 Old Orchard Road, Skokie, IL 60077, www.cement.org.
[14] PCI, 175 W. Jackson Blvd. #500, Chicago, IL 60604, www.pci.org.
[15] Available from International Code Council (ICC), 500 New Jersey Ave., NW, 6th Floor, Washington, DC 20001-2070, http://www.iccsafe.org.
[16] NRMCA, 900 Spring Street, Silver Spring, MD 20910, www.nrmca.org.

(7) Symposium on Bulk Sampling, ASTM STP 114, Am. Soc. Testing Mats., ASTTA, 1951

(8) Tanner, L., and Deming, E.,“ Some Problems in the Sampling of Bulk Material,” *Proceedings*, Am. Soc. Testing Mats., ASTEA, Vol 49, 1949, pp. 1181–1188

(9) Symposium on Usefulness and Limitations of Samples,” *Proceedings*, Am. Soc. Testing Mats., ASTEA, Vol 48, 1948, pp. 857–895

(10) Shook, J. F., “Significance of Test Results Obtained from Random Samples, *ASTM STP 362*, 1964, p. 13

(11) Duncan, A. J., “An Introduction to Acceptance Sampling Plans,” *ASTM Standardization News*, Vol 3, No. 9, September 1975, p. 10

(12) Duncan, A. J., “What Sampling Plan to Use,” *ASTM Standardization News*, Vol 3, No. 9, Sept., 1975, pp. 15–19

(13) Hahn, G. J. and Schilling, E. G., “An Introduction to the MIL-STD-105D Acceptance Sampling Scheme,” *ASTM Standardization News*, Vol 3, No. 9, Sept., 1975, pp. 20–30

(14) Abdun-Nur, E. A., “Significance of Tests and Properties of Concrete and Concrete-Making Materials,” *ASTM STP 169B*, pp. 5–23

Additional information is given in ASTM methods and specifications, and in publications of the Federal Government, Corps of Engineers, and Bureau of Reclamation.

3.2 Samples must be adequately identified and shipped in clean, strong containers. Samples of cement should be shipped in moisture-proof containers, packed in a suitable shipping box. For coarse aggregate samples, heavy cloth bags, such as duck of about 9-oz (300 g/m^2) weight, is suitable, but in any case the instructions of the supervising official should be followed. Bags or boxes for samples containing fine materials must be tight enough to prevent the loss of the “fines.” If the moisture content of a sample is important, the container must be moisture tight. Containers must be clean. Samples must not be placed in “used” sacks that contain residues of undesirable or injurious material, such as sugar, flour, or certain sack preservatives. The sizing in some new sacks can contaminate damp sand samples and entrain small percentages of air if the sand is used in concrete.

3.3 The sample container should be labeled or tagged to convey the necessary information. A duplicate label that will not rot or mildew should be placed in the container. A transmitting letter should be sent to the laboratory with a copy of the letter inside the sample container if possible. Tags and letters should contain all the data requested or deemed pertinent. If the sample container has a removable top, the identifying marking must be placed on, or connected to, the body of the container, not on the top. (Tops may become interchanged.) If certain samples are later transferred to laboratory storage containers, the numbers should be affixed to the containers, not to removable lids.

3.4 When samples are received at the laboratory, pertinent identifying information should be recorded in a permanent book or log. The assignment of consecutive numbers to samples as received is a common practice, but numbers should not be repeated, as starting anew each year, unless the numbers contain additional identification such as using the year designation in the number code. Repetition of numbers has caused serious confusion in studying the results of old tests. Among suggested data to be recorded in a sample book are: kind of material, source, date of sampling, name of the person who sampled the material, date of receipt of the sample at the laboratory, project, reference to related correspondence, tests to be made, person assigned the tests, and date of completion of the report of tests. Many laboratories use specially printed forms or books for properly associating results of tests with the samples they represent.

3.5 If any condition is encountered at any time between sampling and completion of the test that suggests that the requirements of the standard were not followed or that otherwise may cast doubt on the accuracy or validity of the test result, the condition should be documented. It is preferable to resample if possible. If re-sampling is not possible, a note should be included in the test report, along with any evaluation of the effects of the condition, documenting the condition.

4. TERMINOLOGY

Definitions of terms relating to concrete and concrete aggregates are to be found in ASTM Terminology C 125, Relating to Concrete and Concrete Aggregates,[2] and related methods and specifications.

5. TESTING APPARATUS

Testing equipment should be purchased subject to compliance with ASTM specifications. In any event, the apparatus should be tested for dimensions, weight, volume, material, performance, and any other pertinent requirements. The operator should not assume that new equipment meets ASTM specifications. The operator should be satisfied that the equipment meets all requirements. With equipment use, wear does occur and the original calibrations may no longer be valid. Before making calibrations, reference should be made to applicable sections of ASTM standards and publications of the National Institute of Standards and Technology relative to weights, weighing devices, measurements of volumetric glassware, and pertinent standard tables. Existing equipment should be checked to see that it meets requirements of newly revised specifications.

5.1 Proper maintenance of testing apparatus should be emphasized not only for the sake of appearance but because good housekeeping in a laboratory promotes care and interest in the work. Operators should be instructed and trained so that the proper use and maintenance of apparatus becomes a habit, not an occasional observance.

5.2 Because weighing equipment is so widely used in the concrete and concrete-aggregate tests, some general remarks about such apparatus are presented here. Scales and balances should have appropriate capacities, and should also possess the sensitivity and accuracy required by the particular test method being used. Sensitivity and accuracy should not be confused as they are not the same. Noncompensating spring scales should not be used. The operator is cautioned against small weighings on scales of large capacity. Weighing apparatus should be periodically checked to ensure that it is in good condition and meets the requirements of the aggregate and concrete tests involved. The accuracy of scales should be checked: at least every 6 months; when there is some doubt about their accuracy; or after they have been transported or mistreated. The accuracy can be verified with test weights kept for this purpose alone or by utilizing the services of others such as state, county, or city weights and measures departments or the service department of scale manufacturers. Information about requirements and definitions for weighing apparatus, as well as the methods of testing such equipment are found in the appropriate federal publications. One reference that should be on file in every concrete laboratory is a recent edition of the National Institute of Standards and Technology Handbook 44, *Specifications, Tolerances, and Other Technical Requirements for Weighing and Measuring Devices*.[17]

5.2.1 All parts of balances and scales should be kept free from sand and dirt. Overloading must be avoided. Balances should be located on a substantial, stable base, and should not rest on easily removable shims. Zero settings are readily disturbed if the balances rest on uneven, slippery slabs. The weighing of relatively small quantities of some materials, such as an admixture, will usually require weighing equipment other than that used for the aggregates and cement. Balances must be glass-enclosed if weighings are to be made to fractions of a gram. All weights used with the laboratory scales and balances should be plainly marked; their magnitude and units should not be a matter of memory or guess. The weights should be kept in suitable protective containers, and they should be periodically checked for accuracy. Care should be taken not to intermix the weights from a number of platform scales that may have different lever ratios; such intermingling of weights has occurred and has caused large errors in the weighings of the component parts of laboratory concrete mixes. Care should be taken to avoid the loss of set screws or other parts of rider weights on balances and platform scales.

5.3 It is sometimes helpful to make one member of the laboratory staff responsible for periodic maintenance and calibration of equipment. A schedule for this should be established. The dates and results of calibrations should be recorded.

5.4 Apparatus for measuring and controlling temperature, relative humidity, or both, should be frequently checked to determine whether the specified conditions are being maintained. Recording instruments must be checked frequently, particularly as to whether the proper charts are being used.

5.5 Parts of apparatus that come into contact with concrete and mortar should not be made of material that will react with the concrete or mortar under the conditions of the test.

5.6 Information that relates to the care and use of apparatus in specific methods of test is usually included in the related test sections of the manual.

6. SAFETY PRECAUTIONS

Safety precautions are essential, and one person should be authorized to see that the required safety precautions are observed. First aid training not only provides instruction on procedures to be followed in an emergency but also points up the importance of safety measures. Emergency instructions on proper storage of combustible or explosive materials as well as telephone numbers of fire department, doctors, ambulance and police should be conspicuously posted.

6.1 Among some of the more commonly mentioned precautions are: proper grounds on electric equipment, proper fusing, suitable extension cords where their use is necessary, and adequate lighting.

6.2 Provide suitable enclosures for moving parts of machines, particularly belts and gears. Laboratory personnel have been badly injured by contact with exposed gears or by being caught in a machine while testing specimens while alone in a laboratory. In a latter case, the operator managed to kick the switch off with his foot; this he could not have done if the switch had been located at a distance. Keep hands out of moving machinery, and do not touch revolving shafts or rolls, or even the ends of the moving shafts, even though the parts may be polished and smooth. It is particularly dangerous to touch such moving parts with rags or gloves. One experienced laboratory man lost part of a hand when he touched a moving roll with his rubber-gloved hand while cleaning the apparatus in the process of grinding some material. Moving parts will quickly seize cloth, rubber, and so forth, and may draw the operator's hand or arm into the machinery.

6.3 Contact with cement powder or fresh (unhardened) cementitious mixtures can cause skin irritation, severe chemical burns, or serious eye damage. Avoid contact with eyes and skin. Wear waterproof gloves, a fully buttoned long sleeve shirt, full-length trousers, and tight fitting eye protection when working with these materials. Wash cement powder or fresh (unhardened) cementitious mixtures from your skin with fresh, clean water immediately after contact. Indirect contact through clothing can be as serious as direct contact, so promptly rinse out cement powder or fresh (unhardened) cementitious mixtures from clothing. Seek immediate medical attention if you have persistent or severe discomfort. In case of eye contact, flush with plenty of water for at least 15 min. Consult a physician immediately.

6.4 When mixing or testing fresh concrete, wear safety glasses, goggles, or face shields to keep concrete from splashing into the eyes. When working around noisy equipment such as crushers or screening plants, use ear plugs. Use dust masks in dusty areas. Safety shoes are always advised.

6.5 When performing strength testing, a means to contain possible fragmentation of the test specimen should be used at all times. A shield made of perforated or expanded metal, certain type of plastics such as Lexan, or a heavy fabric wrap placed around the cylinder should be used to protect the operator and others in the area. The operator and anyone observing the test should wear goggles, safety glasses, or a face shield. Safety shoes should always be worn when working in the laboratory.

6.6 Keep from under suspended loads. Use a distinctive color of paint for the moving parts of laboratory machinery. Provide elevators and freight lifts with automatic gates. Use goggles, safety glasses, face shields, hard hats, safety shoes, gloves, and respirators whenever they are needed. Do not use chisels with broomed ends. Be cautious about flying fragments. Remember that dry cement splashes like water and that eye

[17] For sale by the Superintendent of Documents, U.S. Government Printing Office, Washington, DC 20402.

protection is necessary, particularly if the cement is hot. Provide collectors for such dust as may be produced in dry grinding, sawing, or otherwise finishing or cutting concrete specimens.

6.7 Some materials now in use in the concrete laboratory warrant special precautions, for example, sulfur, sodium hydroxide, mercury, sulfur cements, benzol, alcohol, and carbon tetrachloride. An emergency eye wash station is advisable.

6.8 Some special lamps must be properly shielded to protect the eyesight of workers. Proper ventilation should be provided, particularly in closed air-conditioned laboratories. Hoods should be provided with suitable fire extinguishing equipment when warranted. Safety showers and eye wash fountains should be at hand for operators in some lines of work, and these should be in working order. Their water supply line must not be controlled by any valve or valves that can be turned off by unauthorized personnel.

6.9 Doors to all rooms and special chambers, particularly fog rooms and freezing-and-thawing spaces, should be fitted with latches that can be readily operated from the inside as well as from the outside.

6.10 A telephone should always be available, particularly when an operator is working in the laboratory alone or at night.

6.11 Capping room, when sulfur is used, should be properly ventilated with an exhaust fan or hood. A fire extinguisher should also be located in the room.

6.12 Most of these safety admonitions have been prompted by recollections of actual happenings and they should not be treated lightly. Most of all, use common sense.

7. INSPECTION OF LABORATORY

An occasional inspection of a concrete laboratory by appropriate members of that laboratory's staff is suggested to learn if the laboratory has proper equipment, employs standard test procedures, practices good housekeeping, and observes safety precautions. This inspection should indicate management's interest in the maintenance and improvement of the laboratory as a whole.

7.1 Since 1929, there has been maintained at the National Institute of Standards and Technology (NIST) a Research Associate Program presently known as the "Cement and Concrete Reference Laboratory." This program is a cooperative project of NIST and the American Society for Testing and Materials, under the sponsorship of ASTM Committees C01 on Cement and C09 on Concrete and Concrete Aggregates. The most important function of the CCRL is to promote uniformity and improvement in testing through the field inspection of cement, concrete, concrete aggregate, steel reinforcing bar, and pozzolan testing laboratories. Using load cells, micrometers, balances, testing weights, and thermometers, which are traceable to the NIST, the CCRL inspectors evaluate equipment and procedures to the requirements listed in the relevant test methods. In the concrete and concrete aggregate areas, the inspection work is based on ASTM C 1077, Practice for Laboratories Testing Concrete and Concrete Aggregates for Use in Construction and Criteria for Laboratory Evaluation.[2] These services are advisory in nature, utilization is on a voluntary basis, and there is no direct regulatory action involved. A second important function is the distribution of proficiency samples of construction materials such as hydraulic cements, pozzolan, and concrete. Laboratories participating in these cooperative testing programs find them to be of great assistance in evaluating the quality of their work. Charges are made for both the inspection and proficiency sample services. Inquiries should be addressed to the Cement and Concrete Reference Laboratory, National Institute of Standards and Technology, 100 Bureau Drive Stop 8618, Gaithersburg, MD 20899-8618.

8. UNIT WEIGHT AND VOIDS IN AGGREGATE

(See Test Method C 29/C 29M)[2]

Samples for test must be carefully selected. Before use, the sample should be thoroughly mixed and spread to a uniform depth on a flat surface. The use of a flat rectangular scoop with sides approximately the same depth as the pile of aggregate to be tested will tend to reduce segregation when filling the measure.

8.1 Measures, particularly the larger ones, should be provided with suitable handles for the safety and convenience of personnel. Attention must be given to the requirements of the method regarding relation between size of measure and size of largest particles of aggregate. The measures should be calibrated as described in the test method. A glass plate is used during the calibration to make sure that the water completely fills the vessel. A film of water pump grease or chasis grease placed on the rim of the container will help prevent leaking. Occasionally the rims of new containers are not plane, and calibration is impossible unless high spots are removed. The rim can be made plane by inverting the measure and grinding it on a steel or glass plate using emery cloth, carborundum, or valve grinding compound as an abrasive.

8.2 The rodding method requires that for the second and final layers, the tamping rod shall penetrate the last preceding layer of aggregate in the measure; it is not practicable to attain this much penetration with many graded coarse aggregates. During rodding, the measure should rest firmly on a rigid base, and there should be no shaking or jolting of the measure. Jigging, vibration, or jolting may give appreciably different results from those obtained by rodding, particularly in the case of the finer materials. Reports should state clearly how the measure was filled. When this method is used for lightweight aggregate, ASTM Specifications C 330, C 331, or C 332,[2] the shoveling procedure is used.

8.3 It is difficult to strike off the aggregate at the top of the measure when large pieces of aggregate protrude above the level of the rim. It may be necessary to remove a few pieces of the aggregate by hand in order to secure an average filled condition but no finer aggregate should be added to fill the voids in the surface. Overmanipulation during strike off will introduce additional compaction. Strike-off procedures are particularly important in loose weight determinations made by the shoveling procedure. Uniform procedures must be followed if different laboratories, different operators, or duplicate tests by the same operator are to check within the precision requirements of the method.

8.4 The method provides the formula for calculating the voids in aggregates after compacting in a standard size measure in accordance with C 29/C 29M procedures; the term "voids" applies to the space between the aggregate particles under test and is expressed as a percentage of total volume.

8.5 Determinations of voids in aggregate also can be performed on material compacted on a damp-loose or an inundated basis for special reasons. In addition, flow methods of loose consolidation as proposed by Rex and Peck (Public Roads) and M. H. Wills (ASTM) are sometimes used to determine void content which provides an index of particle shape which can be used to estimate mixing water required in concrete proportioning.

8.6 The percentage of voids has an effect on the concrete proportions determined by ACI 211 procedures. The shape and grading of particles affects the voids and, generally, smooth, rounded particles will show less voids contained than crushed, angular particles.

9. MAKING AND CURING CONCRETE TEST SPECIMENS IN THE FIELD

(See Practice C 31)[2]

Practice C 31 covers the procedure for making and curing concrete cylinders and beam specimens in the field. When casting concrete specimens in the field, it is also required to determine the slump, air content and temperature of the concrete. Determining the density of the concrete may also be required.

9.1 An important part of properly casting specimens in the field is proper sampling of the concrete. The sampling of concrete is discussed in Sections 3 and 21 of this manual. Improper sampling often leads to non-representative results and may be costly to all parties, including the testing agency, the concrete supplier, and the contractor. This unnecessary additional expense is caused by the negative influence improper sampling may have on the compressive strength, slump, density, and air content.

9.2 The field technicians making and curing specimens for acceptance testing shall be certified. The certification shall include both written and performance examinations.

9.3 For compressive strength specimens made in the field in accordance with Practice C 31, the specified mold size is either 6 by 12 in. (150 by 300 mm) or 4 by 8 in. (100 by 200 mm). The diameter of the mold must be at least three times the nominal maximum size aggregate in the concrete. In cases where the maximum aggregate is larger than 2 in. (50 mm), wet sieve the concrete as described in Practice C 172 to remove aggregate larger than 2 in. (50 mm). (See Table 1 for selection of specimen size.) Avoid the inclination of referring to the mold size as either "large" or "small" because sizes smaller than 4 by 8 (100 by 200 mm) are permitted for use in the laboratory and sizes larger than 6 by 12 in. (150 by 300 mm) are available.

9.3.1 It is important to identify each individual cylinder. Place identifying marks on the outside of the molds, in case the specimen molds are disarranged in handling or transfer. The practice stipulates that if removable lids are used on top of the mold, the identifying marks cannot be placed on the lids. Removable lids are often separated before information is transferred to the cylinder. Etching or scribing of information into the surface of freshly fabricated cylinders is prohibited by the practice.

TABLE 1 Selection of Specimen Size

Aggregate Size Number	Maximum Size	Nominal Maximum Size	Specimen Mold Size
#2	3 in. (75 mm)	2½ in. (75 mm)	Wet sieve, then 6 by 12 in. (150 by 300 mm)
#3	2½ in. (75 mm)	2 in. (50 mm)	6 by 12 in. (150 by 300 mm)
#4	2 in. (50 mm)	1½ in. (37.5 mm)	6 by 12 in. (150 by 300 mm)
#5	1½ in. (37.5 mm)	1 in. (25 mm)	6 by 12 in. (150 by 300 mm) or 4 by 8 in. (100 by 200 mm)
#6	1 in. (25 mm)	¾ in. (19 mm)	6 by 12 in. (150 by 300 mm) or 4 by 8 in. (100 by 200 mm)
#7	¾ in. (19 mm)	½ in. (12.5 mm)	6 by 12 in. (150 by 300 mm) or 4 by 8 in. (100 by 200 mm)
#8	½ in. (12.5 mm)	⅜ in. (9.5 mm)	6 by 12 in. (150 by 300 mm) or 4 by 8 in. (100 by 200 mm)

9.3.2 The concrete cylinders should be molded where the cylinders will be stored for initial curing. Cylinders should not be moved even a few feet if there is any way to avoid it. If cylinders must be moved they should be supported by the base of the mold and moved immediately after finishing. If the surface is marred while moving, refinish the surface of the cylinder. The molds should stand on a level and firm surface that is free from vibration. When the single use mold rests on a soft or uneven surface, the bottom of the hardened specimen may be uneven and difficult to prepare for the compression test. If the axis of the cylinder is not vertical, the ends may not be parallel and will need to be sawed or ground to prevent thick wedge-shaped caps. These conditions may adversely affect compressive strength results.

9.3.3 Cylinders should be properly filled and consolidated by either rodding or vibration. Concrete with a slump of less than 1 in. (25 mm) must be consolidated by vibration. Concrete with a slump of 1 in. (25 mm) or greater may be consolidated by either rodding or vibration. Consolidation equipment and technique will vary depending upon the specimen size (See Tables 2 and 3). Use only rods meeting the requirements of the practice. The use of rebar or other non-standard rods/tools is not permitted. Care should be taken when vibrating high-slump

TABLE 2 Molding Requirements for Rodding Cylinders

Cylinder Diameter in. (mm)	Rod Diameter in. (mm)	Number of Layers	Number of Roddings per Layer
4 (100)	⅜ [10]	2	25
6 (150)	⅝ [16]	3	25

TABLE 3 Molding Requirements for Vibrating Cylinders

Cylinder Diameter in. (mm)	Maximum Vibrator Diameter in. (mm)	Number of Layers	Number of Vibrator Insertions per Layer
4 (100)	1 (25)	2	1
6 (150)	1½ [39]	2	2

concrete to avoid segregation. The practice advises the duration of vibration should be 5 s or less for concrete with slumps greater than 3 in.

9.3.4 Lack of attention to proper consolidation techniques can result in segregation and honeycombing. Excessive overfilling of the last mold layer can cause a concentration of large aggregate at the top, with accompanying overflow of mortar. Ideally, only enough concrete should be placed as the top layer so that it can be finished without addition or removal of concrete. When consolidating with a tamping rod, after each upper layer is placed, allow the rod to penetrate through the layer being rodded. After rodding each layer, tap the outside of the mold lightly 10 to 15 times with a mallet to close any holes left by rodding and to release any large air bubbles that may have been trapped. An open hand should be used in place of a mallet when using light gauge single use molds which are susceptible to damage when tapped with a mallet. If consolidation is by vibration, care should be taken not to overvibrate. Usually sufficient vibration has been applied as soon as the surface of the concrete has become relatively smooth. Continue vibration only long enough to achieve proper consolidation of the concrete. Over-vibration may cause segregation. Removal of the vibrating element too quickly may result in the creation of a mortar pocket. Unusual care must be used in molding concrete of dry consistency in single use molds to prevent damage to the bottom of the mold. When fabricating more than one specimen at a time, the preferred method is to fill and consolidate the same layer of all specimens before continuing with the next layer. This will increase the uniformity of the cylinders.

9.3.5 There are two separate curing methods discussed in the practice with distinct purposes.

Standard cured specimens may be used for:

Acceptance testing for specified strength

Checking the adequacy of mixture proportions for strength

Quality control

Field-cured specimens may be used for:

Determination of whether a structure is capable of being put in service

Comparison with test results of standard cured specimens or with test results from various in-place test methods

Adequacy of curing and protection of concrete in the structure

Form or shoring removal time requirements

Basically, standard curing is used for evaluating the concrete as supplied by the concrete supplier, while field curing is used for evaluating the concrete in the structure.

9.3.5.1 For standard curing, the specimens need to be in a temperature controlled environment. The specimens shall be stored for a period up to 48 h in a temperature range from 60 and 80 °F (16 and 27 °C) and in an environment preventing moisture loss from the specimens. For concrete mixtures with a specified strength of 6000 psi (40 MPa) or greater, the initial curing temperature shall be between 68 and 78 °F (20 and 26 °C). Record the temperature using a maximum-minimum thermometer. This information is important because temperature deviations from those required may directly affect the strength of cylinders. The practice requires that the specimens shall not be transported until at least 8 h after final set. Normally, final set occurs 6 to 10 h after batching. The top of the cylinder should be covered by a plastic or metal lid, a metal or glass plate, or a plastic bag. When using a cover made from a flexible material, do not allow the cover to contact the concrete. A plastic bag placed over the top of the cylinder with a rubber band near the top of the mold does an excellent job. When using cardboard molds, the rubber band should be placed close to the top of the mold to avoid wetting the outside of the paper mold from condensation inside the plastic bag. Burlap or wood should not be in contact with the fresh concrete. Prevent moisture loss during transportation by wrapping the specimens in plastic, wet burlap, by surrounding them with wet sand, or tight fitting plastic caps on plastic molds.

9.3.5.2 For field curing, try to mimic the curing conditions of the formed concrete. Store cylinders in or on the structure as near to the point of deposit of the concrete represented as possible. Protect all surfaces of the cylinders from the elements in as near as possible the same way as the formed work. Provide the cylinders with the same temperature and moisture environment as the structural work. Test the specimens in the moisture condition resulting from the specified curing treatment. Specimens made for the purpose of determining when a structure is capable of being put in service shall be removed from the molds at the time of removal of form work.

9.3.5.3 When hardened specimens are removed from the molds, they should be marked to retain their identity during curing. Black graphite crayon is good for marking a concrete surface that has been in contact with an oily mold. Felt tip marking pens are generally satisfactory. Avoid ordinary colored crayons, because in moist air their markings will quickly vanish. If identification marks are placed on the top of a cylinder, they should also be placed on the sides to prevent loss of identification after capping.

9.3.6 Major problems in transporting cylinders from the field to the laboratory include moisture loss, damage from jarring, and temperatures outside the curing range. During transporting, protect the specimens with suitable cushioning material to prevent damage from jarring. During cold weather, protect the specimens from freezing with suitable insulation material. Practice C 31 specifies that the molded cylinder be protected against moisture loss. Moisture loss can be minimized by transporting cylinders in their molds with tight fitting lids or covers. Where it is necessary to demold cylinders prior to transportation, moisture loss can be minimized by wrapping the cylinders in plastic or by surrounding the cylinders in wet sand or wet sawdust. Damage due to jarring can be prevented by placing the cylinders in padded containers that prevent movement. Practice C 31 requires that transportation not exceed 4 h.

9.3.7 In some instances a cylinder not cast by the laboratory may be tested in the laboratory. Whenever a cylinder is not in the charge of the laboratory from casting to testing, extensive notes should be taken. If a cylinder is not cast by the laboratory but delivered to the laboratory after initial curing, a note should be made which describes the initial curing, the transportation container used, and the condition of the cylinder upon receipt. This information may prove useful later if the cylinder fails to meet expected strength requirements.

9.4 Practice C 31 also covers the making and curing of flexural test specimens or beams in the field. The earlier discussion of selecting a site to mold the cylindrical test specimens and the curing after molding apply to the flexural specimens as well.

9.4.1 Practice C 31 requires that molds shall be watertight as judged by their ability to hold water poured into them. Most beam molds require the use of a sealant to meet this requirement. In addition to the grease, modeling clay, or molten microcrystalline wax mentioned in the practice, the laboratory may wish to consider the use of silicon, latex or acrylic caulking as possible sealants. Their ease in application, quick setting time, continued flexibility and availability make any one of the three a good choice. Care should be taken in applying the sealant to the joints to avoid excess sealing material in the interior of the mold. This could result in irregularities along the edges of the beam. A smooth bead of sealant approximately 1⁄16 in. fillet on the interior corners is recommended.

9.4.2 Many beam molds are of the reusable type and, as such, should be maintained in good condition. The inside surfaces should be smooth and free from a build-up of hardened concrete. The use of mineral oil or a non-reactive form release agent is required on the inner surfaces of the mold. Unless required by project specification, the minimum size of beams made in the field shall have a depth and width of at least 6 in. The length of the mold shall be at least three times larger than the depth plus two inches. For 6 in. deep beams the minimum length is 20 in. ((3 x 6 in. depth) + 2 inches = 20 inches). The sides and bottom of the mold shall be free of warpage and be within 1⁄8 in. of the nominal 6 in. width or depth. The use of molds not conforming to the requirements of the practice can adversely affect test results.

9.4.3 While molding the beam, consolidation is accomplished by rodding or vibration. If rodding is used, the number of strokes per layer is dependent on the top surface area. Consult the *Molding Requirements of Rodding* table in the practice for the correct number of strokes. If consolidation is by vibration, care should be taken not to over-vibrate. Usually, sufficient vibration has been applied as soon as the surface of the concrete has become relatively smooth. Continue vibration only long enough to achieve proper consolidation of the concrete. Over-vibration can result in segregation of the concrete. Removal of the vibrating element too quickly may result in the creation of a mortar pocket.

9.4.4 If consolidation has been accomplished with rodding, close the voids of each layer by tapping the outside of the mold; spade the concrete along the sides and ends of the mold with a trowel. Do not spade a beam that has been consolidated by vibration.

9.4.5 The practice allows for two types of curing, depending on the job specification. The *Reporting* section of the practice requires that the type of curing be reported along with details of the curing.

9.4.6 When field curing, the beam is cured as nearly as possible, in the same manner as the concrete in the structure. If the beam represents a pavement, store specimens on the ground with the sides and ends banked with moist sand or soil. Treatment of the top surface should be the same as the pavement it represents. If the beam represents structure, store the concrete as near as possible to the structure it represents. Again, the temperature and moisture environment should be the same as the structure. At 24 h prior to testing, immerse the beam in a water storage tank containing calcium hydroxide saturated water. For complete information on water storage tank requirements, see the *Water Storage Tank* Section in the *Specification for Moist Cabinets, Moist Rooms, and Water Storage Tanks in the Testing of Hydraulic Cements and Concretes* (C 511).

9.4.7 When standard curing is used, the curing is broken down into two stages: the initial curing when the specimen is still in the mold and the final curing after the specimen has been removed from the mold.

9.4.8 Two primary concerns during the initial curing period are to maintain the specified temperature range and prevent moisture loss from the beam. If the beams are allowed to dry during any part of the curing period, shrinkage cracks may form in the specimen, thereby lowering the flexural strength. It is especially important that beams be protected from moisture loss during the initial period of curing in the mold. Temperatures during the initial curing period must be maintained between 60 to 80 °F (16 to 27 °C). For flexural strengths above 700 psi, the initial curing temperature is 68 to 78 °F. The *Initial Curing Section* in the practice details several ways to accomplish these goals.

9.4.9 In the final curing period, the beams are removed from the mold and cured in a more closely controlled environment. When de-molding the beam, the mold should be completely disassembled and the beam should be carefully removed to avoid damage to the concrete. Do not attempt to remove the beam by force. Tools such as hammers, screwdrivers, mallets, or tamping rods can damage both the molds and the concrete and should not be used. Within thirty minutes of de-molding, store the beam in either a moist room or water storage tank conforming to the requirements of Specification C 511 until 20 h prior to testing. A good way to avoid shrinkage cracks is to store the beams in saturated lime water for the entire curing period after de-molding. During the last 20 h of curing, the beams must be stored in a water storage tank.

9.4.10 Another factor which can influence the ultimate strength of beams is transportation. If at all possible, beams should be made at the location of the final curing. If beams must be transported, the beam must be continually supported over its entire length due to its weight. A bed of damp sand is one method of providing this support. Prevent damage due to jarring by providing cushioning material between the beam and other items in the vehicle. The beams should not be transported on end. Temperature and moisture loss are also concerns during transportation. In extreme temperature conditions, some method of temperature control or insulation should be provided. Wet burlap or plastic sheet covering all exposed areas will prevent moisture loss. The practice limits the transportation time to 4 h.

10. COMPRESSIVE STRENGTH OF CYLINDRICAL CONCRETE SPECIMENS

(See Test Method C 39/C 39M)[2]

Test Method C 39/C 39M describes the testing of concrete cylindrical test specimens for compressive strength. Molded cylinders are prepared based on Practice C 31[2] which describes field preparation or Practice C 192[2] for laboratory preparation. Drilled concrete cores which are also cylindrical test specimens are obtained by following procedures in Test Method C 42.[2] Prior to testing, cylinder ends should be capped or ground in accordance with the requirements of Practice C 617[2]or the unbonded cap system described in Practice C 1231.[2] The remainder of Section 10 assumes that C 617[2] is used for end treatment of cylinders. Additional information can be found in Section 33 (C 617) of this manual. For information on the unbonded capping system refer to Section 38 of this manual. However, when using the unbonded capping system, Section 10 should be read for a complete understanding of making and curing concrete test specimens.

10.1 In order to report the compressive strength, the cross-sectional area of the cylinder must be calculated prior to test. To determine the cross-sectional area the diameter of the cylinder must be calculated. The calipers and scale shown in Fig. 1 can be used to measure the diameter of the cylinder provided the scale is accurate to 0.01 in. (0.25 mm). Another option for this measurement is micrometer calipers. Two measurements at right angles at a midpoint on the cylinder should be made. The diameter used to calculate the cross-sectional area is the average of the two measured diameters. Pi tapes do not provide individual diameter measurements and therefore should not be used to determine the average diameter. If cylinders are molded with molds that consistently produce a cylinder diameter within a range of 0.02 in. (0.51 mm), measurement of cylinders can be reduced to three a day or one in every ten, whichever number of measurements is greater. The measurement of the height is only necessary if the length to diameter ratio exceeds 2.2 or is less than 1.8. If the L/D ratio is less than 1.8, refer to the calculation section in Test Method C 39/C 39M. If the L/D ratio is greater than 2.2, the length of the cylinder should be reduced to the proper length. The correction of length is typical for drilled cores.

10.2 Prevent moisture loss whenever cylinders are removed from the curing environment. This can be done by storing them in moist air, under water, or wrapping in wet burlap.

NOTE 1—The outside caliper and the scale are used to measure the diameter of the cylinder for computing the area.

FIG. 1 Checking Planeness of the Capped End of a Concrete Cylinder Prior to Testing Using a 6-in. (152-mm) Machinists's Parallel and a 0.002-in. (0.05-mm) Feeler Gauge

10.3 Test Method C 39/C 39M requires that the cylinder be centered with relation to the upper spherically seated bearing block. This phase of the testing operation often does not receive adequate attention. If a skewed cylinder is centered on the lower bearing block, the requirement that the axis of the cylinder be aligned with the center of thrust of the spherically seated block cannot be met. Suitable jigs have been used to conveniently locate the specimen with respect to the bearing blocks, but it is necessary that the blocks themselves be well centered if they are to be the basis for measurements. Lower blocks may not always be in proper position. The upper bearing block assembly in some types of machines may sometimes be out of position with respect to center of the crosshead, generally because of improper positioning when the assembly was last replaced in the machine. In these cases, reposition the upper head prior to testing. The upper bearing block should be rotated as it is brought to bear on the specimen to obtain uniform seating. The objective of this rotation is to orient the face of the upper bearing block so that it is approximately parallel with the upper end of the specimen.

10.4 Test Method C 39/C 39M specifies that the load shall be applied at a rate of movement (platen to crosshead measurement) corresponding to a stress rate on the specimen of 28 to 42 psi/s. For a 6 in. diameter cylinder the increase in load in a 30 s interval should be 23 700 to 35 700 lbf. In computer controlled machines, two options for the rate of loading are available. For C 39/C 39M the machine must be run as displacement-rate controlled. This monitors the movement of the piston to establish a rate. For these machines, preliminary testing will be necessary to establish the required rate of movement to achieve the specified stress rate. The required rate of movement will depend on the size of the test specimen, the elastic modulus of the concrete, the stiffness of the testing machine, and capping system used.

10.5 During the first half of the anticipated load, any convenient loading rate is acceptable. The required rate of movement shall be maintained at least during the latter half of the anticipated loading phase. The specified rate of loading must be observed, but the rate cannot be increased in an attempt to maintain the rate when the specimen begins to fail. The actual observed maximum of breaking load should be recorded, as well as the computed compressive strength.

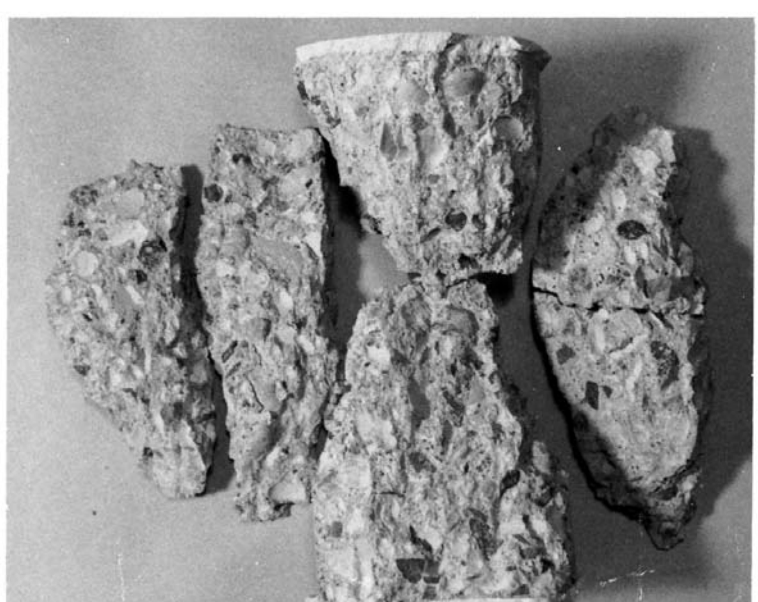
10.6 The cylinder must be tested to failure in order to determine the type of fracture. Failure means the specimen can no longer support an increasing load. Operators should not drop the load in order to prevent explosive failures or damage to compression machines unless the capacity of the machine is being approached. The type of fracture should be reported along with the compressive strength. If the compressive strength of a tested cylinder is less than anticipated the type of fracture may be of assistance in determining the cause. Fig. 2 shows a typical conical fracture of a concrete cylinder in compression. Conical fractures more commonly occur in lower strength concretes. Higher strength concretes more frequently have columnar fractures. For more information regarding the reasons for the formations of the conical fracturing refer to ASTM STP 169D. Fig. 3 shows a cylinder which does not have the typical conical fracture expected. This type of failure was noted in a large number of tested cylinders in a discarded cylinder pile at a laboratory and was brought to the attention of the supervisor. It was found that non-standard testing procedures caused this type of failure. Correction of the testing procedure resulted in conical fractures and a large increase in compressive strength.

10.7 The following are numerous comments on testing machines, their use, and maintenance. Some of the remarks are general, while others refer to only one type of machine.

10.7.1 Testing machines should be inspected and verified every twelve months and there should be someone assigned responsibility for maintenance. Although this verification is done by an outside service, some means of checking the accuracy on a more frequent basis should be used by the laboratory. This should be used to establish if more frequent verification is required.

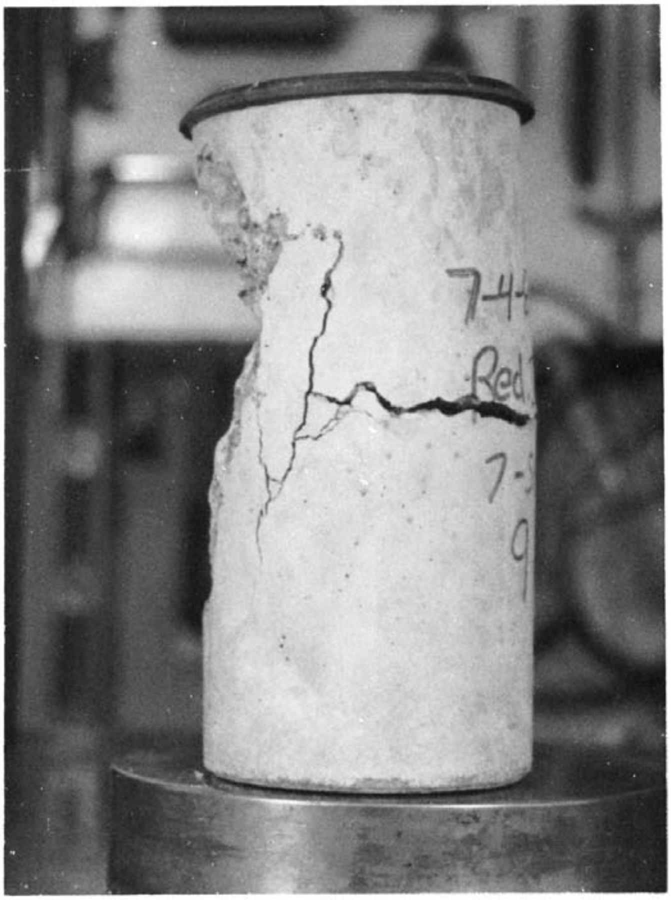
10.7.2 Testing machines should be kept clean with no accumulation of debris or dust between platens and crosshead screws and around the base of the loading ram. Use of protective shields on rams, exposed screws, and test specimens may prove helpful to reduce this accumulation. Machines should be lubricated according to an appropriate schedule if necessary. Smooth operation of loading and crosshead screws may be facilitated by applying a mixture of heavy lubricating oil and flake graphite, worked well into the threads by a brush and by running the crosshead up and down a few times.

10.7.3 Travel limit switches, safety cutouts on gages, and safety by-pass valves on loading lines should be checked occasionally. The main switches of the machine should be relocated if not within immediate reach of the operator.



NOTE 1—Cones are usually better defined. The upper cap on this cylinder is too thick.

FIG. 2 Typical Conical Fracture Expected in the Compressive-Strength Test



NOTE 1—Correction of testing procedures resulted in increase of compressive strength in similar concrete.

FIG. 3 Atypical Failure of a Concrete Cylinder Due to Incorrect Testing Procedures

10.7.4 Each operator should be adequately instructed in the operation of the machine. Instructions for the use and maintenance of the machine should be available to the operator; too often such papers have been found filed with the purchase papers.

10.7.5 The moving head of a machine should not be allowed to come in contact with the upper frame or the lower platen. If contact must be made, as in changing heavy bearing blocks or imposing a load for some adjusting purposes, an intervening wooden block should be in position between the metal faces. Under no circumstances should a testing machine be left unattended while running, even for a short time. Damage to the machine may result.

10.7.6 The surface of the platen or table of the machine should be carefully maintained. The use of a supplemental lower bearing block meeting the requirements of the standard would be helpful. In cases where a supplemental bottom bearing block is used and the platen is large, a piece of plywood has been used to protect the platen surface. The plywood is cut to the shape of the platen with a cut-out to accommodate the lower block. Concrete specimens should be set in place, not pushed across the platen, and the surface of the platen should not be used to grind or rub cylinders. If the machine is a universal type and is also used to test specimens in tension, the platen should be properly protected from damage during the tension operation. Under no circumstances should the testing machine be used as a press, as in forcing shafts out of assemblies. Such misuse has been known to necessitate expensive refinishing of the faces of the large spherical block assembly. To prevent unauthorized use of the testing machine for this purpose it may be advisable to keep a lock on the switch box.

10.7.7 Drainage is recommended for all machine pits to guard against flooding and consequent damage to motors, bearings, screws, pumps, weighing systems, and so forth. This is very important in the case of the larger machines. If dust is to be blown out of machines and motors, an electrically driven portable hand blower or a commercial size vacuum cleaner with rubber or plastic nozzle should be used in order to avoid the occasional moisture and scale from ordinary compressed air lines.

10.7.8 The hydraulic testing machines vary in design and operation. The instructions of the manufacturer should be followed strictly to avoid damage to the machine and to secure the best operation. The motor of the hydraulic pump should not be stopped before releasing the load on the weighing system. Control and release valves should be used properly so as to avoid shocks to the weighing system. Oil in the pump reservoir should be maintained at the proper level. If loads cannot be obtained or maintained satisfactorily, check the reservoir, pressure relief valves, and also the voltage on the line to the loading pump. The crosshead should not be jammed nor should the ram be used at its lowest point of travel.

10.7.8.1 The most common type of load indication for compression machines is the liquid crystal display (LCD) or light emitting diode (LED) read-out. Generally speaking, they employ a hydraulic ram to exert pressure on the test specimen. This hydraulic pressure is converted to an electrical signal by means of a transducer. Some machines have multiple ranges on the same read-out. Some difficulty with the single read-out may be encountered in the area of increment of load change where a smaller transducer stops and one with a larger capacity takes over.

10.7.8.2 Older machines use load indicating dial gages. The dial gauges should be tapped lightly when setting the hand at zero load. Maximum hands should be checked for satisfactory free movement. Be sure that dials, particularly the smallest of a number of ranges, are not being overloaded. If the machine is equipped with more than one dial, occasionally note the nature of the agreement of different dials at the same load. When possible, remove the load gradually, and have gauge control valves set so as to avoid excessive backlash in the dial mechanism when a specimen breaks.

10.7.8.3 Capsule clearances, if a feature of the machine, should be frequently checked to determine whether the correct amount of oil is in the weighing system. Capsule clearances are measured by inserting a feeler gauge into the multiple openings below the ram. The average of these readings should be compared to the clearance stamped on the capsule. When the average of capsule clearance varies from the assigned clearance by more than 0.003 in. adjustments to the capsule should be made. Add oil when capsule clearances are greater than the maximum allowed. When oil is added, precautions should be taken to avoid the introduction of air into the system.

10.7.8.4 The specified air pressure should be maintained for the null type weighing systems. Compressed air used in such systems should be filtered and dehydrated to remove oil, rust, dirt, and water. This filter should be checked periodically.

10.7.8.5 Use proper wrenches on oil valves on hydraulic weighing systems to avoid defacing or damaging the special valve assemblies. If trapped air in a hydraulic line is bled from the weighing system, tighten the plug in the Bourdon tube before releasing the load. If oil is being lost rapidly from the weighing system, check for loose joints on lines and loose packings on valves. Use the oil recommended by the manufacturer for replacement.

10.8 It is important that proper bearing blocks and any spacers used be kept in good condition. The faces of the upper and lower bearing blocks should be checked for planeness and hardness. The check on planeness can be made with a straightedge and 0.001 in. feeler stock. A block should be refinished when the planeness requirement is not met. Fig. 4 shows the planeness of upper and lower bearing blocks being checked with a 6 in. (152 mm) machinist's parallel and a feeler stock of the required thickness. Scribed concentric circles on the bearing face of the upper block are required when the diameter of the block exceeds the diameter of the specimen by ½ in. These rings on the upper spherically seated bearing blocks are necessary to facilitate proper centering. Lower bearing blocks are important in providing the necessary loading conditions, protecting the lower platen of the machine against wear and concentration of high loads, and facilitating the placing of the test specimens. Concentric rings for the lower block are optional. Whenever a spacer is used between the platen and bearing block, be sure that the spacer has parallel bearing surfaces.

10.8.1 The upper spherically seated block should comply with all the requirements Test Method C 39/C 39M. The center of the sphere must coincide with the center of the bearing face. Ease of movement is important in securing the proper seating of the block when subjecting the test specimen to load. To maintain this ease of movement, the spherical portion and the socket should be cleaned and oiled periodically. Do not use pressure type grease. The spherical portion and the socket should be held in close contact with each other.

10.8.2 Avoid heavy concentration of load, such as encountered with proving rings and load cells, without appropriate intervening special bearing blocks or plates. Avoid use of cast iron bearing blocks, particularly with concentrated loads, even though the block has a hardened center insert because of the potential for sudden fracturing.

10.8.3 Prior to verifying a compression machine, review the information found in Section 40.

10.9 Keep any centering pinholes clean; debris from test specimens sometimes becomes packed so tightly in these holes that it interferes with the proper seating of the lower block.

11. OBTAINING AND TESTING DRILLED CORES AND SAWED BEAMS OF CONCRETE

(See Test Method C 42)[2]

Test Method C 42 applies to securing test specimens from hardened concrete. When samples are taken from hardened concrete, the safety or adequacy of the structure is often under question. Under these conditions the locations from which samples are to be taken must be selected with care in order to obtain the desired information. The selection of sampling locations may be aided by applying non-destructive test

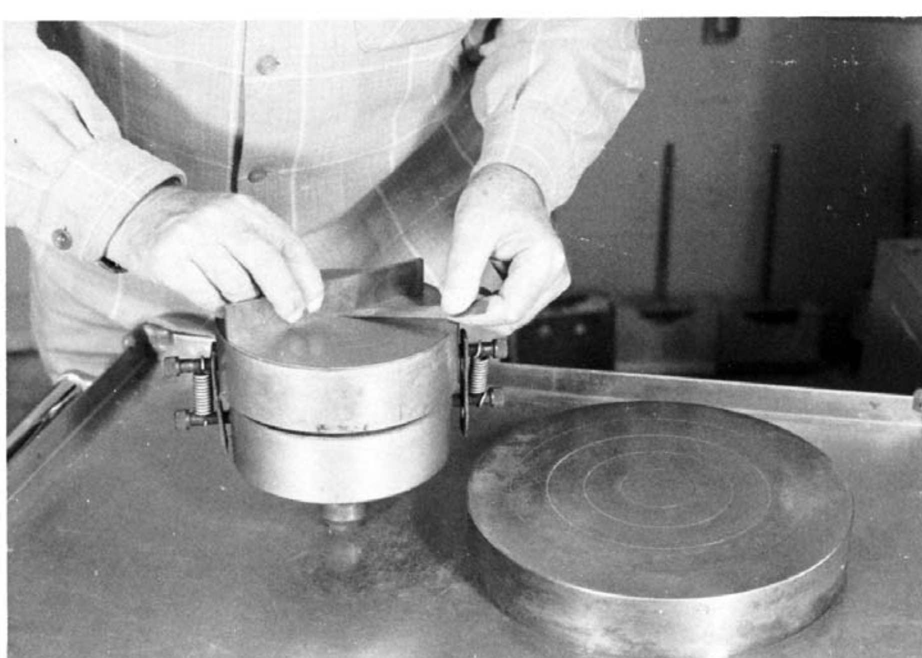


FIG. 4 Checking Planeness of Upper and Lower Bearing Blocks for a Testing Machine Using a Machinist's Parallel and a Feeler Gauge of the Required Thickness

methods such as Test Method C 803, Penetration Resistance of Hardened Concrete[2] or C 805, Rebound Number of Hardened Concrete[2] which, when used by qualified personnel, can be helpful in assessing the uniformity of concrete in situ, or to delineate zones or regions (areas) of poor quality or deteriorated concrete in structures. The selection of sampling locations must not be left to personnel who are unfamiliar with the structural requirements. Specifications for pavements usually specify the number and location of drilled cores. Test Method C 42 covers quite well the details of securing the samples, but the following comments should be considered.

11.1 Large strains in the core can occur during drilling if the vertical shaft wobbles. This condition is usually caused by worn or loose drill bearings, or by lack of rigidity of the frame of the core drill. Cores obtained under such conditions often will not meet the requirements for dimensions specified in the test method.

11.2 It is particularly important that the ends of the cores be properly prepared for testing. The ends of cores that are not drilled perpendicular to the surface of a slab should be sawed to produce square ends in order to avoid the use of thick wedge-shaped caps. The bottom end of cores should be prepared in strict accordance with the requirements of the test method, wherein are prescribed the tolerances in projections in end surfaces, variations in diameter, and departures from perpendicularity between the end surfaces and the axis of the core. Core ends that do not come within the tolerances should be finished by sawing or tooling until they conform.

11.3 Test Method C 42 requires that the temperature of the water in which the specimens are stored shall be 73.4 ± 3.0 °F (23 ± 1.7 °C).

12. SURFACE MOISTURE IN FINE AGGREGATE

(See Test Method C 70)[2]

In Test Method C 70 the weight and volume of a sample of damp sand are determined. With an accurate knowledge of the saturated surface dry specific gravity of the sand, the free moisture content can then be computed. If the saturated surface dry specific gravity of the sand does not change and the same weight of sample is always used, the rather involved formulas can be simplified, or graphs prepared for their simple, rapid solution.

12.1 The calcium carbide gas pressure method, although not an ASTM test method, is frequently used in the laboratory. In this method, a small sample of damp sand is placed in a closed container with calcium carbide. The free water reacts with the calcium carbide, producing acetylene gas and, therefore, a gas pressure. The pressure gauge is calibrated in percentage of free moisture in the sand. Because of the small quantity of sand used, sampling technique is particularly critical.

12.2 Electrical and nuclear moisture meters are widely used in the field, but they are not well adapted to laboratory work.

12.3 In concrete technology, the total moisture content is the sum of the amounts of water absorbed on the interior of the particles and the free water on the surface of the particles. Hot plate and oven drying methods dry samples to constant weight and therefore measure total moisture content. Displacement and calcium carbide gas pressure methods measure free or surface moisture. Electrical and nuclear methods do not measure moisture per se. Their indication will depend upon the method used to calibrate the meter.

12.3.1 The method used to compute moisture content is important and will determine the calculation procedures used to adjust batch weights.

13. FLEXURAL STRENGTH OF CONCRETE (USING SIMPLE BEAM WITH THIRD–POINT LOADING)

(See Test Method C 78)[2]

The curing of concrete beams from casting to testing is very important. Beams should never be allowed to lose moisture before testing. Beams should have free moisture on their surfaces up to the time the specimens are placed in the testing machine. Surface water can be removed with a damp rag prior to testing. For a more complete discussion of curing, see the section for *Making and Curing Concrete Test Specimens in the Field* (C 31).

13.1 The orientation of the beam in the testing machine varies depending on the type of specimen. Molded specimens must be tested on their side, while sawed specimens are loaded on the top and bottom.

13.2 Inspection of laboratory equipment has shown many bearing blocks for flexural testing are outside the 0.002 in. planeness tolerance. One cause of this wear is the abrasion between the block and the specimen occurring when the beam is placed on the blocks. Care should be taken not to slide the beam across the blocks when positioning it for testing. One method to prevent this problem is to use two individuals to handle the beam. When placing the beam on the blocks, a protective covering may be used over the lower blocks, provided that it is removed prior to testing. Another method of preventing wear is to always use leather shims between the beam and the bearing blocks. If the bearing blocks are independent of each other, it is critical that the proper spacing be maintained. Blocking or mechanical connections between the bearing blocks may be necessary to prevent lateral movement of the bearing blocks.

13.3 The test method requires that contact surfaces between the beam and the blocks be checked for planeness. Verify the planeness of the beam surface by placing the beam in the testing apparatus and bringing the load-applying block into contact with the surface of the specimen. Place a slight load on the beam and sight along each block looking for gaps between the specimen and block. If a gap of more than 1 in. in width is found, check the gap using feeler gages of 0.004 and 0.015 in. If the 0.004 in. feeler gauge can be placed in the gap for a length of 1 in. or more but not a 0.015 in. feeler gauge, shim the beam with leather shims. If the 0.015 in. feeler gauge can be placed in the gap for a length of 1 in. or more, the beam must be capped or ground. If capping or grinding is required, mark the location on the beam where it is contacted by the blocks, while it is still positioned in the testing machine. This will help to locate the area requiring surface preparation on the beam.

13.4 Both Test Methods C 78 and C 293 refer to grinding or to capping of bearing surfaces of the beam that vary from planeness by more than 0.015 in. (0.38 mm). Care should be taken when grinding beams to prevent moisture loss. Practice C 617 does not address capping of beams; however, one of the materials specified in the practice, sulfur mortar, has been found to work well for the application. Due to deterioration in water, the use of high strength gypsum plaster is not recommended.

13.5 The capping plate must be a plane and level surface, which exceeds the dimension of the beam. The plate should be sufficiently rigid to prevent distortion under the weight of the beam. Minimum thicknesses for various plate materials are listed under the *Capping Equipment* Section of Practice C 617.

13.6 The beam should be capped in the following manner: As a safety consideration and to facilitate the capping operation, use two individuals to handle the beam. Remove the surface moisture from the beam in the areas to be capped. Place the beam on the capping surface and transfer the bearing locations previously marked to the capping plate. Remove the beam and place a band of capping material on the plate at each bearing location. Sufficient material should be used to provide a finished beam surface of at least one inch wide across the entire width of the beam. Carefully lower the beam into position and press down to spread the capping material under the beam to an average thickness of not more than 1/4 in. Position the beam so that the thickness of the capping material appears to be level. If capping is required on both sides, repeat the process for the other side after the capping material on the first side has hardened. During the curing of the capping material, make sure that the beam is kept moist.

Care should be taken in positioning the bearing blocks. Position the bearing blocks in the testing machine so that the distance from the support block to the load applying block is equal to the depth of the beam within ± 3 %.

13.7 The requirement for the rate of loading is listed in the Procedure Section of the test method. A formula is also provided. Using the formula for a beam with a 6 x 6 cross section and a span length of 18 in., the rate of loading should be between 1500 and 2100 lb/min. It may be helpful to express this rate as 1800 ± 300 lb/min. Maintain this rate of loading from start to failure.

13.8 In determining cross sectional area, take the average of three measurements at each edge and the middle across the fractured faces for both the width and depth determinations. If the fracture occurs at a capped section, include the capped thickness in the measurement. Measurements should be recorded to the nearest .05-in. The calculation section requires that the tension surface be identified in making a judgment about acceptable tests. The tension surface is the surface where the blocks are spaced furthest apart. With a permanent marker, extend a line on the side of the beam from the bearing blocks on the load surface down to the tension surface. The formula used to calculate the modulus of rupture varies depending on the location of the fracture. Use this line to determine if the fracture occurs within the middle third of the span length or outside the middle third but within 5 % of the span length. If the fracture occurs outside the middle third of the tension surface span length by more than 5 % of the span length, discard the results of the test.

14. MATERIALS FINER THAN 75-μm (NO. 200) SIEVE IN MINERAL AGGREGATES BY WASHING *(See Test Method C 117)*[2]

When accurate determination of the total amount passing the 75-μm (No. 200) sieve is desired as stated in Method C 136, Sieve Analysis of Fine and Coarse Aggregate,[2] both washing and subsequent dry sieving on the 75-μm (No. 200) sieve may be required. It is essential to refer to the applicable aggregate specifications to determine if both washing and dry sieving are required to establish compliance with the required specifications.

14.1 The test method lists two procedures, one using plain wash water and the other using a wetting agent (household detergent) with the wash water. Unless otherwise specified, the plain wash water procedure should be used. A wetting agent will weaken the bond holding clay particles to larger aggregate particles, and is necessary to cut the oily film which occurs on aggregate particles which have been through a dryer for use in bituminous mixtures and for aggregates extracted from bituminous mixtures. As with all test procedures, the sampling procedure, sample size, and accuracy of weighing are important for proper results.

14.2 The minimum sample size (mass) required for this test method varies depending upon the nominal maximum size aggregate used. See the Sampling Section of the test method for the minimum mass requirements. After drying as required, record the mass of the sample at the start of the test.

14.3 The container used for this test must be of sufficient capacity and shape to (*1*) hold the aggregate sample, (*2*) hold the wash water, and (3) permit agitation of the sample and wash water without loss.

14.4 Once the sample and sufficient wash water have been added to cover the sample, agitate the sample until the finer particles are suspended in the wash water. Agitation is best accomplished by stirring with a spoon or by hand. A good indicator of sufficient agitation is when the water becomes cloudy. Be careful not to lose any of the sample or wash water during the agitation process. Rinse hands or stirring implement over the container to recapture any adhered particles.

14.5 With the fine aggregate particles suspended in the wash water, immediately pour (decant) the wash water over the nested 1.18 mm (No. 16) and 75-μm (No. 200) sieves. The 1.18 mm (No. 16) sieve is used above the finer meshed sieve to prevent damage in case any of the coarse aggregate is mistakenly poured onto the nested sieve. Only the particles suspended in the wash water should be poured from the container. Care should be taken not to pour any of the coarser aggregate particles onto the sieves.

14.6 Add a second charge of wash water to the sample container and repeat the agitation and decanting process. Continue the cycle of adding wash water, agitating and decanting until the wash water remains clear after agitation.

14.7 Using an external source of water, flush all aggregate retained on the sieves back into the container. Place the sample container including the water used to flush the sieves in the oven and dry to a constant mass. Record the dry sample mass. Do not dispose of the water used in flushing in any way except through evaporation in the oven as it may contain fine aggregate particles.

14.8 Calculate the amount of material passing by using the formula in the Calculation Section of the test method.

14.9 Common mistakes made in performing this test method are (*1*) pouring the entire sample including the coarse aggregate on the nested sieve and (*2*) disposing of the water used to flush the aggregate retained on the sieves in a manner other than through evaporation during the sample drying process.

15. SPECIFIC GRAVITY AND ABSORPTION OF COARSE AGGREGATE *(See Test Method C 127)*[2]

The test method is not considered applicable to highly porous lightweight aggregates because of difficulties involved in properly drying the very irregular, rough surfaces of these particles. Surface drying of normal weight aggregates having rough, vesicular surfaces is also difficult and must be carefully done if consistent results are to be obtained.

15.1 The balance should be suited to weighing the amount of material required. The container for holding the immersed sample should be immersed to a depth sufficient to cover the container at all times. The wire bails supporting the container should be of the smallest practical size to minimize the effects of a variable immersed length of wire bail. Entrapped air should be freed from the sample prior to determining the weight of the immersed sample by shaking the container while immersed.

15.2 Because of the difficulty of surface drying small aggregate particles within the coarse aggregate test sample, the material smaller than the 4.75-mm (No. 4) sieve is generally discarded. Test Method C 127 provides for separating material at the 2.36-mm (No. 8) sieve for very fine coarse aggregate.

15.3 When the results of the test are to be used for proportioning concrete mixtures with aggregates used in a moist condition, drying to a constant weight at the start of the test may be eliminated. The oven-dry weight is not needed if bulk specific gravity (SSD) will provide sufficient information. The oven-dry weight will be needed to determine the absorption of aggregate. Using aggregate without drying prior to soaking may be preferable when testing certain aggregates of relatively high absorption, since preliminary oven drying prior to test may remove moisture that cannot be regained in 24 h of soaking.

16. SPECIFIC GRAVITY AND ABSORPTION OF FINE AGGREGATE *(See Test Method C 128)*[2]

In performing the determinations described in this test method, probably the most important step is that of bringing the sample to the saturated surface dry condition. The drying procedure specified does not involve the use of heat other than a gentle current of warm air, since the application of heat may remove moisture from within the particle. The intent is to remove water from between the particles and from the surfaces of the particles. Care must be exercised to prevent the loss of fines when free water is drained from the sample in the initial drying procedure. In addition, the sample should be stirred or raked rather frequently during the drying to avoid undue drying of particles at the edge of the pile. The cone procedure employed in this test method accurately defines the saturated-surface-dry condition for the vast majority of sands; however, for a few angular sands and sands containing small quantities of certain highly plastic clays, the sample will not slump until after the average surface-dry condition has been passed. In these instances the technician may have to exercise some judgment in determining the end point by observing the typical color change that takes place as the sample reaches the saturated-surface-dry condition. Another procedure involves placing a pat of sand on a dull or dark surface for 1 min; if the surface appears damp after removal of the sand it is not yet SSD and additional drying is required.

16.1 Additional precautions should be taken to ensure that the material used for the mold is sufficiently rigid to prevent deformation with continued use. A minimum thickness of 0.032 in. (0.8 mm) is required.

16.2 When filling the volumetric flask, the operator must be sure that all air bubbles which may be trapped between the sand grains are eliminated by inverting and agitating the flask. Air remaining with the sample will result in erroneous specific gravity values. The final temperature of the flask, water and sand is important and must not change.

16.3 During removal of the aggregate from the pycnometer, care should be exercised to avoid the loss of fine material, since after drying, this weight will be compared to the original weight to determine the absorption.

17. SIEVE ANALYSIS OF FINE AND COARSE AGGREGATES *(See Test Method C 136)*[2]

This test method determines the particle size distribution of fine and coarse aggregate by sieving. This determination is accomplished by using a stack of sieves of decreasing mesh size from top to bottom. A sample of known mass is placed on the top sieve and then agitated either by hand or mechanical means. The mass retained on each sieve is recorded and calculations based on these masses and the original sample mass are performed.

17.1 The test method specifies that the size of the field sample used to obtain material for this test should be as required in Table 1 of Practice D 75, Sampling Aggregates, or four times as large as the test sample to be used, whichever is greater. This sample is reduced to testing size by using one of the procedures described in Practice C 702, Reducing Field Samples of Aggregate to Testing Size. The importance of proper material handling techniques during sampling and reduction cannot be overemphasized. For more information on proper material handling techniques, please read the section on Reducing Samples of Aggregate to Testing Size in this manual. The sample should be dried to constant mass using a ventilated oven. When close temperature control is not required, samples may be dried by microwave oven, hotplate, or electric heat lamp. Caution should be used to avoid degradation of the aggregate. For control purposes, samples of coarse aggregate may be sieved in a damp condition.

17.2 The minimum size of the test sample listed in the Sampling Section in C 136, should be carefully observed. A sample that is smaller than specified may be non-representative. Since it will affect test results, weighing out an exact predetermined mass is not permitted.

17.3 The required test sample size for lightweight aggregates differs from the normal weight aggregate test sample size listed in Test Method C 136. The sample size requirements for Lightweight aggregates are shown in Specifications C 330, for Lightweight Aggregates for Structural Concrete;[2] C 331, for Lightweight Aggregates for Concrete Masonry Units;[2] and C 332, for Lightweight Aggregates for Insulating Concrete.[2] The coarse aggregate sieve sample shall be 2830 cm^3 (0.1 ft^3) or more of the material used for determination of bulk density. To minimize degradation, do not mechanically sieve lightweight aggregates for more than 5 min. Hand sieving may be preferable for these materials.

17.4 Only sieves conforming to Specification E 11, Wire-Cloth Sieves for Testing Purposes,[2] are to be used with this test procedure. Specification E 11 contains sieve sizes, dimensions of openings and wires, and tolerances in those dimensions for the sieves. In recent years the standard sizing of sieve openings as listed in E 11 has transitioned from inch and number sizes to millimetres. Some confusion in the laboratory may result from mixing old and newly purchased sieves. Table 1 in E 11 lists the standard in millimetres and the alternative in inch and number sizes. A common problem in laboratories is the loss of the label that indicates the sieve size and the subsequent incorrect identification with a permanent marker on the side of the frame. Any sieve without proper labeling does not meet the requirements of E 11 and should be removed from service.

17.5 Wires for sieve cloth are readily available that do not conform to E 11. Since the weave prevents the wires from lying in precisely the same plane, the wire diameter used affects the size of the separated particles. For this reason the use of larger than standard wires in order to increase screen life will produce nonstandard test results. In addition, larger than standard wire diameters will reduce the percentage of open screen area and may increase required sieving time.

17.6 Sieves are expensive and easily damaged. Careful maintenance of sieves will make them last longer and preserve their efficiency. The fine aggregate sieves should be brushed clean to reduce blocking of the mesh openings to a practical minimum. It is unnecessary to remove all particles lodged in the sieve after each use. For sieves 300-µm (No. 50) and coarser, use a stiff bristle brush (soft brass bristles and stencil brushes are satisfactory) on the underside of the sieve, but avoiding a harsh raking action. For sieves 150-µm (No. 100) and finer, use a soft bristle brush to the underside after each test, taking care not to damage the wire cloth by too much pressure or by scraping.

17.7 Sieves, particularly those with smaller mesh, should be examined periodically for holes and breaks around the edges. Any sieves with permanently mounted sieve cloth with holes or other defects in the sieve cloth must be replaced. Sieves suspected of wear and damage can be checked by a split sample comparison with good sieves. Observation of the particles on each sieve for uniformity of size can help detect defective sieves. Do not expose fine mesh sieves to temperatures greater than the melting point of solder, approximately 375 °F (191 °C).

17.8 Jolting sieve cloths by impact to dislodge aggregate particles caught in the openings can result in damage to the wire mesh or the frame. Avoid striking sieves on another object, such as the edge of metal trashcans, to protect them from cuts and indentations. Damaged frames make it unlikely that the sieves will nest properly. Sometimes the only way to clear sieve cloth and avoid damage to delicate wire cloth is by striking the top frame of the sieve against a firm pad. If this becomes necessary, to prevent the damage discussed above make sure that the entire surface of the top of the frame is contacting the pad at the same time.

17.9 Mechanical sieving devices are practical means for processing large amounts of material rapidly. Two areas of concern when using these devices are the adequacy of sieving time and the overloading of an individual sieve.

17.10 The standard requires that mechanical sieving devices be compared to the hand sieving operation to ensure that the material has been adequately sieved. Section 8.4 of C 136 describes the procedure for determining this sufficiency of sieving. The sieving time for the mechanical sieving device is adjusted until not more than 1 % of the material retained on any given sieve used in the device will pass that sieve during the subsequent hand sieving of each individual sieve. The need for the procedure to determine the sufficiency of sieving by mechanical devices or hand sieving is particularly important in the case of very fine or angular materials, or when an 8-in. (203-mm) diameter sieve retains more than about 150 g of material. A cautionary note in the test method that sieving beyond ten minutes may result in the degradation of the sample should also be a consideration. Since the sieving time for the device will vary depending upon the aggregates used, the sufficiency of sieving should be checked for all aggregate sources frequently tested by the laboratory. A chart located near the device with the various sieving times for the different aggregates will greatly assist the technician in the correct operation of the mechanical sieving device. The material on each sieve should be observed to see that it consists of discrete or separate particles and not agglomerations of particles. Agglomerations may occur with dirty aggregate.

17.11 For fine aggregate, the maximum amount retained on any sieve is limited to 0.62 g/cm^2 (0.009 $lb/in.^2$) of sieving surface (200 g for the 8 in. (203-mm) diameter sieve). This requirement is intended to prevent overloading any individual sieve, and in many cases will determine the maximum amount of material to be sieved at one time. When the sample size required for the aggregate exceeds the allowable amount of material to be sieved at one time, then additional intermediate size sieves can be inserted between the critical sieve and the next larger sieve. Alternately, the sample can be reduced to several smaller sub-samples and the results from these sub-sample portions can then be combined for weighing after sieving.

17.12 The test method requires that the test sample mass be recorded before the test and that this mass be compared to the sum of the individual fractions after the test has been completed. The summed mass must agree with the starting mass to within 0.3 % or the results cannot be used for acceptance testing.

17.13 The Fineness Modulus (FM) of an aggregate is related to its gradation. The computation of the FM is described in the Calculations section of Test Method C 136. The FM is a unitless number used for aggregate evaluation, aggregate quality control, and concrete mix design. The FM is obtained by adding the total percentages retained on each of a specified series of sieves, and dividing the sum by 100. The percentage retained on a given sieve is cumulative in the sense that any material retained on a sieve with a larger opening would also be retained on that given sieve and, therefore, regarded as retained material. The sieve sizes used for the FM calculation are listed in the Calculations section of Test Method C 136. Use values for all sieves in this series, but no other sieves. Intermediate sieves such as the 12.5 mm (½ in.) or 25.0 mm (1 in.), which are not in the fineness modulus series, will frequently be employed when the aggregate has a narrow range of sizes or to determine compliance with some specifications, but are not used in calculating the FM. In general, a small value for FM indicates a fine material, while a large value indicates a coarse material. However, the same FM may be obtained from a number of different gradations. FM of concrete sands will range from about 2.30 for fine sands to 3.10 for coarse sands.

18. UNIT WEIGHT, YIELD, AND AIR CONTENT (GRAVIMETRIC) OF CONCRETE *(See Test Method C 138)*[2]

Data obtained in the determination of the weight per cubic foot of the freshly mixed concrete by ASTM Test Method C 138 is used to compute the yield or volume of a batch of concrete, cement content, and air content (gravimetric). Test Method C 138 gives detailed instructions for calculating these parameters from the batch weights of materials used and from results of the unit weight test. Since the air content is computed from the difference between the theoretical and actual unit weights of the concrete, small errors in the unit weight test or in the theoretical unit weight caused by errors in the specific gravity of the materials can result in relatively large errors in the air content as computed in this test method.

18.1 The test method provides for a range of container sizes from 0.2 to 3.5 ft^3 (6 to 99 dm^3) for concrete having a range of maximum nominal aggregate sizes of 1 in. (25 mm) to 6 in. (152 mm). The larger size containers when filled with concrete are too large to be lifted by hand. Mechanical means, such as hoists and trolleys are necessary to move them onto scales and to empty them. It is, however, advisable to use the largest convenient measure to improve accuracy of test.

18.2 When calibrating the measure with water and a glass plate, it is necessary that the open upper end of the measure be plane. By inverting the measure on a glass plate that has been coated with a light coat of machinist's blue, it is easy to detect any high spots that require work to provide the planeness required.

18.3 In the final filling of the measure, if it is necessary to add or remove concrete, it should be done by adding or removing concrete, not mortar, so that the concrete proportions remain the same. The optimum amount of concrete is such that after the rodding and tapping operation no concrete will have to be added or removed. This ideal situation is rarely achieved so the usual practice is to have a very slight excess to be removed by a strike off-plate. A flat plate of glass, acrylic or metal is required for striking off and finishing the surface of the concrete. The plates should be at least ¼ in. (6 mm) thick for steel and ½ in. (12 mm) for acrylic or glass. The edges of the glass plates should be ground. Erroneously, a tamping rod, trowel, wood float or straightedge is sometimes used instead of the specified plate to strike off the concrete. The tendency when using these instead of the plate is to leave the concrete high resulting in a higher indicated unit weight which affects the computations which depend upon the unit weight.

19. SLUMP OF HYDRAULIC CEMENT CONCRETE *(See Test Method C 143)*[2]

Test Method C 143 describes the slump mold (commonly referred to as a slump cone) as made of metal not attacked by the cement paste. It does permit alternative materials as long as the material is not absorbent, rigid enough to maintain dimensions, and can be demonstrated in comparative testing to give similar results as the metal mold. For a complete explanation of the comparative testing see the Apparatus Section of the test method.

19.1 When a metal mold is used, the most common design is a mold formed by the spinning process with spot-welded handles and foot pieces. When a riveted mold is used, the interior surface of the mold should be smooth and show no evidence of the seam. The interior surface of any mold should be smooth and free of dents, hardened concrete, cement paste, and hardened mortar. When using molds made from an alternative material, make sure that the interior surface is not abraded due to repeated use. The bottom edge of the mold should have even contact when placed on a flat surface. Slump molds may become out-of-round for various reasons during shipment, transportation, or use and thus may be outside allowable specification tolerances. For this reason, slump molds should be checked for dimensional requirements prior to being placed into service and routinely thereafter or whenever abuse is suspected. Practice C 1077 requires annual verification of each slump mold. However, more frequent checks should be made if it is found that some molds do not meet the dimensional requirement during this verification.

19.2 This test method may not be applicable for concrete with a slump less than ½ in. (15 mm) or for concrete with slump higher than 9 in. (230 mm). Due to the natural angle of repose of the coarse aggregate in a sample of "over-wet concrete", this test method may not be applicable for slumps higher than about 7 ½ in. (190 mm).

19.3 The use of a flat, nonabsorbent, rigid base under the mold is mentioned, but no specific materials or dimensions are stated. A metal plate is preferable, but a sheet metal or a nonabsorbent coating on a wooden base can be used satisfactorily. An untreated wooden base is not satisfactory because of its absorptive qualities. One person operation is facilitated if clamping devices on the base are used to hold the foot pieces firmly to the base plate. The devices must be capable of releasing without moving the mold. A concrete floor may be used as a base provided it has a steel trowel finish. The base should be sufficiently flat to prevent the loss of water or paste from the concrete in the mold. When the test is made in the field, a small level will aid in leveling the base, which should be free from movement and vibration during a test.

19.4 Prior to testing, dampen both the interior of the mold and base; remove any standing water from the base. Fill the mold in three layers, each layer approximately one third the volume (not the height) of the mold. Some like to paint two stripes around the outside of the mold, one 2 ⅝ in. (67 mm) from the bottom, the second 6 ⅛ in. (155 mm) from the bottom as an aid in determining the approximate depths for the equal volume points. When rodding the middle and top layers of concrete, the rod should penetrate only slightly into the layer below. Excessive penetration of the rod into the lower layers must be avoided. Heaping of the final layer of concrete above the mold rim before rodding is important. Sufficient concrete should be placed in the mold so that the surface of the concrete before striking off will be only slightly above the top of the mold. If the mold is obviously under-filled, pause after rodding 10 or 15 strokes to add an additional representative sample of concrete. Screed the top of the concrete with a tamping rod and remove any concrete that has collected around the outside of the base of the mold. The mold must then be lifted promptly in a vertical direction at a rate of 12 in. (300 mm) in 5 ± 2 s. The mold should be removed carefully and uniformly only in a vertical direction without twisting.

19.5 Slump measurements should be made promptly to the nearest ¼ in. (5 mm). The standard says to measure the distance "between the top of the mold and the displaced original center of the top surface of the specimen". When the mold is removed, the specimen retains the shape (if somewhat distorted) of the conical mold. The "displaced original center" is the center of the surface struck off with the tamping rod. If the top of the specimen tilts to one side, the measurement should be made in what was originally the center of top of the specimen. If the specimen falls away or shears off on one side, the test must be disregarded and a new test made.

19.6 The entire process from molding to measurement must be completed within 2 ½ minutes. Since concrete may lose slump rapidly with time, the slump test should be started within 5 min of obtaining the sample as specified in Practice C 172, when the test is performed in the field. When the test is performed in the laboratory, the test should be started immediately after mixing as specified in Practice C 192.

20. LENGTH CHANGE OF HARDENED HYDRAULIC-CEMENT MORTAR AND CONCRETE *(See Test Method C 157)*[2]

Length change as determined by this test method is the increase or decrease in a linear dimension of the test specimen. The test method covers numerous details of the required apparatus and procedure. Attention is directed to the required control of temperature, relative humidity, and rate of evaporation.

20.1 The molds required are those specified in Practice C 490, Apparatus for Use in Measurement of Length Change of Hardened Cement Paste, Mortar, and Concrete.[2] That practice requires a thin coating of mineral oil on the interior surfaces of the mold. Do not use lard, animal, or vegetable oils since these may soften the surfaces of specimens. Molds should be pre-oiled before the gauge studs are mounted, to prevent the deposit of oil on the gauge stud through contact with oily fingers, oily rag, or lubricating brush.

20.2 Micrometer dials generally used on a comparator as described in Practice C 490 frequently have a contact end (anvil) that screws into the stem of the dial. This insert should not be permitted to become loose. The proper use of a micrometer comparator requires that a check reading be made on a standard reference bar before and after making readings on specimens, more frequently if a large number of measurements are to be taken at a given time. The reference bar is described in Practice C 490. The length of the reference bar should be known, so that a replacement bar of the same length can be obtained should it be damaged or lost. The procurement of a second reference bar, tied in by comparative measurements with the currently used bar might be considered. The hardened, polished ends of the reference bar should be kept clean, but caution is urged not to decrease the overall length by improper cleaning methods. For example, the measurements of an important long-term study were seriously affected by the operator's practice of rubbing the reference bar ends on a piece of cloth or canvas that probably contained cement dust. These frequent rubbings over a long period of time were found to have caused significant wear of the reference bar. When reading the dial micrometer, a gentle tapping with a pencil on the dial case is recommended. The dial stem should be clean and should move freely, but should not be lubricated.

20.2.1 Practice C 490 describes in detail the apparatus for use in Test Method C 157, and all precautions and recommendations therein should be observed.

21. SAMPLING FRESHLY MIXED CONCRETE *(See Practice C 172)*[2]

When samples are taken in the field, they should come from predetermined batches in accordance with the sampling plan. The practice of testing only batches of low or high slump will fail to accurately describe concrete quality and uniformity. Practice C 172 is applicable to obtaining samples of fresh concrete from stationary, paving, and truck mixers and from agitating and nonagitating equipment used to transport centrally mixed concrete. Sampling should normally be performed as the concrete is discharged from this equipment at the project site to the conveying vehicle used to transport the concrete to the forms; however, specifications may require other points of sampling such as at the discharge of a concrete pump. Samples from concrete that has been compacted or manipulated after its discharge from a mixer or agitator or conveyance are not suitable for making acceptance tests for consistency, air content, or potential strength.

21.1 Time limitations are imposed on taking different portions of the composite samples, on preparing the composite samples for slump and air content tests, and for molding specimens for strength tests. The time limitations should be carefully observed to ensure that results of tests are consistently representative of the concrete. Elapsed time between compositing samples and performing tests or molding test specimens should be the minimum possible. Compositing of samples and remixing should be performed at the place where tests are to be made or where specimens are to be molded. Tests and molding of specimens should be performed as close to the point of sampling as possible.

21.2 The practice of sampling concrete from the discharge stream from a mixer or truck, or from a pile, by means of a scoop or shovel, and then filling a test container (slump cone, airmeter bowl, cylinder, or beam mold) with several such samples without the required remixing should not be permitted. The filling of a 6 by 12 in. (150 by 300 mm) cylinder mold by placing it in the stream of discharging concrete is prohibited.

21.3 Practice C 172 provides for wet-sieving concrete where the concrete contains aggregate larger than can be accommodated by the test equipment or larger than is suitable for the size of the test specimens to be made. For example, Test Method C 143 for the slump of concrete states that the test is applicable for concretes having aggregates up to 1½ in. (37.5 mm) in size. If the concrete contains aggregate larger than this size, for example, 3 in. (75 mm) maximum size, the aggregate larger than 1½ in. (37.5 mm) is removed by wet sieving, and the slump test is made on the minus 1½ in. (37.5 mm) fraction of the concrete.

21.3.1 Various other tests require that the concrete be wet-sieved if the maximum aggregate size is larger than is suitable for the size of the test equipment to be used or the test specimen to be made. Most test procedures require that the minimum dimension of the specimen or the mold shall be at least three times the maximum size aggregate used in the test or the specimen. The specific requirements are given in the various applicable test procedures.

21.3.2 When there is a need to wet sieve concrete, this must be anticipated ahead of time, and wet-sieving equipment that will satisfactorily accomplish the wet-sieving operation as rapidly as possible with a minimum of effort shall be provided. Attempting to use an 8 in. (200 mm) diameter sieve by hand method is not satisfactory.

21.3.3 Wet sieving concrete is best accomplished with equipment that shakes or moves back and forth rather than using high frequency vibration. Fig. 5 shows hand-operated wet-sieving equipment suitable for occasional or lighter-type wet-sieving work. This consists of an 18 by 26 in. (457 by 660 mm) Gilson sieve tray supported by a homemade wooden frame. The sieve tray is moved forward and backward by hand as rapidly as possible. The concrete which passes through the sieve falls on a clean, moist, non-absorbent surface or pan, is remixed for testing.

21.3.4 Fig. 6 shows wet-sieving equipment powered by an electric motor suitable for larger jobs and for mass concrete. The interchangeable sieve mounted on the movable frame which is tilted slightly is moved forward and backward by the driving mechanism. Concrete to be wet-sieved is shoveled onto the sieve. Concrete that passes the sieve falls into the pan underneath and is used for further testing after it is recombined with a shovel. Aggregate that does not pass the sieve rolls to the lower end of the sieve and into a pan or wheelbarrow to be discarded. Wet-sieving of concrete should be done rapidly, and the concrete should be protected from the sun and the wind. The sieves should not be overloaded.

21.4 When wet-sieved concrete is used for the air content test, the air content measured is the wet-sieved fraction, not the total concrete. The aggregate larger than the designated size, which is removed and coated with a small amount of mortar, is assumed to contain no (or little) air. Concrete specifications may specify air content for the full mix or for a fraction of the

FIG. 5 Equipment for Wet Sieving Concrete by Hand

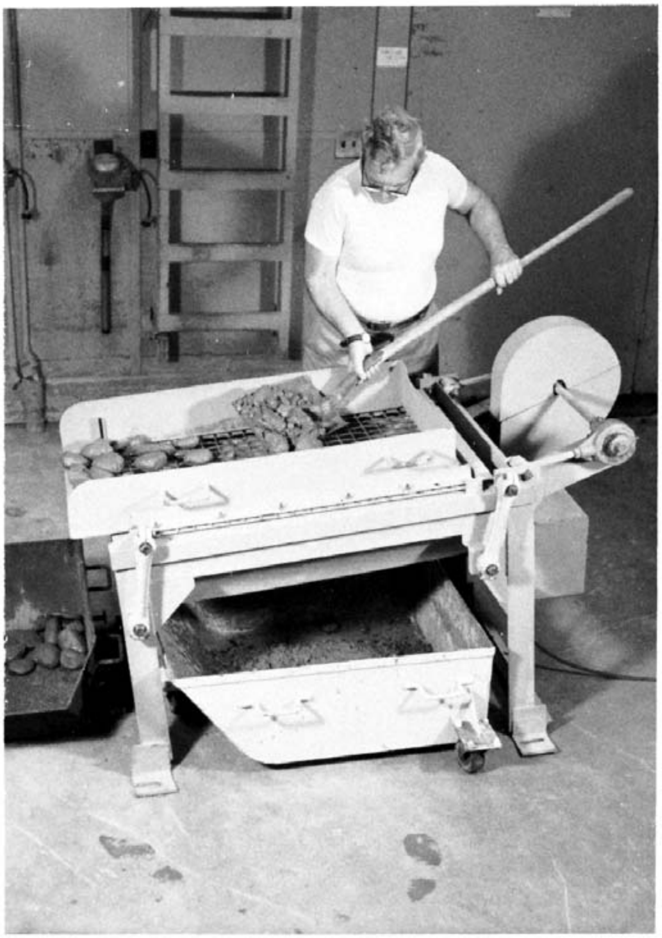


FIG. 6 Mechanical Equipment for Wet Sieving Concrete

concrete wet-sieved to a designated size. If the test is made on the sample wet-sieved to a given size, the air content of the full mix may be calculated if the concrete-mix proportions are known or determined. The air content of the full mix is obtained by multiplying the air content of the wet-sieved fraction by the ratio of the volume of the full mix. (This may be calculated from the known or determined mix for 1 yd^3 or 1 m^3 of concrete.) For example, 3 in. nominal maximum size aggregate concrete is being produced. The air content of −1½ in. wet-sieved fraction of the concrete as determined with an airmeter is 4.9 %. From the mix calculations for 1 yd^3(27.0 ft^3) of this concrete, the +1½ in. fraction has an absolute or solid volume of 4.62 ft^3. The volume of the −1½ in. fraction of the concrete is then 27.0 − 4.62 = 22.38 ft^3. The air content of the full mix is 4.9 × 22.38/27.00 = 4.1 %.

21.4.1 Unit weight tests to be used for concrete-mix computations are best made on the full mix, although unit weight tests of a wet-sieved fraction of concrete can be corrected to the full mix when the mix details are known.

21.5 The test sample of concrete should have a volume of at least 25 % greater than that needed to make all required specimens. The sample size requirement also applies to the amount of material left after wet sieving when large aggregate has been removed.

22. AIR CONTENT OF FRESHLY MIXED CONCRETE BY THE VOLUMETRIC METHOD

(See Test Method C 173)[2]

This test method is applicable to concretes containing any type of aggregate. It is the only procedure considered satisfactory for determining air contents of concretes made with lightweight aggregates, air-cooled slag, and highly porous or vesicular natural aggregates. The bowl of the apparatus is permitted to have a minimum capacity of 0.075 ft^3 (0.002 m^3). Typically this is the size of bowl used. With samples of material this small, it is very important that a representative sample of the concrete is tested. Concrete containing aggregate retained on the 1½ in. (37.5 mm) sieve shall be wet sieved before testing.

22.1 The current test method is designed to better define the end point of the test. To accomplish this task, a large amount of isopropyl alcohol (rubbing alcohol) is used and time limits have been inserted into the test method. The test method may appear complicated; but the appendix of the test method offers a flow chart to help guide the user through the process.

22.2 Fill the bowl in two layers and properly rod each layer. After rodding each layer, tap the side of the bowl with a rubber mallet. After the concrete has been struck off and the upper and lower portion of the apparatus secured, insert the funnel through the opening in the graduated neck and add at least one pint (0.5 L) of water. Then add a pre-selected amount of alcohol to the meter. Water is then added to zero the meter. The alcohol is added to prevent foam on top of the liquid and to obtain a stable reading. The amount of alcohol is determined by various factors in the mix. The note immediately after the section Adding Water and Alcohol in the test method offers some guidance as to the amount of alcohol needed and the factors affecting the addition. To avoid delays when field-testing unfamiliar mixes, it may be appropriate to run trial tests prior to field tests. Be sure to record the amount of alcohol used. When using more than 2.5 pints, air content readings tend to be higher than the actual air content; a correction, which is subtracted from the final reading, is used to compensate for this difference.

22.3 To release air entrained in the concrete it is important that all concrete in the bowl be dislodged during the inverting operation. Tip the device upside down and agitate it vigorously to get the concrete out of the bowl. To prevent the aggregate from becoming lodged in the neck of the meter, do not invert the measure for more than 5 s. Continue to invert and agitate the measure at these short intervals for a minimum of 45 s and until all the concrete is freed from the bowl. Aggregate should be heard rolling around in the meter when the concrete is freed from the bowl. It is important to continue to invert and agitate until the aggregate is heard moving in the meter.

22.4 After the measure is inverted and the concrete is freed from the bowl, return the meter to an upright position and roll the meter. Follow the procedure in the Rolling section to accomplish this procedure. Do not invert the meter after the rolling procedure has begun. Continue the rolling procedure for 1 min. The aggregate must be heard sliding in the meter during the rolling procedure.

22.5 The remaining steps in the procedure include a series of readings to determine the air content. When reading the level of liquid in the neck of the meter, the test method requires the reader to "read the bottom of the meniscus." The surface of the liquid in the graduated neck tends to take the form of a curve. The bottom of the meniscus is the bottom of this curve.

22.6 A stable initial reading is obtained when the level of liquid in the meter does not change by more than 0.25 % within a two-minute period. To accomplish this, read the meter when the liquid level appears to be stabilized; read the meter again after two minutes and compare the two readings. If a stable reading cannot be obtained within 6 min or if the foam in the neck is more than two percent, discard the sample and start a new test using more alcohol (see 22.2).

22.7 Once an initial stable reading has been established and recorded, the rolling procedure is repeated and a second stable reading is obtained. If the two readings are within 0.25 %, the last reading becomes the final meter reading. The final reading minus any correction for the amount of alcohol used becomes the reported air content. Corrections to the air content are based on the amount of alcohol used; see the table in the calibration section for these corrections.

22.8 If initial and repeat stable readings are not within 0.25 %, then the repeat reading becomes the initial and a third rolling and reading procedure is run. If the third stable reading does not agree with the previous reading within 0.25 %, discard the sample and start a new test using more alcohol (see 22.2).

22.9 When the apparatus is disassembled, the contents of the bowl should be examined to insure that no concrete is stuck in the bowl. Do not confuse packed sand and gravel in the bowl with undisturbed concrete. Remove and examine the contents of the bowl to make an accurate evaluation of the make up of the materials. If concrete is stuck in the bowl discard the sample and run the test method again.

23. MAKING AND CURING CONCRETE TEST SPECIMENS IN THE LABORATORY *(See Practice C 192)*[2]

Record Keeping—All pertinent information concerning the materials used in preparing laboratory concrete should be recorded. Experience has shown that such data may be valuable long after when details cannot be readily supplied from memory. Record the actual weight of all materials used as well as the proportion of the mixture. The description of the cement should include type, manufacturer, source of shipment, type of container, and any applicable laboratory sample numbers. If a cement other than portland cement or other cementitious materials is used, the specific gravity should be determined and recorded. If bagged cement is being used, the weight per bag should be recorded. The description of any admixture used in the concrete should indicate the nature of the material, manufacturer's name, brand, and lot number. If solutions of admixtures are prepared in the laboratory, records should show the actual quantities of admixture and water used. The quantity of any liquid used in the mix should be recorded. The quantity of mixing water should be recorded in terms of the units actually used in the measurement, even though different units may be used in the final report. A description of the type and capacity of the mixer should also be included along with the total mixing time. Note any deviation from the standard.

23.1 *Batch Size*—The batch should be of sufficient volume to leave about 10 % extra material after the test of plastic concrete and specimen fabrication has been completed. The size of the batch must be within the working capacity of the mixer. A batch of less than one tenth of the mixer's rated capacity will not be mixed in the same manner as a standard size batch, and the percentage of mortar retained in the mixer will be excessive. Exceeding the recommended batch size may result in the sample not being thoroughly mixed, spillage, and damage to the driving unit. Concrete used to fill the slump cone and unit weight measure may be returned to the batch, re-mixed by hand and reused. Concrete used in filling either the pressure or volumetric air meter must be discarded after testing. The following is a list of equipment typically used and the volume of material needed to fill each vessel:

Test Equipment	Volume of Material Required, ft^3
Slump cone (C 143)	0.2
Cylinder mold (C 192) 6 × 12 in.	0.2
Unit weight measure (C 138) ½ ft^{3}[A]	0.5
Air content - pressure (C 231) Type B	0.25
Air content - volumetric (C 173)	0.075
Flexural beams (C 192) 6 by 6 by 20 in.	0.5

[A] Capacity of the measure may vary due to aggregate size.

A batch of concrete using non-entrained, Portland Type I cement with normal weight aggregates weighs approximately 150 lb/ft^3.

23.2 *Temperature of Materials*—Practice C 192 requires that materials be at a uniform temperature, in the range from 68 to 86 °F (20 to 30 °C). It is preferable to have the materials at this temperature for 24 h prior to testing. Comparative concrete mixtures should have about the same "as-mixed" temperatures.

23.3 *Material (Cement)*—Trial batches are usually made with bagged cement. If available, it is better to obtain a representative sample from the bulk cement supply. The dry cement should be uniformly blended. The cement stock should be stored in tightly closed, moisture-proof containers, preferable metal, throughout the tests. A steel drum with an easily opened lock rim with a gasket is one of the preferred types and is easily emptied and cleaned. Practice C 192 states that all cement material shall be passed through a No. 20 sieve prior to testing. Special attention should be given to this detail when bricking or lumping are observed in the cement sample.

23.4 *Material (Aggregate)*—It is important that a representative sample of both the coarse and fine aggregate be used. Because aggregate may segregate during shipping, re-mix the pile continuously during sampling. A description of the aggregate should include absorption and moisture content. The section on Preparation of Materials in Practice C 192 contains several procedures for determining the weight of the aggregate and the weight of the water contained in the aggregate. No matter which procedure is used it is important to add the amount of free water (surface moisture) contained in the aggregate to the amount of mixing water when reporting mix water amounts. Due to the porous nature of lightweight aggregate it is important to saturate the aggregate prior to use. Otherwise the lightweight aggregate will remove mixing water from the batch during the mixing operation.

23.5 *Material (Admixture)*—Concrete produced in the laboratory often involves the use of chemical and mineral admixtures which may be either in powdered or liquid form. Each type is handled differently. Insoluble admixtures in powdered form should be pre-mixed with the cement prior to introduction into the mechanical mixer, and mixed with the sand and cement when mixing by hand. Care must be taken in adding the powdered admixtures that are used in very small amounts (often from 0.01 to 0.2 % by weight of cement) to distribute them evenly and blend them uniformly with the cement when preparing a concrete mixture.

23.5.1 Soluble chemical admixtures should be prepared as a water solution unless instructions dictate otherwise. Such solutions and chemical admixtures that are marketed as liquids should generally be introduced into the mixer with the mixing water. The solution should be included in the calculation of the water content of the concrete. Solutions that are not compatible, such as calcium chloride and certain air-entraining agents or set retarders, should not be intermixed prior to their introduction to the mixer, but should be added to the batch of concrete in accordance with the manufacturer's recommendations. Air entraining admixtures, when used with either water-reducing or set controlling admixtures or both, are often added to the damp sand to reduce possible adverse effects when they are added closely together.

23.5.2 Specification C 260, Air-Entraining Admixtures for Concrete[2], and Test Method C 233, Air-Entraining Admixtures for Concrete[2], respectively, cover the requirements for and methods of test for air-entraining admixtures. Specification C 494, Chemical Admixtures for Concrete[2], covers the requirements for other chemical admixtures such as water-reducers, retarders, accelerators, high-range water reducers, and so forth. Specification C 618, Coal Fly Ash and Raw or Calcined Natural Pozzolans for Use as a Mineral Admixture in Portland Cement Concrete[2], covers the requirements for pozzolanic admixtures. When using admixtures, attention should be given to the instructions and precautions furnished by the manufacturer of the admixture with particular attention to dosage rate and time of addition. Since the dosage size is relatively small, make sure the method of measure is accurate and all of the admixture is delivered to the batch. Syringes, pipettes, or cylindrical graduates have been found to be effective delivery systems. Admixture manufacturers typically issue dosage rates in oz/cwt (ounces per 100 weight) of cementitious material per cubic yard. When mixing batches with admixtures in the laboratory, it is recommended that dosages be measured in millilitres due to the amount used. In calculating the dosage size of admixtures for trial batches, the following formulas could prove useful:

Amount of cement used per cubic yard of concrete:

$$X \times 94 \text{ (lb/bag)} = \text{lb of cement/yd}^3$$

where X = number of bags of cement per yard of concrete.

Amount of admixture used per cubic yard of concrete:

$$(\text{lb of cement/yd}^3/100) \times D = \text{ounces of admixture/yd}^3$$

where D = dosage rate of admixture, oz/cwt/yd^3.

Amount of admixture used in mix batch:

$$\text{oz of admixture/yd}^3 \times (V/27) = \text{oz of admixture/batch}$$

where V = volume of the concrete batch to be mixed in the laboratory, ft^3.

Convert ounces to millilitres:

$$\text{ounces} \times 29.57 = \text{millilitres}$$

Solutions should be labeled and stored in accordance with the manufacturer's guidelines. Nonmetallic containers are preferred for storing solutions. Outdated solutions should not be used.

23.6 *Material(Water)*—In calculating the amount of water for batching, allowance should be made for free and absorbed water in the aggregate.

23.6.1 When mixing batches of concrete, the water cement ratio is usually specified or previously determined by trial batches in which the water-cement ratio is determined based on the strength of the concrete. The water-cement ratio is used to calculate a mix design weight of water. Calculate the amount of mixing water to be batched by determining the actual moisture content in both fine and coarse aggregate. In making these calculations, the following formulas may be of assistance.

Percentage of water in aggregates:

Free water, %^{A}= total moisture content, %– maximum absorption, %

where:

Total moisture content, % = total amount of water contained in the aggregate expressed as a percentage ((weight of water in the aggregate/oven-dried weight)^A 100), and

Maximum absorption (%) = maximum percentage of water trapped in the aggregate ((absorbed water/oven-dried weight)^A 100)

^{A} A negative number for free water, %, means the aggregate will absorb some of the mix water.

Amount of free water in aggregates:

Weight of free water = free water, % × oven-dried batch weight

where:

oven-dried batch weight = mix design quantities of oven-dried aggregate adjusted proportionally to batch size.

Amount of water to be batched:

Mixing water for the batch = design mix water – free water

where:

design mix water = mix design quantities of water adjusted proportionally to batch size.

23.6.2 Vessels for storage of water must be clean. Volumetric measures should be checked for accuracy and their capacity should be marked thereon. The tare weights of vessels used for weighing water should be checked occasionally.

23.7 *Safety*—Belt, chain, or gear drives on mixers should be adequately guarded to prevent injury. Fresh concrete can cause chemical burns. Personnel should wear safety glasses, goggles, or face shields to protect the eyes from concrete splatters during mixing. Hands and exposed skin should be protected from contacting the concrete. If hardened specimens are cured in limewater, technicians should wear waterproof gloves to protect skin from irritation and rashes on the hands and arms when placing or removing specimens from water storage. Lifting devices are commercially available which allow cylinders to be removed from the storage water without placing hands in the limewater.

23.8 *Mixer Operation*—The mixing action of tilting drum laboratory mixers should be critically observed and deficiencies corrected. Mixers of this type sometimes run too fast to properly mix concrete of the type used in laboratory work. The concrete should roll off the blades in a tumbling action for thorough mixing. Sometimes mixing action can be improved by reducing the speed or changing the angle of inclination or tilt of the drum, or both.

23.9 *Batch Weighing*—Practice C 192 requires that all materials shall be weighed on scales in accordance with the requirements for sensitivity and tolerances prescribed by the *National Institute of Standards and Technology Handbook 44*.[17] In weighing materials for batching, it is important to use the correct capacity scale to ensure accurate scale readings. The material to be weighed should have a weight greater than about 10 % of the capacity of the scale but not more than the capacity of the scale. Further clarification is provided in the Scales section of Practice C 192 and the accompanying note.

23.10 *Buttering*—When a concrete mixer is first used, a coating of mortar is left on the interior surfaces of the mixer after the batch has been discharged. To avoid this loss of the batch material, the mixer should be buttered prior to batching concrete. The mixer is "buttered" by mixing a batch proportioned to simulate closely the mortar portion of the first test batch. Discharge the contents of the mixer once all interior surfaces have been coated with the mortar. The coating of mortar adhering to the mixer will prevent the loss of mortar from the test batch. "Over-mortaring" is another option to "buttering." In this technique, the mortar portion of the batch is adjusted to include the amount of mortar that will remain in the interior of the mixer after the batch is discharged. The amount of mortar added to the batch is dependent on the size of the mixer in the laboratory.

23.11 *Adding Admixtures*—The timing and method of introducing the admixture into the batch can have important effects on properties of the concrete and it must be the same from batch to batch. For example, delaying the introduction of a retarding admixture as little as 30 to 60 s after the start of mixing has been shown to have important effects on the time of set, air content, and water requirement for a given consistency. To avoid influencing future batching, the mixer or mixing pan should be cleaned thoroughly after preparing concrete containing a different chemical admixture. The cleaned mixer should be re-buttered before mixing a new batch of concrete.

23.12 *Mixing*—Practice C 192 describes the procedure for hand mixing of concrete. Hand mixing is not to be used for air-entrained concrete. The requirement for a "damp" metal pan in hand mixing does not mean standing water in the pan. Excess water will affect the slump of the concrete. One method to prevent this from occurring is to place water in the pan and wet all interior surfaces and then turn the pan upside down and allow any excess water to drain. For either the revolving drum or the open-pan type of mixer, the mixing cycle is clearly presented in the Machine Mixing section of Practice C 192. The equipment, procedure, and time of mixing can greatly affect the compressive strength and amount of entrained air, and no variations from the required cycle should be permitted. If deviations occur, they should be recorded in the notes on the batch.

23.13 *Sampling After Mixing*—Sampling of either hand-mixed or machine-mixed concrete has an impact on the test results of concrete. It is necessary that each scoopful or shovelful of concrete taken from the batch to fill the specimen molds be representative of the batch. In order to maintain uniformity of machine-mixed concrete, the concrete must be remixed by shovel or scoop after depositing in a clean, damp pan. Concrete that tends to segregate (slumps larger than 3 in. (76 mm) or concrete containing nearly spherical coarse aggregate) should be remixed after the removal of one or two scoopfuls or shovelfuls. Scoops or shovels should be used to sample the concrete. Sample the concrete, not in horizontal layers, but throughout the depth of the batch with the leading edge of the scoop or shovel, sliding along the bottom of the pan.

23.14 *Molding*—After each layer of concrete is placed in the mold, rod or vibrate test specimens in accordance with the section on Methods of Consolidation in Practice C 192. When using single-use plastic cylinder molds care should be used not to contact the mold with the vibrating element or tamping rod during consolidation. Also, the tamping rod should not be used in closing the voids left by rodding. When using light-gauge or single-use plastic cylinder molds, the open hand may be used to close these voids. When using a vibrator as a means of consolidation, do not overfill the top layer of the mold before vibration. In addition, it is preferable to vibrate all specimens of equal slump and proportions in a test group for the same length of time and in an identical manner. Over-vibration should be avoided. Usually sufficient vibration has been applied as soon as the surface has become relatively smooth. Excessive paste and bleed water on the top surface of the specimen is an indication of over-vibrating. After the molding operation has been completed, move specimens as little as possible. Attention is invited to the Place of Molding section in Practice C 192.

23.15 *Curing*—Practice C 192 requires that after 24 $\pm$ 8 h in the molds, the concrete specimens be demolded and stored in either moist air or limewater at 73 $\pm$ 3 °F (23 $\pm$ 2 °C). The moist storage rooms or water storage tanks used in curing shall be in accordance with the requirements of Specification C 511, Moist Cabinets, Moist Rooms and Water Storage Tanks Used in the Testing of Hydraulic Cements and Concretes.[2] Most laboratories use moist-air curing because of space required to cure the typical number of specimens in an average size testing facility, and the ease in locating a test specimen. There should be free air space around each specimen, and free water must be maintained on all surfaces of the specimen. In a good moist room, the fog spray will be thick enough to hamper visibility at 10 to 15 ft.

23.15.1 When storing strength test specimens in water, the water should be saturated with calcium hydroxide (high calcium hydrated lime) as required in Specification C 511. The purpose of the calcium hydroxide-saturated water is to prevent the leaching of calcium hydroxide from the test specimens. Calcium hydroxide, sometimes referred to as "mason lime," should not be confused with ground limestone or "agricultural lime." The water should be saturated with calcium hydroxide and the temperature stabilized before immersing the first cylinder. Storage water is considered to be saturated when the calcium hydroxide being added will not go into solution. The water depth must be sufficient to completely cover specimens at all times.

24. FUNDAMENTAL TRANSVERSE, LONGITUDINAL, AND TORSIONAL FREQUENCIES OF CONCRETE SPECIMENS[18]

(See Test Method C 215)[2]

Two alternative procedures are permitted in determining the fundamental resonant frequency. These procedures are: (1) the forced resonance method or (2) the impact resonance procedure. The same procedure must be used for all specimens in a given group.

24.1 The forced resonance method uses an electro–mechanical driving unit to vibrate a specimen. The driver unit is operated by a variable–frequency oscillator. A lightweight pickup unit attached to the specimen is used to measure the amplitude of vibration as the driving frequency is varied. The amplitude of vibration is displayed on an electronic indicator. The value of the frequency causing maximum amplitude is the resonant frequency of the specimen.

24.1.1 The impact resonance method uses a small impactor (hammer) and a lightweight accelerometer to measure the vibration of the specimen. The output of the accelerometer is recorded by a computer–based system which determines the resonant frequency of the specimen by analyzing the recorded data.

24.2 *Forced Resonance Method*—The accuracy of forced resonance method depends on the accuracy with which frequency can be determined. The actual oscillator frequency should agree closely with the indicated frequency, within the specified ±2 % or else a calibration curve should be prepared. The oscillator can be calibrated over its complete range by use of an electronic counter or by synchronization with the standard time signals broadcast daily over station WWV by the National Institute of Standards and Technology. If a calibrated electronic counter is included in the oscillator circuit, it may be used for frequency determination, and the oscillator calibration is not required. It is necessary only that the frequency output of the oscillator at any setting be stable during the duration of the test.

24.2.1 A 3 by 4 by 17–in. (76 by 104 by 430–mm) aluminum prismatic bar has been found suitable for system verification. Such a bar may be used to check system operation at about 2000, 2500, 3200, and 5900 cps (Hz). These correspond to two transverse resonant frequencies, the torsional resonant frequency, and the longitudinal resonant frequency. The resonant frequencies of the aluminum bar are determined using the same procedure as for a concrete specimen. A reference bar of this type can be used at any time and can be shipped from place to place to check and synchronize several pieces of equipment. Smaller size aluminum or other metal prisms can also be used, however the resonant frequencies will have a higher values than stated above.

24.2.2 The sonic equipment should be allowed to warm up for 2 min prior to use to stabilize the electronic circuits.

24.2.3 The driver unit can be conveniently mounted on a stand so that it can be readily placed against the test specimen. Some driver units are made from an audio speaker that has been modified by attaching a steel tip to the speaker diaphragm. In contacting the concrete with the tip of the driver, care should be taken not to break the tip loose from the diaphragm. The tip should not be struck sharply or subjected to great pressure. The driver unit should be pushed against the specimen with just enough force to prevent a chattering sound when the specimen is being vibrated. Avoid excessive force. The pickup unit can be held against the concrete by spring loading or by a rubber band, or by the weight of the pickup unit alone if sufficient to provide good contact. The pickup should not be allowed to become wet, since water may damage it. A small amount of grease can be added to the tip of the stylus to aid in coupling the transducer to the concrete.

24.2.4 When moving the pickup and test specimen, the gain of the indicator circuit should be reduced to avoid damage to the meter.

24.2.5 The driving amplitude should be maintained as low as is feasible for good response at resonance to avoid distortion. Maintaining the driving amplitude as low as possible also saves wear and tear on the equipment and spares the ears of other laboratory employees. Between tests of individual specimens the driver amplitude should be reduced so as to be inaudible.

24.2.6 The sonic equipment should be kept in a dry place.

24.2.7 Drift can be determined by periodically checking with the aluminum bar, an electronic counter, or by other means. If drift is detected, the instrument should be checked by a knowledgeable electronics technician or returned to the manufacturer for repair.

24.2.8 In measuring the fundamental resonant frequency, the operator should have a general idea of the approximate value to be measured. Otherwise, it is possible to make a gross error in the measured value of the resonant frequency. This error occurs when the specimen is driven at a frequency that is a fraction of the fundamental resonant frequency. For example, if the fundamental resonant frequency is 3000 Hz and the specimen is driven at a frequency of 1500 Hz, the specimen will vibrate at its fundamental resonant frequency and the amplitude indicator will indicate a peak value. Thus the user could report the resonant frequency as 1500 Hz. High amplitude vibration would also occur if the specimen were driven at 1000 Hz, that is ⅓ of the fundamental frequency. To avoid this

[18] For additional explanation see Whitehurst, E.A., "Evaluations of Concrete Properties From Sonic Tests" ACI Monograph No 2., and Malhotra, V.M., "Testing Hardened Concrete Nondestructive Methods" ACI Monograph No. 9., American Concrete Institute, Farmington Hills, Michigan.

problem, the instrument should be equipped with an oscilloscope that displays the oscillator output versus the receiver output. When the specimen is being driven at the fundamental resonant frequency, the oscilloscope shows an elliptical pattern. If the specimen is driven at ½ its fundamental resonant frequency, the oscilloscope shows a pattern resembling the infinity sign, (∞).

24.2.9 Usually torsional frequencies are determined only when it is desired to determine Poisson's ratio or the modulus of rigidity. In order to calculate Poisson's ratio, it is necessary to determine the torsional frequency and either the transverse or longitudinal frequency. Some laboratories routinely determine all three resonant frequencies when testing specimens. In determining E from the longitudinal frequency, it is not necessary to know Poisson's ratio provided L/d is not less than 2. The fundamental longitudinal frequency is normally considerably higher than the fundamental transverse frequency. For the previously mentioned aluminum bar, the fundamental longitudinal frequency is about 5950 cps (Hz) and the fundamental transverse frequency in the direction of the smaller dimension is about 2000 cps (Hz). It is a matter of choice whether to use longitudinal or transverse frequencies, since Young's modulus can be calculated from either. The amplitude of vibration in the longitudinal direction is much smaller than in the transverse direction, and more operator skill is required to determine the longitudinal resonant frequency. The choice may also be influenced by the use of the data. The longitudinal frequency reflects the average condition of the specimen, whereas surface disintegration produces a disproportionately high reduction in transverse frequency. Test Method C 666 specifies transverse frequency because it is important to detect surface deterioration as well as general deterioration.

24.2.10 Temperature change within the normal laboratory range should not affect results appreciably. Moisture content probably has a slight effect on results but this is probably not significant unless the moisture content is changed appreciably (completely dry to saturated, for example). Poisson's ratio is reported to increase with degree of saturation.

24.2.11 Specimens containing freezable water will show higher fundamental frequencies if tested when frozen. However, to eliminate completely effects of temperature and changes in moisture content, beams on which several successive readings are to be taken should be kept at the same temperature (above freezing) and moisture content, if possible.

24.3 *Impact Resonance Method*—In the impact resonance method, the specimen is struck at the appropriate position with a small hammer. The impact causes the specimen to vibrate in its natural modes. An accelerometer mounted in the proper position is used to monitor the vibration of the specimen. The output of the accelerometer is analyzed to determine the vibrational frequencies. This technique is analogous to ringing a bell by striking it with a hammer.

24.3.1 There are two common methods for determining the resonant frequency from impact testing. One method is based on counting the number of zero crossings of the accelerometer signal. This is accomplished by electronic circuitry, and the instrument displays the digital value of the resonant frequency. The other technique uses a digital signal processing method that determines the predominant frequencies contained in the accelerometer signal. These frequencies include the fundamental resonant frequency plus the frequencies of higher vibrational modes. The output from the signal processing is a graph of amplitude versus frequency, known as the amplitude spectrum. Resonant frequencies appear as peaks in the amplitude spectrum. The fundamental resonant frequency is the peak with the highest amplitude and lowest frequency. In this second method, the frequency resolution is the inverse of the duration of the sampling period. A longer sampling period results in higher frequency resolution. For example, if the sampling frequency is 20 kHz (sampling interval of 0.00005 s) and 1024 points are recorded, the resolution is 19.5 Hz (1/0.0512 s). If the sampling frequency were lowered to 10 kHz, the frequency resolution would be 9.8 kHz. The user must make sure that the sampling frequency is at least twice the resonant frequency to be measured. For example, if the sampling frequency is 20 kHz, the maximum frequency that can be measured is 10 kHz.

24.3.2 The nature of the impact is critical in the success of the impact resonance method. If the duration of the impact is too long, it may not be possible to excite the fundamental resonant frequency of the specimen. Test Method C 215 specifies a hammer that has been found to be suitable for the typical specimens used in Test Method C 666. For smaller specimens, it may be necessary to use hammers of smaller mass. The force of the hammer impact does not have an appreciable effect on the resonant frequency. However, the user should use a similar impact force from specimen to specimen. Some practice may be required to learn the proper technique, which should be a sharp, quick impact. It is best to hold the handle of the hammer loosely between thumb and forefinger when striking the specimen.

24.3.3 By using the impact resonance method, it is possible to determine the torsional resonant frequency of a cylindrical specimen. To excite the torsional mode, it is necessary to strike the specimen with a tangential blow as shown in Fig. 4 of Test Method C 215. Practice will be required to develop the proper technique. The user should know the approximate value of the torsional resonant frequency as a check that the torsional mode has in fact been excited by the impact.

24.4 The paper by Gerald Pickett, "Equations for Computing Elastic Constants from Flexural and Torsional Resonant Frequencies of Vibration of Prisms and Cylinders," Proceedings, ASTM, ASTEA, 1945, Vol. 45, p. 846, is a most useful reference when making calculations based on results obtained from sonic tests. By use of the charts and equations set forth in this paper, constants for flexural and torsional vibration of prisms and cylinders can be computed.

25. AIR CONTENT OF FRESHLY MIXED CONCRETE BY THE PRESSURE METHOD

(See Test Method C 231)[2]

The test method describes apparatus of two basic operational types, Type "A" and Type "B", employing the principle of Boyle's law. Both methods are based on the fact that changes in pressure affect changes in volume. The test method is considered applicable to concretes and mortars made with relatively dense aggregates. It is not applicable to concretes made with lightweight aggregates, air-cooled blast furnace slag, or aggregates of high porosity where the aggregate correction factor would exceed about 0.5 %. Changes in elevation of more than 600 ft (183 m) require recalibration when using the Type A meter. The Type B meter is unaffected by elevation. Both meters require an aggregate correction factor to be determined for the aggregate used in the concrete being tested.

25.1 The internal surface of the assembly cover on both meters should be clean and free from oil or grease; the surface should be wet, to prevent the adherence of air bubbles that might be difficult to dislodge after assembly.

25.2 The Type "A" meter should be checked before being taken to the field after a period of nonuse. Leaky air valves and faulty seals in the hand pumps may cause difficulty in maintaining the desired air pressure. The air valve near the top of the cover assembly should be clean and free from oil. It is advisable to have on hand an extra pump and extra cores for the air valve.

25.3 The interior of the graduated precision-bore glass tube and the glass face on the attached pressure gauge (Type "A") should be cleaned frequently, using a soft brush or a soft cloth. Even with frequent cleaning, it is sometimes necessary to use a dilute (1:4) solution of hydrochloric acid to remove the film that adheres to the inner surface of the glass on drying.

25.4 For Type "B" meters, any leaks in the air chamber or the seal between the bowl and the cover are a problem. After completely filling the meter, leaks in the main air valve can be detected when pumping to the initial pressure with the petcocks open. No air should be observed coming out of the petcocks. Air escaping at this point of the test indicates a leak in the main air valve between the air chamber and the interior of the meter. A drop in gauge pressure would also indicate a leak somewhere in the air chamber. Submerging the lid or the assembled meter up to the top of the air chamber or using a soap solution may detect leaks. It is advisable to keep spare gaskets with the meter.

25.5 The calibration procedures described in the text should be followed carefully and methodically. Some meter manufacturers supply calibration instructions, which are based on procedures different from those given in the test method.

25.6 The aggregate correction factor represents the volume change attributed to the voids in the aggregate. Because water in the concrete can be forced into the aggregate voids during testing that would not normally be filled during concrete production, an aggregate correction factor is necessary. This factor must be subtracted from the apparent air content of the concrete before the true air content of the concrete can be determined. The factor is determined by placing the same amount of fine and coarse aggregate in the measuring bowl of the meter that would be part of the concrete to be tested. Since there is only fine aggregate, coarse aggregate and water in the meter, any air measured can be attributed to the aggregates. The combined sample should be added to the measuring bowl filled approximately 1/3 with water. The aggregate should be gradually introduced into the measuring bowl in such a manner that will not entrap air. Tapping the sides of the bowl, and rodding or stirring the upper layer of the aggregate will help eliminate the entrapped air. Add additional water as needed to keep the aggregate immersed and remove any accumulated foam as the measuring bowl is filled.

25.7 For the "A" meter, clamp the cover with a pressure tight seal and add water through the standpipe until the water level is approximately halfway up the standpipe. Incline the meter at a 30° angle and using the base as a pivot point, rotate the meter in several complete circles. Return the meter to the upright position and fill the water level in the standpipe to a level slightly above the zero mark. During the rotating and topping of the water level, lightly tap the sides of the meter to remove any entrapped air. Bring the water level to the zero mark and close the vent at the top of the meter.

25.7.1 Apply more than the test pressure (about 0.2 psi) to the meter and tap the sides of the measuring bowl sharply to dislodge entrapped air. The pressure reading should fall during the tapping. When the gauge registers the exact pressure required, read the level of the water in the standpipe and record the reading as (h_1) to the nearest half division.

25.7.2 Gradually release the air pressure through the vent at the top of the water column and tap the sides of the measuring bowl for about 1 min. Record the reading on the water level as (h_2) to the nearest half division. The correction factor is equal to $h_1 - h_2$.

25.8 For the "B" meter, clean the seals and flanges of the measuring bowl and the cover so that an airtight seal can be obtained. Clamp the cover to the bowl with the clamps provided. Close the air vent between the bowl and the air chamber. Open both of the petcocks found on the outside of the cover. Inject water with a syringe through one of the petcocks until water emerges from the other petcock. While continuing to inject the water, sharply tap the outside of the bowl with a rubber mallet to dislodge entrapped air. Continue until all air has been expelled. Close the air bleeder valve on the air chamber and pressurize the air chamber with the hand pump until the gauge hand is indicating the initial pressure line. After waiting a few seconds, make whatever adjustment is necessary to place the gauge hand on the initial pressure line. Close both of the petcocks and release the pressure in the air chamber into the bowl while tapping the sides of the bowl with the mallet. Tap the gauge lightly by hand and read the percentage on the dial. The correction factor is equal to this reading.

25.9 The testing of the concrete begins with preparation of the test sample. For concrete with 2 inch or greater nominal sized aggregate, the concrete must be wet-sieved to remove the larger aggregates with a 1½ in. sieve. Since the air content determination is based on a portion of the aggregates used in the mix and the removed aggregates are assumed to contain no air, adjustment must be made in the calculation for the loss of this volume. For additional information, see the section on Sampling Freshly Mixed Concrete of this manual.

25.10 The number of layers used to fill the measuring bowl is based on the methods of consolidation. Two layers are used when using vibration to consolidate and three layers are used when using rodding to consolidate the concrete. Base the consolidation method on the slump. Rod concretes with a slump greater than 3 in. (75 mm). Rod or vibrate concretes with a slump of 1 to 3 in. (25 to 75 mm). Consolidate by vibration concretes with a slump of less than 1 in. (25 mm). Failure to properly rod or to close voids left by the tamping rod will indicate incorrect higher air contents.

25.11 When consolidating with a vibrator, the duration of the vibration should be carefully monitored and kept to a minimum. The test method requires that each layer be vibrated in three insertions evenly distributed around the surface of the measuring bowl. Vibration is easier for the operator and the tendency is to over-vibrate resulting in loss of air and increased density. Vibration should cease when all the coarse aggregate is submerged, and the surface takes on a smooth glistening appearance.

25.12 When consolidating with a tamping rod, consolidate each layer with 25 strokes being careful to distribute the strokes over the entire surface of the concrete. In the first layer, the depth of the penetration should be throughout its depth being careful not the strike the bottom of the measure with excessive force. The depth of penetration on the second and third layer should be into the previous layer by about an inch. Close the voids left by rodding by striking the sides of the measuring bowl 10 to 15 times with a rubber mallet. The term "smartly" is used in the test method to describe the force with which to use in closing the voids. The force used should be just sufficient to close all voids left by rodding in the 10 to 15 taps.

25.13 Strike off the top surface of the measuring bowl with a strike off bar unless the material in the bowl will first be used to determine unit weight of the concrete (C 138), in which case a strike off plate conforming to C 138 may be used. In striking off with the bar, slide the bar across the flange of the meter in a sawing motion. When finished, the layer of the concrete should be just even with the top surface of the measuring bowl. For the procedure used to strike off the concrete using the strike off plate, see the Strike-Off section in C 138.

25.14 The procedure for assembling the meter, adding the water, and pressurizing the meter is identical to the procedures stated earlier in this section when describing the aggregate correction determination. For the "A" meter, the procedures in 25.7-25.7.2 should be reviewed. For the "B" meter, the procedures in 25.8 should be reviewed.

25.15 In calculating the final air content, be sure to subtract the aggregate correction factor from the apparent air content.

26. BLEEDING OF CONCRETE *(See Test Methods C 232)*[2]

The methods of determining the relative amount of bleeding either without disturbance or with specified intermittent vibrations are described in the procedure. Certain precautions should be taken when making the bleeding test according to this test method. For concrete made in the laboratory, the aggregates and concrete should be prepared as prescribed in Practice C 192. The interior surface of the container must be smooth and free from corrosion, coatings and lubricants. It is important that the concrete be properly placed in the container as specified in Test Method C 232, and kept within the temperature limits of 65° to 75 °F (18 to 24 °C) when so placed and be free of vibration or unnecessary disturbance. Any variation from the prescribed method may affect the bleeding rate. Test Method C 232 does not specify the ambient relative humidity, but does require that the filled container be covered with a suitable lid. The lid should fit the top of the container so that evaporation is reduced to a minimum and should be kept in place throughout the test except when drawing off water.

27. FLEXURAL STRENGTH OF CONCRETE (USING SIMPLE BEAM WITH CENTER–POINT LOADING) *(See Test Method C 293)*[2]

The comments on Test Method C 78 also apply generally to Test Method C 293. This method requires that the specimen be kept wet until the moment it is placed in the testing machine. Test Method C 31 requires that the last 20 h of curing prior to testing the beams must be immersed in water saturated with calcium hydroxide (high-calcium hydrated lime).

27.1 For testing, the beam should be placed on its side with respect to the mold. If any protrusions on the edges of the beam are left from the molding process, carefully remove these by use of a masons rubbing stone or Carborundum. Grinding or rubbing should be minimized inasmuch as grinding may change the physical characteristics of the beam.

27.2 Place the specimen in the testing apparatus and preload the beam to approximately 3 to 6 % of the estimated total load. Using 0.004 and a 0.015 inch feeler gages, determine if there is any gaps in length of 1 in. or more between the specimen and any blocks. For gaps more than 0.004 and less than 0.015 in.; grind, cap or use leather shims. Gaps over 0.015 in. require grinding or capping. Leather for shims may be obtained from shoe makers or leather belts.

27.3 The timing of the planeness determination is critical if the beam needs to be capped. For more information on determining the planeness of the beam, please refer to the *Flexural Strength of Concrete (Using Simple Beam with Third-Point Loading)* Section of this manual. Sulfur capping materials requires two h to cure. The last 20 h of curing prior to testing the beam must be immersed in water. Therefore, high strength gypsum caps cannot be used because they soften or deteriorate if stored in water for more than a very brief time period. Although permitted by the standard, due to curing time consideration, the use of neat cement is not recommended here.

27.4 After testing, measure the width and depth of specimen at the point of fracture to the nearest 0.05 in. (1 mm). The depth measurement is particularly important since the calculated strength varies inversely as the square of the depth. If fracture occurs at a capped section, include the cap thickness in the measurement.

28. TIME OF SETTING OF CONCRETE MIXTURES BY PENETRATION RESISTANCE *(See Test Method C 403)*[2]

Test Method C 403 specifies apparatus and procedures for making the test in necessary detail. As added precautions in making the test, specimens should be stored on a level base free from vibration, and a specimen should not be tilted until the surface has stiffened sufficiently to avoid displacement of the mortar.

28.1 The test method currently requires that not less than six penetration resistance determinations be made in each rate of hardening test and that the time intervals between penetration resistance determinations be such as to give a satisfactory rate of hardening curve as indicated by equally spaced points.

Points on the rate of hardening curves should be carefully plotted and the times of setting determined as detailed in the test method.

29. MOLDS FOR FORMING CONCRETE TEST CYLINDERS VERTICALLY

(See Specification C 470)[2]

The most widely used mold for concrete cylinders is the single use plastic cylinder mold. The quality of these molds varies greatly. It is in the interest of the user to obtain the certification from the manufacturer required in the Materials Section of the practice. A certified mold material should greatly reduce the problems encountered in using plastic molds. In addition to this certification, three randomly selected molds from each lot should be verified by the laboratory. After verifying that these molds meet the dimensional requirements, point the bottom of each mold at a light source and look into the interior of the mold. Areas of light or lighter shades of color could indicate damage to the mold or a mold that was not formed properly during the injection molding process. If this condition exists, examine the remainder of the lot in a similar manner and communicate your observations to the manufacturer. Using the dry crushed aggregate specified in the standard, fill and compact the aggregate in accordance with the specified procedure. Then check the molds for water tightness and damage.

29.1 Storing and handling plastic molds in extreme temperature can cause problems. Molds stored in a very cold environment may become brittle and fracture with rough handling. Molds in a very warm environment may lose their shape if not stored in a vertical position. If you suspect distortion from improper storage, rolling the mold on a flat surface may display an out of round condition.

29.2 The top of the mold may not be sufficiently strong to maintain the correct diameter when filled with concrete. A rigid plastic cap will help ensure the correct diameter and also minimize moisture loss.

29.3 Single use plastic molds should not be reused. When a single use mold is reused, the removal process tends to expand the diameter and deform the bottom of the mold. Plastic reusable molds are generally made of thicker, stronger material than the single use mold to withstand repeated use.

29.4 This specification requires that all molds be watertight. Some reusable type molds are made of two or more pieces. These molds require the use of a sealant on the seams and joints to make the molds watertight. The excess sealant on the inside bottom of the mold should not exceed the dimension for the inside fillet given in the specification. Any sealant used should be non-reactive with the concrete and compatible with the material of the mold. Check sealed molds for leakage by filling with water and subjecting to tapping and jarring similar to that which occurs when making a cylinder. Check for leaks one h after jarring. Materials such as wheel bearing grease, caulking compound, rosin-paraffin, and micro-crystalline wax may be suitable.

29.5 After the initial dimensional check and dry rodding have been performed, cardboard molds should be checked for absorption, height and volume change under wetting. If cardboard molds are stored at temperatures above 90 °F (32 °C), the paraffin coating may melt and collect in the bottom of the mold. This paraffin often adheres to the hardened cylinder and must be removed before the cylinder is capped.

30. SPLITTING TENSILE STRENGTH OF CYLINDRICAL CONCRETE SPECIMENS

(See Test Method C 496)[2]

The details of testing are adequately covered in the test method. When cardboard molds are used, the concrete cylinder should be rotated to select the two diametral elements for loading that are nearest to being in a plane. Although the plywood strips compensate for small irregularities in the line bearings, specimens should be made in molds that comply with the requirements of Practice C 31.

30.1 The centering of the horizontal cylinder lengthwise under the spherical bearing block requires unusual care if the diameter of the bearing block or the length of the bearing bar or plate is not the same as the length of the cylinder. If the vertical axial plane of the cylinder does not pass through the center of the spherical bearing block, the block will tilt, and the load cannot be applied. The use of an aligning jig, as illustrated in Test Method C 496, is recommended.

31. MOIST CABINETS, MOIST ROOMS, AND WATER STORAGE TANKS USED IN THE TESTING OF HYDRAULIC CEMENTS AND CONCRETES *(See Specification C 511)*[2]

The maintenance of specified moist curing conditions for cement and concrete samples is important, particularly with specimens to be tested for flexural strength. For comparison testing, companion flexural test specimens in the final 24 h curing were stored in either lime saturated water or in the air of the laboratory. Reductions in flexural strength were as high as 20 % for the 24 h laboratory storage specimens. Effects of variation in temperature on certain properties may also be great; therefore, specified curing temperatures should be carefully maintained. All moist cabinets or moist rooms shall be equipped with a temperature recording device.

31.1 Thermostatic control of the temperature is required in the area surrounding the room or in the room itself. In most cases, thermostatically controlled heating and cooling equipment is required. Heating the moist room may be accomplished by heating the water used in humidification sprays, by hot water baseboard heat or by forced air heat. Similarly, cooling the moist room may be accomplished by cooling the water used in sprays, by cold water coils located in the room or by forced air cooling. Forced air typically has low humidity; therefore, when forced air is used, incoming air should be directed away from the specimens. When thermostatically controlling the room temperature, the sensing elements for both heating and cooling shall be located in the room and preferably near the center of the room.

31.2 Necessary humidification may be obtained by the use of suitable spray nozzles, air-water jets or fog sprays. Experience has shown that some combination of compressed air and water spray provides the best humidification. Figure 1 in Specification C 511 offers an example of such a device that has proven to work very well. In addition to the requirement of at least 95 % relative humidity, the specification also requires that all specimens look and feel moist. To meet these requirements, the room needs adequate humidification and good air circulation. To promote free air circulation, there should be ample space around individual specimens. In order to maintain the humidification requirements, it is essential that the system not be shut down for prolonged periods of time.

31.3 Although not required by the practice, test specimens are generally stored on racks or shelves in the moist room. This aids in providing free air circulation, and along with an identification numbering system marked on the specimen, this can greatly assist the laboratory personnel in locating the specimens to be tested on a given day. Racks or shelves should not be made of aluminum as the alkaline condition causes corrosion. Hot-dipped galvanized steel racks, reinforced concrete planks, synthetic decking materials, pressure treated wood, or concrete blocks are all good choices. Material such as burlap, paper, and some types of wood can aid or support the growth of molds, slimes, and algae; these should not be used in a moist room. Although it is doubtful that these types of growth affect the strength or durability of concrete, they do cause a hazard in the handling of the specimens and in walking over the slime-coated floor. The room should be cleaned regularly. These hazards may be controlled by the use of ultraviolet lights.

31.4 Safety is an important consideration whenever moisture and electricity are present at the same time. Electric switches should be located on the outside of the room and should be provided with indicating lights. Lights inside the room should be of the type suitable for the moist conditions, and electric feeds should be by suitable cable in conduit. Moist storage room doors must be provided with internal latches so that the doors may be opened from within.

31.5 When curing specimens in water storage tanks, the temperature of the tank or the room in which the tank is located must be thermostatically controlled. When directly controlling the temperature of the tank, heat may be provided by thermostatically controlled immersion heaters. Chilling the circulating water or a liquid in tubing inside the tank can provide cooling. Insulation applied to the outside of the tank, including the top and bottom, is helpful in maintaining a constant temperature. Tanks can be raised off the floor to limit heat loss to the ground. If storage tanks are located in workrooms, providing lids for the tanks may help in maintaining the temperature, by reducing the cooling effect of evaporation.

31.6 The storage water in the tanks is required to be saturated with calcium hydroxide (high-calcium hydrated lime) to prevent lime leaching from the test specimens. Crushed limestone (agricultural lime) and dolomite are not acceptable substitutes for calcium hydroxide. The solution is considered to be saturated when additional lime added to the water will not go into solution. Once achieved, one way to maintain saturation is to place a quantity of calcium hydroxide in a container that will hold the lime but allow the water to pass through the container. A submerged sock or other permeable material tied off with string at the end works well as a container. Periodically stir the water and check the container for the presence of calcium hydroxide. As long as calcium hydroxide in powder form is present in the sock, the solution may be considered to be saturated.

31.7 A recording thermometer or datalogger is required for each storage tank when tanks are independent of the moist room. To eliminate the need for several recording thermometers, tanks may be connected by tubing that allows the flow of water between tanks. With respect to the recording thermometer requirement, these tanks may be considered as one unit as long as there is some means of water circulation and the temperature variation between each tank does not exceed 1 ºC. Maintaining the records of these temperature readings through a change of seasons is required by the practice to prove that the temperature control system can function within the required temperature limits. An examination of the temperature monitoring device on a weekly basis is considered good laboratory practice. Check that the recorder or datalogger is functioning normally and note any unusual deviations outside the required temperature limit since the last check. Deviations could be an indication of the breakdown in the system or a need to improve heating or cooling in the system.

32. TOTAL EVAPORABLE MOISTURE CONTENT OF AGGREGATE BY DRYING *(See Test Method C 566)*[2]

Test Method C 566 requires the use of a ventilated oven for more precise determinations and when aggregates would be affected by excessive temperatures. The method permits other suitable heat sources such as a hotplate, heat lamp, or microwave oven. As recognized in the test method, the procedure will generally measure the moisture content in the test sample more reliably than the sample can be made to represent the aggregate supply. When the moisture content of a coarse aggregate exceeds 3 or 4 % or a fine aggregate exceeds 7 to 9 %, the free water on the aggregate will drain or collect in the bottom layers and truly representative samples will be difficult to obtain.

32.1 All moisture contents are expressed as percentages of oven-dry weight of aggregates. Total moisture content by Test Method C 566, less the absorption by Test Method C 127, Specific Gravity and Absorption of Coarse Aggregate,[2] or Test Method C 128, Specific Gravity and Absorption of Fine Aggregate,[2] provides the percentage of surface moisture in the sample.

32.2 With certain aggregates of relatively high absorption, the method used to determine moisture content and absorption can affect the computed amount of surface moisture (see Test Method C 128 on Specific Gravity and Absorption of Fine Aggregate).

33. CAPPING CYLINDRICAL CONCRETE SPECIMENS *(See Practice C 617)*[2]

Practices C 617[2] and C 1231[2] deal with the treatment of ends of cylinders when testing for compressive strength. The information in this section refers to Practice C 617.[2] For information on the unbonded cap system, Practice C 1231,[2] refer to section 40 of this manual.

33.1 Prior to testing, the ends of the cylinders must be checked for planeness and perpendicularity. If either end departs from planeness by more than 0.002 in. (0.05 mm), or either end departs from perpendicularity by more than 0.5° (1⁄16 in. in 6 in.), the end(s) of the cylinder must be ground or capped. Three types of caps for cylinders are discussed in the practice: sulfur mortar, gypsum plaster and neat cement paste. Sulfur mortar and gypsum plaster are used on hardened cylinders and cores. The neat cement paste is used on the top surface of the freshly molded cylinders.

33.2 An alternative to capping is wet grinding. The drawbacks of grinding are cost and lack of skilled operators and proper apparatus. Grinding should be done by the wet lapping process. Dry grinding should not be used because it may cause heat damage to the ends of the cylinder.

33.3 Sulfur mortar is a composition of sulfur and granular materials. This mixture is heated to a temperature of about 265 °F (130 °C) until the sulfur is molten. The sulfur mortar is ladled into the bottom of a vertical capping device. The cylinder is immediately placed squarely against the guide bars and slowly lowered into the molten mortar. If a horizontal device is used the cylinder is placed in the device and the material is then poured into the device through openings at the top. After the sulfur mortar hardens, the cylinder is removed, care being taken not to damage the capping plate or the mortar cap.

33.3.1 The sulfur mortar must have a compressive strength of at least 5000 psi (34.5 MPa) at 2 h when tested as a 2 in. (50 mm) cube. The procedure for testing the strength of the mortar is detailed in Practice C 617. Sulfur mortar gains strength with age. For some materials, a 2 h strength of 5000 psi (34.5 MPa) may increase to 9000 psi (62.1 MPa) at 24 h. Strengths are considerably lower at an age of less than 2 h. The required waiting period of at least 2 h between capping and testing of cylinders capped with sulfur mortar should be strictly enforced unless a sacrifice of apparent strength is allowable as expedient in job control of detensioning of prestressed concrete.

33.3.2 Sulfur mortar, either laboratory prepared or commercial type, can sometimes produce rubbery caps that deform or flow under load. This is caused by a plasticizer in the commercial material, by contamination of either type with oil, grease, water, paraffin, or by overheating. The capping material should flow freely at the recommended temperature. If the material thickens from overheating, it must be cooled and stirred until thin. In most instances, cooling will restore the mixture to a satisfactory condition if it is stirred during cooling. If it is greatly overheated, it should be replaced. If water contaminates the mortar, foaming may occur. In this case, the pot should be recharged with new mortar. Sulfur mortars having an exceptionally high sulfur content will produce caps that warp or crack on cooling.

33.3.3 The ends of cylinders should not be oiled before capping, as is sometimes done to facilitate the removal and reuse of caps from tested cylinders. Using reclaimed sulfur mortar is not recommended unless the material is frequently checked for strength and deformation under load. The practice limits the number of uses of the material to five times.

33.3.4 Reusable steel cylinder molds use mineral oil as a release agent between the steel and the concrete, and cardboard cylinder molds use a coating of wax between the cardboard and concrete to prevent moisture loss and absorption. A residue of these materials may be found on the cylinders. A concrete cylinder with a coating of mineral oil or paraffin on the bottom should not be capped until the wax or oil has been removed. Prior to capping, the ends of the cylinders must also be free of moisture. Clean the surface with a wire brush and rag. Failure to treat cylinder ends properly may result in air voids or steam pockets between the cap and the cylinder end. This will cause the cap to yield before the cylinder fails during testing. If tapping with a piece of metal (for example, coin, key or light hammer) on a sulfur mortar cap produces a hollow sound, an unsound cap is indicated. The unsound cap should be removed and the cylinder end cleaned and recapped.

33.3.5 Sulfur mortar caps should be as thin as practical; 1⁄8 in. is ideal. In no instance shall any part of the cap be more than 5⁄16 in. thick. A vertical capping device generally produces thinner caps than a horizontal apparatus. Cylinder ends that are sloped, very uneven, or highly convex should be rubbed down with a carborundum rubbing stone, or should be squared by cutting with an abrasive or diamond saw before capping. This is particularly important if sulfur mortar or high-strength gypsum plaster is used. Poor finishing or handling are the major causes of unsatisfactory cylinder ends. Such conditions should be reported to those responsible for making the cylinders so the work can be corrected and done properly in the future. Thicker caps may also be caused by the sulfur mortar hardening somewhat before the cylinder is lowered into the molten mixture. This can be corrected by starting with a warm capping plate, using the capping material to preheat the plate, or by working faster, that is, placing the cylinder into the molten sulfur mortar before it begins to harden. **Warning:** Technicians must be aware, however, of the hazards of dropping the cylinder into the molten sulfur mortar and thereby causing a splash of the material.

33.3.6 When cylinders are capped with sulfur mortar, the ends of the cylinders must be free of all surface moisture to avoid steam pockets under the cap. During drying of the cylinder ends and in the process of capping, considerable moisture may be lost from the sides of the cylinder. This can be prevented by wrapping in wet burlap until time of test. Cylinders should never be allowed to dry for long periods before capping nor during the 2 h or more waiting period after capping. This can be prevented by storing the cylinder in moist air, underwater, or by wrapping in wet burlap, until the time of test.

33.3.7 The plates of the capping apparatus should be oiled or greased lightly before use, but the ends of the test specimens should not be oiled before applying the sulfur mortar caps. Penetration oils should not be used to oil capping plates. Plates should neither be too hot or too cold. Cold plates will produce thick caps and should be warmed by pouring one or two ladles of material onto the plate, allowing it to harden, and then removing before the first cylinder is capped. If plates are too hot, caps will harden slowly causing an unnecessary delay. The use of additional plates will reduce excessive heat build up.

33.3.8 Capping devices should be occasionally checked to determine whether the plates meet the planeness requirements in Practice C 617. Fig. 1 shows the planeness of caps being checked with a 6 in. (152 mm) machinist's parallel and a 0.002

in. (0.05 mm) feeler gauge. The planeness of capping plates should be checked periodically using the same apparatus. Quarterly reviews are recommended or whenever indentations are observed. Such checking does not eliminate the necessity of checking planeness of capped specimens since the caps may warp when cooled.

33.3.9 The practice, in describing the capping device, refers to a recess in the capping plate which holds the molten sulfur mortar. On most new capping devices, the recess has been replaced with a metal ring which is affixed to the top surface of the plate. Whether a recess or ring is used the depth or height of this device should not exceed ½ in. (12.7 mm). This requirement assists in limiting the thickness of the sulfur mortar cap that can be produced in the capping device. Limiting the thickness of the caps helps to prevent cylinders or cores with excessively sloped, uneven or convex ends from being capped without the ends being ground or sawed.

33.3.10 A suitable container and source of heat must be provided for melting the sulfur mortar and maintaining the preferred temperature of about 265 °F (130 °C). The melting pot should be of suitable design, electrically heated with automatic controls, and provided with thermal safety melting links. Due to the corrosive action of the sulfur, electrical contacts should be protected from sulfur fumes. A heavy gauge steel lip around the container may aid in protecting the pot when hardened sulfur mortar is chipped from around the edges. A metal ladle of sufficient capacity to fill the capping plate in one pour should be provided. The use of a small air-driven stirring device in the molten material will help to maintain the uniformity of the material. A large, perforated sheet metal strainer or spoon is helpful in removing small lumps of solid material.

33.3.11 Operators who handle hot sulfur mortar should wear leather-faced cotton or suitable work gloves, face shield or safety glasses, and long sleeves. Due to the toxic nature of the sulfur fumes, the melting pot should be under a hood with forced ventilation to the outside air. **Warning:** Severe burns have resulted from explosion of sulfur mortar being overheated when the material in the bottom of the pot melted and boiled before the surface had melted, causing a build-up of pressure. In these cases, the explosion might have been prevented if the metal ladle had been left in the pot. The ladle conducts heat up from the bottom of the pot and thereby melting a relief channel to the surface of the mortar and preventing built-up pressure. Heating elements located on the sidewalls of the pot have been found to eliminate this problem.

33.3.12 The flash point of sulfur is approximately 440 °F (227 °C) and the mixture can ignite due to overheating. To prevent fires caused by failure of electrical contacts, melting pots specifically designed for continuous use with sulfur are recommended. A tight cover for the melting pot or wet burlap bags should be located in the capping area. Either can be used to cover the pot in case of fire. A dry chemical fire extinguisher should also be available for emergencies. **Warning:** Sulfur burns with a low, blue flame and may be difficult to detect. Hazards such as flammable materials or explosive gases should not be present in the capping area. Practice C 386,[2] is a useful reference for safety considerations.

33.4 Another capping material permitted by Practice C 617 is gypsum plaster. This plaster can be used for capping concrete specimens expected to have a compressive strength below 5000 psi (34.5 MPa), provided the plaster has a compressive strength of 5000 psi (34.5 MPa) or greater when tested as 2 in. (50 mm) cubes. Reference is made to Method C 472[2] for details on filling the cube mold and timing in striking off the top surface of the plaster in the mold.

33.4.1 Certain problems and precautions are connected with the use of high-strength gypsum plasters for capping. The mixing water used should be between 26 to 30 %. The amount of water used in testing the plaster for strength should be carefully measured and recorded, along with the air and water temperature, and the time interval between mixing and testing. The same proportion of gypsum plaster to water should be maintained in mixing for capping as was established in compressive strength testing. The temperatures of air and mixing water during the capping should be substantially the same as when strength tests were made. Free water on the surface of the concrete softens the gypsum cap, and should be removed before applying the cap. After the cylinder has been capped, it should be wrapped immediately in several layers of moist burlap, but the capped end or ends should not be covered. It takes about 20 min for gypsum plaster caps to harden, but specimens must not be tested in less time than the interval established during strength testing.

33.4.2 Gypsum plaster caps should be as thin as practical, and a vertical capping jig is advisable to obtain thin and parallel caps at right angles to the axis of the cylinder. Capping plates, whether metal or glass, should meet the planeness requirements of Practice C 617. Plate glass, ¼ in. (6.4 mm) thick, 7 by 7 in. (180 by 180 mm) can be obtained with a planeness of 0.002 in. (0.05 mm) in any 7 in. dimension.

33.5 Neat cement paste caps made of portland cement are applicable to freshly molded specimens. This method requires moist curing of the concrete specimens and constant moisture conditions must be maintained during the setting of the paste and the curing of the hardened caps. Lack of moisture, and absorption of moisture from the paste by the drying concrete can result in caps that are cracked, nonplane, or of poor strength. The paste caps must be aged sufficiently so that they will exceed the strength of the concrete cylinder being tested. Caps should never be made with a mixture of plaster of paris and portland cement. This mixture can have a strength considerably lower than either of its constituents.

33.5.1 When using neat cement paste in capping a cylinder in the mold, allow the cylinder to cure after molding for 2 to 4 h before capping. A stiff cement paste that has been mixed 2 to 4 h prior to use will reduce the tendency of the cap to shrink. In capping the cylinder, exercise care when working the glass plate on the cement paste to avoid breakage and possible injury. The cap should be checked for planeness before testing. Such capping is feasible only when rigid, watertight molds are used, and the concrete specimen has no bleeding water on its top surface.

34. RESISTANCE OF CONCRETE TO RAPID FREEZING AND THAWING

(See Test Method C 666)[2]

There are two procedures for Test Method C 666 for performing laboratory freezing and thawing tests: Procedure A, Rapid Freezing and Thawing in Water; and Procedure B, Rapid Freezing in Air and Thawing in Water. Test Method C 671, Critical Dilation of Concrete Specimens Subjected to Freezing,[2] is another reference standard.

34.1 These test methods describe the equipment and procedure in considerable detail and are intended for use in determining the effects of variations in the properties of concrete on the resistance of the concrete to the freezing and thawing procedures specified in the test methods. They are not intended to provide a quantitative measure of the length of service that may be expected from a specific type of concrete.

34.2 The freezing and thawing of water in concrete is one of the major causes of concrete deterioration. The intensity of natural freezing and thawing ranges from slight to very great, with no two cycles identical even at the same location. Freezing and thawing tests in the laboratory cannot duplicate natural exposure in all respects, but can evaluate relative durabilities under standardized exposure conditions. This is the main function of laboratory freezing and thawing tests, that is, the determination of the relative durabilities of concretes or concrete materials.

34.3 The Highway Research Board Committee on Durability of Concrete—Physical Aspects, conducted an extensive cooperative evaluation of four freezing and thawing methods. These results were published in *Special Report 47*, H.R.B., 1959. Among the numerous lessons learned was the importance of preparatory matters such as condition of the aggregates, air content, curing, and a variety of details prior to the start of actual testing. These are discussed concisely in Appendix F, Suggested Operating Procedures, of the H.R.B. report. Because of the value of these suggestions they are reproduced in their entirety below.

APPENDIX F

SUGGESTED OPERATING PROCEDURES

This research has produced no evidence that any of the ASTM freezing-and-thawing test methods in its present form is both sufficiently quantitative and reproducible to provide absolute limits for the routine acceptance or rejection, on a general basis, of concrete or concrete materials. The methods do, however, provide useful procedures for comparing the relative durability of different concretes within a given laboratory. In that connection, the Committee recommends attention to the following cautions:

1. Concretes to be compared should be mixed at as nearly the same time as feasible, placed into and removed from curing at the same time, and exposed to freezing and thawing concurrently.

2. Each class of concrete should be represented by at least three batches, preferably mixed on different days. It is desirable to have three or more test specimens from each batch as a check on within-batch uniformity. As indicated under item 1, all classes of concrete to be compared should be mixed on each mixing day.

3. Air content of the concrete should be known as accurately as possible, and, if the object is to evaluate relative durability of a given concrete, the air content of the freezing-and-thawing specimens should duplicate as closely as possible that of the given concrete. If aggregate is the variable under study, the air content should be sufficiently high to provide positive frost protection for the cement paste. For all concretes to be compared, the air content should be the same within ±0.5 percentage point. Each specimen should be weighed in air and under water to provide an indication of uniformity. Whenever possible the air content and air-void characteristics should be determined by microscopic examination of the hardened concrete specimens, and preferably on specimens which have actually been frozen and thawed.

4. Unless aggregate saturation is a controlled variable, the aggregates for all classes of concrete should be soaked in water for seven days after they have been dried to essentially constant weight in air. The aggregates must not be allowed to dry out before incorporation in concrete. Necessary adjustments must be made in the quantity of mixing water to compensate for the free moisture retained by the aggregates. In the case of certain natural aggregates and many lightweight aggregates, a seven day soaking period may not be desirable. Shorter periods of soaking or no soaking may be called for in these special cases as being more representative of actual conditions of use.

5. Unless mixing condition or treatment of the fresh concrete is a variable, extreme care should be exercised to assure that the procedures for mixing and handling the concrete and fabricating specimens are as nearly identical as possible for all classes of concrete which are to be compared.

6. Unless treatment of test specimens is a controlled variable, all specimens should be identically protected and cured between the time of molding and exposure to freezing and thawing. One acceptable sequence of operations is as follows:

(a) Immediately after molding, place the specimens in a fog room (relative humidity not less than 95 %) at 73 ± 3 °F covered with at least four layers of wet burlap.[19]

(b) After 24 ± 4 h, strip the specimens from the molds, mark them for identification on both ends and on the sides of the specimens while they dry, and immerse them immediately in a saturated limewater solution at 73 ± 3 °F. This operation shall be handled in such a way that the time between removal

[19] This recommendation differs from the procedure outlined in Practice C 192.

from the molds and immersion in the limewater is held to an absolute minimum and no surface drying of the specimens occurs.

For concrete containing a retarder, or insufficient cement to attain adequate strength, or if strength development is slow for any other reason, additional time in the molds up to 44 h may be desirable.

(c) Remove specimens from the limewater at the same age (14 days unless otherwise specified) and, after necessary measurements of weight and fundamental frequencies, place them in the thawing environment of the test exposure, taking care to minimize drying during handling.

A drying period, after the initial minimum storage of 14 days in limewater, may sometimes be used as a specified variation of the test procedure. Drying should be under constant conditions of temperature and relative humidity. Normally, resaturation of the dried specimens in limewater prior to the beginning of the freezing cycle will also be a part of the variation from the standard procedure.

7. Every effort should be made to assure that all specimens to be compared receive the same exposure to freezing and thawing. Ability to accomplish this may depend not only on the characteristics of the apparatus but also on the arrangement and location of the specimens. Turning specimens end for end and changing location in the apparatus each time specimens are returned after measurement will help to minimize the effects of unavoidable differences in environment.

8. Supplementary tests and the keeping of detailed records will often be helpful in accounting for poor reproducibility of test results. Changes in weight of specimens during curing may reveal differences in saturation of presumably identical specimens. Measurements of density may provide a check on uniformity of air content. Obviously, records of such things as equipment breakdown and deviations from prescribed methods may be vital in interpreting test data. Such records are readily made at the time, but are often impossible to reconstruct after the tests are completed.

34.4. A constant check should be made to ensure that the time-temperature cycles specified are being maintained. Note that the maintenance of a capacity load of specimens in the equipment at all times will materially aid in meeting these requirements. If specimen containers are used, it is essential that dimensions of both specimens and containers be highly uniform to secure a liquid zone of constant thickness, otherwise the rates of temperature change and, hence, the severity of exposure may not be the same for all specimens. Note that after each measuring period the specimens should be turned end-for-end when returned to test. In addition, the specimens should be returned to random positions in the apparatus. Particular attention should be given to the various procedures outlined for handling the specimens in the event of an interruption in the operation of the apparatus.

34.5. The above discussion is based upon experience with normal-weight concretes. It is believed that the freezing and thawing methods are applicable as well to concretes made with lighweight aggregates.

35. MAKING, ACCELERATED CURING, AND TESTING CONCRETE COMPRESSION TEST SPECIMENS *(See Test Method C 684)*[2]

There are two primary purposes for using accelerated or early-age strength testing. The first is to obtain reliable information at the earliest possible age about the potential strength of a concrete mixture. The other is to provide information on the variability of the concrete production process so that appropriate corrective actions can be taken as promptly as is possible.

35.1 Rather than wait until an age of 28 days to perform a standard compression test, as is commonly done, strength tests may be performed at ages as early as 24 h depending on which procedure is used. These early age tests are made after specimens are subjected to either standard or elevated temperature curing.

35.2 In this test method, elevated curing temperatures are provided so as to accelerate the cement hydration reactions. Depending on the procedure that is used, compression tests are performed at ages ranging from 24 to 48 h. At these early test ages, the strength of concrete is highly dependent on the actual temperature history, and proper control of curing temperatures is essential in order to reduce day-to-day variability in test results. Thus, it is essential to keep accurate records of the curing temperatures of the specimens.

35.2.1 The concrete specimens are exposed to elevated temperatures and stored either under water or in sealed containers. The cylinder molds must retain their original shapes during curing to minimize the possibility of induced early-age damage to the concrete resulting from dimensional changes of the molds because of high temperature and moisture. Cardboard molds and single-use plastic molds are not permitted for making specimens.

35.2.2 In procedure A, the warm water method, the specimens are stored in a water bath whose temperature must be maintained at 95 ± 5 °F (35 ± 3 °C). To minimize variability of test results the design of the curing tank must assure uniform water temperature. This may be achieved by using mechanical stirrers, circulating pumps, or natural convection currents. To achieve uniform temperature through convection currents, the heating elements must be uniformly distributed over the bottom of the tank. Before using a curing tank, the water temperature at various locations should be measured to assure that the required degree of uniformity is achieved. In addition, the heaters should be of sufficient capacity to re-establish the required temperature within 15 min after immersion of the colder specimens. The ability of the curing tank system to satisfy this requirement shall be verified by pretesting.

35.2.3 In procedure B, the boiling-water method, the specimens are stored for the first 23 h at an ambient temperature of 70 ± 10 °F (21 ± 6 °C). To minimize day to day variability in test results, the ambient temperature conditions should be maintained as close as practicable to a constant value throughout the testing program.

35.2.4 In procedure C, the Autogenous Method, elevated temperature is provided by containing the heat evolved by cement hydration. The temperature history of a particular specimen depends on the total heat evolution, the insulating efficiency of the container, and ambient temperature history for the container. In interpreting test results account must be made of the actual temperature histories experienced by the specimens. Thus it may be desirable to monitor not only the minimum and maximum temperature but also the complete temperature history of representative specimens.

35.2.4.1 When accelerated curing tests are used for estimating an equivalent 28-day strength under conventional standard curing conditions, a correlation relationship must be developed by performing conventional and accelerated curing tests of concrete mixtures made with the same materials. In developing this data, mixtures with different water-cement ratios must be prepared so that a wide range of strength levels can be obtained. The correlation data should be subjected to rigorous statistical analysis so that meaningful confidence limits can be placed on the predicted 28-day strengths. The user is directed to the following publications for guidance on proper statistical treatment of data from accelerated curing tests: *ASTM STP 169 B* (Significance of Tests and Properties of Concrete and Concrete-Making Materials); *ACI 214.1R-81* (Use of Accelerated Strength Testing); and *ACI SP-56* (Accelerated Strength Testing). It must be emphasized that the correlation relationship is only applicable for the same materials and testing conditions used in its development.

35.3 The variability of properly conducted accelerated strength tests have been found to be similar to strength tests under conventional curing conditions. Hence, accelerated strength test results can be used directly to monitor the variability of concrete production and to signal the need for process adjustments. Correlation relationships or prediction equations are not required for such applications.

36. REDUCING SAMPLES OF AGGREGATE TO TESTING SIZE *(See Practice C 702)*[2]

36.1 The concrete laboratory will frequently find it necessary to reduce a sample of aggregate to a smaller volume. Such reduction in sample volume must be done very carefully if the resulting smaller sample is to represent the larger lot accurately. Fine aggregate should be moistened before reduction to minimize segregation and loss of dust, except when using an enclosed sample splitter. Practice C 702 describes procedures for reducing field samples of aggregate to the appropriate size for testing which minimize variations in characteristics between the test samples so selected.

36.2 When quartering is performed, be sure to clean the floor when a tarp is not used. If the material contains a significant amount of fines, be sure to retain all of this material.

37. MEASURING EARLY-AGE COMPRESSIVE STRENGTH AND PROJECTING LATER-AGE STRENGTH *(See Test Method C 918)*[2]

This test method uses the maturity concept and the strength versus maturity relationship proposed by Plowman (*Magazine of Concrete Research*, V.8, N.22, March 1956). Test specimens are cured following Practices C 31 or C 192, and a record is maintained of the temperature immediately adjacent to the specimens. At an early age of about 24 h, the specimens are tested in compression. The value of maturity is calculated from the test age and the temperature record. Since most specimens will be tested prior to an age of about 48 h, protection precautions in Practice C 31 concerning transportation and handling of early-age specimens should be followed.

37.1 The early-age strength and maturity values may be used to estimate the later age, such as 28-day, compressive strength or may be compared to concrete mixture design data at similar maturity. Later-age strengths are estimated by using a previously established prediction equation that was developed for the specific concrete being tested. The prediction equation is obtained by measuring the maturity and compressive strength of specimens at ages from 24 h to 28 days, plotting the test results on a semi-log scale, and deriving the best fitting equation for the data.

38. USE OF UNBONDED CAPS IN DETERMINATION OF COMPRESSIVE STRENGTH OF HARDENED CONCRETE CYLINDERS *(See Practice C 1231)*[2]

An alternative to the sulfur, gypsum, or cement capping methods of Practice C 617 is the unbonded method described in Practice C 1231. The practice describes the use of elastomeric pads and metal retaining rings, commonly known as pad caps, in testing concrete cylinders. The testing of cores by this practice is not permitted. The practice may be used when anticipated strength levels are between 1 500 and 12 000 psi (10 to 85 mPa). Cylinder ends with depressions greater than 0.20 in. (5 mm) must be sawn or ground prior to using pad caps. If the ends of cylinders meet the requirements of Test Method C 39/C 39M for planeness they may be tested with no caps. Although pad caps may be used on one end of the cylinder in combination with methods mentioned in Practice C 617 on the other end, normally the pad caps are used on both ends of the cylinder. For testing, the pads are placed in the retaining rings and then placed on the ends of the cylinder. The cylinder and caps are then centered in the compression machine using the upper spherical block and upper retaining ring. After rotating the upper spherically seated bearing block as contact is made, the test specimen is initially loaded up to 10 % of the anticipated total load and the cylinder is checked for perpendicularity. When the cylinder is properly positioned, the test is completed in accordance with the procedure described in Test Method C 39/C 39M.

38.1 Neoprene pads conforming to the requirement listed in the Elastomeric Pad Section of the practice need not be qualified when used below 7 000 psi. Other elastomers are permitted but must be qualified. The pads are required to have a Shore "A" durometer hardness in a range of 50 to 70. The pad distributes the force of the compression over the entire surface area of the cylinder by acting as a hydraulic fluid. Different strength levels require different durometer hardness. Pad manufacturers are required to supply the durometer hardness. Use the table located in the practice to determine the correct hardness number to be used and when qualification is required.

38.1.1 The number of cylinders that can be tested using the same pads varies with the strength levels of the concrete cylinders being tested and the hardness of the pad. Pads with high durometer hardness generally last longer than softer pads when testing cylinders at higher strength levels. Use the table in the practice to refer to the maximum number of reuses.

38.2 Neoprene pads need not be qualified when testing concrete with strength levels below 7000 psi and with less than 100 reuses. Pads must be qualified after 100 reuses, if they are made from a material other than the neoprene listed in the Elastomeric Pad Section of the practice , or if the strength level exceeds 7 000 psi. When qualification is required, contact the manufacturer to see if they have the necessary qualification data. If qualification tests are required; requalify the system when one of the following items have changed: (*1*) pad material, (*2*) pad dimensions, (*3*) pad hardness, (*4*) retaining ring design, and (*5*) retaining ring material. However, variations of a particular parameter need to be qualified only once. Pad cap systems are qualified by testing companion cylinders; one ground or capped in accordance with Practice C 617 and the other tested using pad caps. Companion cylinders are cylinders made from the same batch, at the same time, by the same technician. A minimum of ten sets of companion cylinders shall be tested at the minimum strength level and ten sets at the maximum strength level at which the pad caps will be used. These test results must be within a range of 1 000 psi, for each strength level. Additional companion cylinders may be needed to qualify the system. All test results of companion cylinders for a desired strength level should be included in the calculation for qualification. Pad cap systems are considered to be qualified if the results of the comparison tests indicate that pad caps did not reduce the strength of the concrete by more than two percent when compared with the cylinders which have been ground or capped in accordance with Practice C 617. If the laboratory wishes to use the pad beyond 100 uses, then it must be checked again at 200 uses. The cylinders used in these qualification tests must be within a range of 2 000 psi of each strength level.

38.3 The design of the retaining ring is important in the pad cap system. Erroneous strength results are often produced when cylinders are not properly centered in the testing machine. Since the cylinder is centered in the testing machine by centering the retaining ring on the upper bearing block, a means for centering the retaining ring should be considered. Centering the cylinder is easy when the diameter of the retaining ring is the same diameter as that of the bearing block. The practice requires that the diameter of the pad shall not be more than 1⁄16 in. (2 mm) smaller than the inside diameter of the retaining ring. Experience has shown that the inside diameter of the pad should be as close as possible to the inside diameter of the retaining ring. The smaller the gap between the ring and the pad, the less the pad will deform or spread laterally. Reducing the amount of lateral deformation or spread will reduce the amount of cracks along the edge of the pad and increase pad life. The practice requires that the base of the ring which contacts the bearing blocks of the compression machine must be plane to 0.002 in. (0.05 mm).

38.4 In addition to being properly centered in the testing machine, the cylinder must be tested in the vertical position. The pad is made of soft material and the only method to ensure that the cylinder is perpendicular to the platen of the compression machine is to check the perpendicularity of the cylinder under load.

38.4.1 Center the pad caps on the cylinder and place the cylinder on the lower platen of the testing machine. To ensure perpendicularity, the cylinder should be oriented with the finished end toward the upper spherical block. As the upper spherically seated block is brought to bear on the pad cap, make sure to carefully center the upper pad on the block and rotate the block's movable portion gently by hand so that uniform seating is obtained.

38.4.2 Begin applying load to the cylinder. Before the load has reached 10 % of the anticipated cylinder strength, stop increasing the load. While holding the load constant, check to see that the cylinder is vertical within a tolerance of 1⁄8 inch in 12 inches (3 mm in 300 mm) and that the ends of the cylinder are centered in the retaining rings. This is accomplished by placing a carpenters square or drafting triangle with the corner cut out to accommodate the retaining ring on the platen and noting the gap at the cylinder. This should be done twice 90° apart. A pin of appropriate diameter can be used to check the gap. If the cylinder alignment does not meet these requirements, release the load; remove the cylinder; and, check for debris on the pad or platen. Rechecking the ends to make sure that the cylinder itself meets the 1⁄8 inch in 12 inches (3 mm in 300 mm) criteria may be necessary. If it does not, minor corrections can be made by sulfur mortar capping as long as the cylinder meets the 1⁄8 in 6 inches (3 mm in 150 mm) requirement in the End Condition section of Practice C 617. If the cylinder cannot be capped, the cylinder end must be corrected by sawing or grinding. If the cylinder does meet the requirements, repeat the above procedure, rechecking the centering and alignment of the cylinder. If the cylinder is not perpendicular to the platen of the machine, the ultimate strength may be reduced.

38.5 The fractured cylinders will rarely display the conical fractures typical of the sulfur mortar caps. One reason for this difference is that the energy stored in the pad is released to the concrete resulting in a more explosive break with more rubble than is seen with sulfur caps. Pad capped cylinders occasionally will develop early cracking associated with the lateral flow of the cap, but will continue to carry increasing load and therefore should be tested to complete failure.

38.6 Because of the explosive nature of breaks associated with pad caps, the testing machine needs to be fitted with some form of protective cage. The sudden release of energy stored in the pads has reported to have caused damage to some compression testing machines.

39. SAMPLING AGGREGATES *(See Practice D 75)*[2]

Practice D 75 is of importance to laboratory personnel even though sampling sources of concrete aggregate is not within the scope of this manual. In many instances aggregate samples for trial batches and preliminary laboratory tests will be obtained several months before the job is started or even before the aggregates that will be used on the job are produced. Under these conditions samples must be taken with particular care. Past production records should be examined to determine if the samples taken are likely to represent material to be produced in the future. When construction is started, the material furnished to the project must be tested to determine if it is of similar quality to that used in earlier tests. When aggregate samples are for preparation of trial batches the moisture condition of the material should be noted in order that the aggregate can be incorporated in laboratory batches in a moisture condition representative of the aggregate to be used in the job concrete. This is particularly important for highly porous aggregates such as structural lightweight concrete aggregates.

39.1 Particular attention is directed to the need for observing the requirements for minimum sample sizes in different methods. Refer to the test methods to determine the number and size of test portions required. The size of sample obtained from the field should be at least twice as large as the total amount required for the tests to be conducted to provide for any waste, reruns of tests, or additional tests if required.

40. FORCE VERIFICATION OF TESTING MACHINES *(See Practices E 4)*[2]

Test Method C 39/C 39M requires verification at a 13-month maximum interval. Verification is also required after the machine is installed or relocated, whenever repairs or adjustments that affect the operation of the force applying or the load indicating system are made, and whenever there is reason to doubt the accuracy of the results. Small testing machines and machines subjected to repeated explosive breaks or operating under other unfavorable conditions may require more frequent verification.

40.1 Calibration equipment, such as proving rings and load cells, requires very careful handling, and their use is not recommended unless the operator has become familiar through experience with the methods and precautions involved. Literature from the National Institute of Standards and Technology and ASTM covers many details of requirements and use of calibration equipment. Definitions and information about verification of machines are given in Practice E 4.

40.2 The upper spherical bearing block is typically used in verification. Debris and inadequate lubrication of the spherically seated portion can directly affect the verification of the machine. Remove and disassemble the upper spherically seated bearing assembly, clean the spherical portion and spherical seat of debris and existing oil, lubricate the spherical portion with a light coating of a petroleum based oil such as a conventional motor oil, and reassemble. **Warning:** The use of a pressure type grease must be avoided because the design of the spherically seated bearing block is intended to cause the bearing block to lock into place under load and the grease will not allow this to occur, creating a potentially hazardous situation. In some machines, it is not possible to obtain verification within the required 1 % accuracy over the full range of movement of the loading platen. To ensure accurate verification, have the machine verified at the height normally used in routine testing.

40.3 During the verification operation, additional blocks should be used above and below the calibration device to protect the bearing surfaces of the testing machine. Care should be taken to avoid damage to the machine's bearing surfaces by using blocks large enough to dissipate the load. The calibration device must be properly centered in the testing machine to avoid eccentric loading errors. The operator of the calibration device should relate the zeroing technique used during the verification/calibration operation to laboratory personnel. The laboratory personnel must use this zeroing during normal testing operations to ensure accurate test results.

40.4 When verifying the compression machine with proving rings, the combination of the spherically seated bearing block, the small diameter of the proving ring at the contact surfaces, the rounded boss at the top of the proving ring, and a proving ring that is not centered may result in eccentric loading of the ring. When this occurs, the machine is no longer applying pressure directly to the top and bottom of the ring but rather to a corner of the top and the opposite corner of the bottom. **Warning:** The condition described above can cause inaccurate verification results and is extremely dangerous. In one case, the ring was thrown from the machine resulting in serious injury to the operator. During verification with proving rings, remove the spherical bearing block and replace it with a solid bearing block; or if a replacement block is not available, lock or shim the spherical block into a position parallel to the lower block or platen. The use of load cells to verify compression machines varies appreciably from the procedures used with the proving rings, but the same precautions and care should be followed with regard to eccentric loading to ensure safe and accurate verification results.