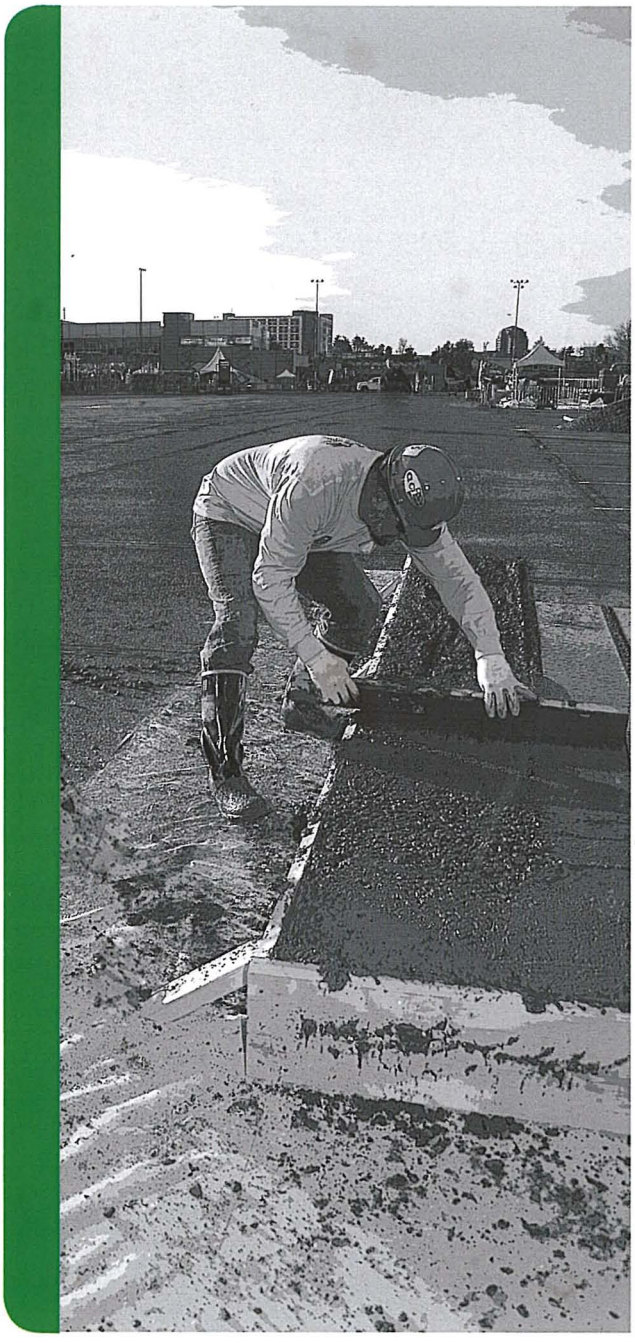


ACI Certification

Concrete Flatwork Technician & Flatwork Finisher

Craftsman Workbook
Publication CP–10(10)

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CRAFTSMAN WORKBOOK

ACI Certification Program for
Concrete Flatwork Technician and Flatwork Finisher

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Alejandro Duran-Herrera
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Colin Lobo
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Jon I. Mullarky
William D. Palmer
John J. Schemmel
Vinicio Suarez

John W. Nehasil, Staff Liaison

Developed by
ACI Committee C640—Craftsman Certification

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Cecil L. Bentley
Bryan M. Birdwell
Anthony DeCarlo
Daniel P. Dorfmueller
Robert P. Harris
Jerry A. Holland
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Steve Lloyd
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Michael E. Murray
William D. Palmer
William F. Rossi
Joseph E. Rottman

Associate Members

Kenneth Beaudoin
Kurt Brickley
David Scurto
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C. Robbins

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Editor
Claire A. Banner

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American Concrete Institute
38800 Country Club Drive
Farmington Hills, Michigan 48331
Phone (248) 848-3700 • FAX (248) 848-3701

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PREFACE

While the field of concrete technology is one of the best established in the construction industry, it is, like other fields, subject to pressure to constantly upgrade its standards. Steadily increasing requirements for not only the technology but also the personnel in the field of concrete construction make an independent national program of training and certification highly desirable.

The performance of a concrete structure, particularly concrete flatwork, is significantly influenced by the skill and knowledge of the craftsmen who constructed it. Increased concern over the availability of skilled construction craftsmen has led prominent business people and organizations such as the Business Roundtable to pressure the construction industry both to provide criteria for determining what skills and knowledge trained craftsmen need, and to establish specific training programs for them.

The American Concrete Institute provides leadership in the field by administering the Craftsman Certification Program for Concrete Flatwork Technician and Flatwork Finisher. ACI's position as an established and independent group of acknowledged concrete experts enables it to effectively operate a national certification program that is widely recognized.

The program is designed to provide a basis for certifying experienced concrete finishers, alleviate problems related to improper field practices, upgrade the quality of concrete construction, and prepare the industry for the possibility of mandatory certification in the future. Craftsmen who upgrade their skills and credentials through ACI certification may increase their own opportunities as well as contribute to the advancement of the industry.

This Craftsman Workbook (CP-10) describes the operation of the certification program and provides information necessary to prepare for the ACI certification examinations. Other materials used in this program include the ACI/PCA video Finishing Concrete Flatwork (CP-8).

Check the ACI website for updated information and/or errata/addendums:
https://www.concrete.org/publications/documenterrata.aspx

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PROGRAM INFORMATION

Purpose and Importance of ACI Certification

As the building industry continues to upgrade its standards, it is clear that craftsmen with proven credentials will have an advantage. There will likely be more and better opportunities for advancement and increased earnings in the competitive working world.

Because ACI certification demonstrates that you have the ability to pass the ACI examinations, current and future employers may consider you to be more valuable than a non-certified craftsman. ACI-certified craftsmen are able to represent themselves as skilled professionals in the concrete field. Simply pursuing ACI certification is a sign that you are the kind of employee who cares about the quality of your work.

ACI certification also has value for the future. As certification requirements become more widespread, you will find it more and more important to be certified. In addition, certification programs for construction supervisors may be offered in the future. It will be easier to attain certification at that level if you are already certified by ACI as a Concrete Flatwork Finisher.

Being certified by ACI means being recognized by an independent organization of experts in the concrete field. ACI standards for design and construction are recognized and followed around the world, and ACI certification of the people working in the concrete field has the same wide recognition. This makes it one of the best ways of advancing your career in concrete construction.

Overview of the ACI Program

Achieving certification from ACI as a Concrete Flatwork Finisher involves meeting the one of the following requirements:

CRITERIA A

1. One year (1500 hours) of verified work experience in finishing concrete flatwork including experience in placement, consolidation, finishing, jointing, curing, and protection of concrete flatwork.
2. A passing grade on the ACI written examination.
3. Successful completion of the ACI performance examination (or equivalent).

CRITERIA B

1. Three years (4500 hours) of verified work experience in finishing concrete flatwork including experience in placement, consolidation, finishing, jointing, curing, and protection of concrete flatwork.
2. A passing grade on the ACI written examination.
3. Successful completion of the Work Experience Form for Flatwork or the Client Affidavit for Flatwork Finisher.

In addition, ACI offers Concrete Flatwork Technician certification for individuals who pass the written examination but have not satisfied the performance evaluation requirement nor possess the necessary work experience to be granted Finisher certification.

Administration

The American Concrete Institute, through its Certification Programs Committee, administers the certification program. This includes the development and maintenance of all program policies and procedures, instructional materials, and examinations.

The ACI certification program is conducted by a sponsoring group, such as an ACI chapter, a state or local concrete industry association, a college or university, or other organization committed to upgrading the quality of concrete. This group is responsible for scheduling and conducting all sessions; arrangement of facilities, material, equipment, and personnel; payment of all bills; and establishment and collection of all registration fees.

The ACI Certification Department assists the sponsoring groups in setting up the program and manages the daily operation of the program. This includes the publication and dissemination of all instructional materials and examinations, grading examinations, maintenance of certification records, and issuance of certification to successful candidates.

Definitions

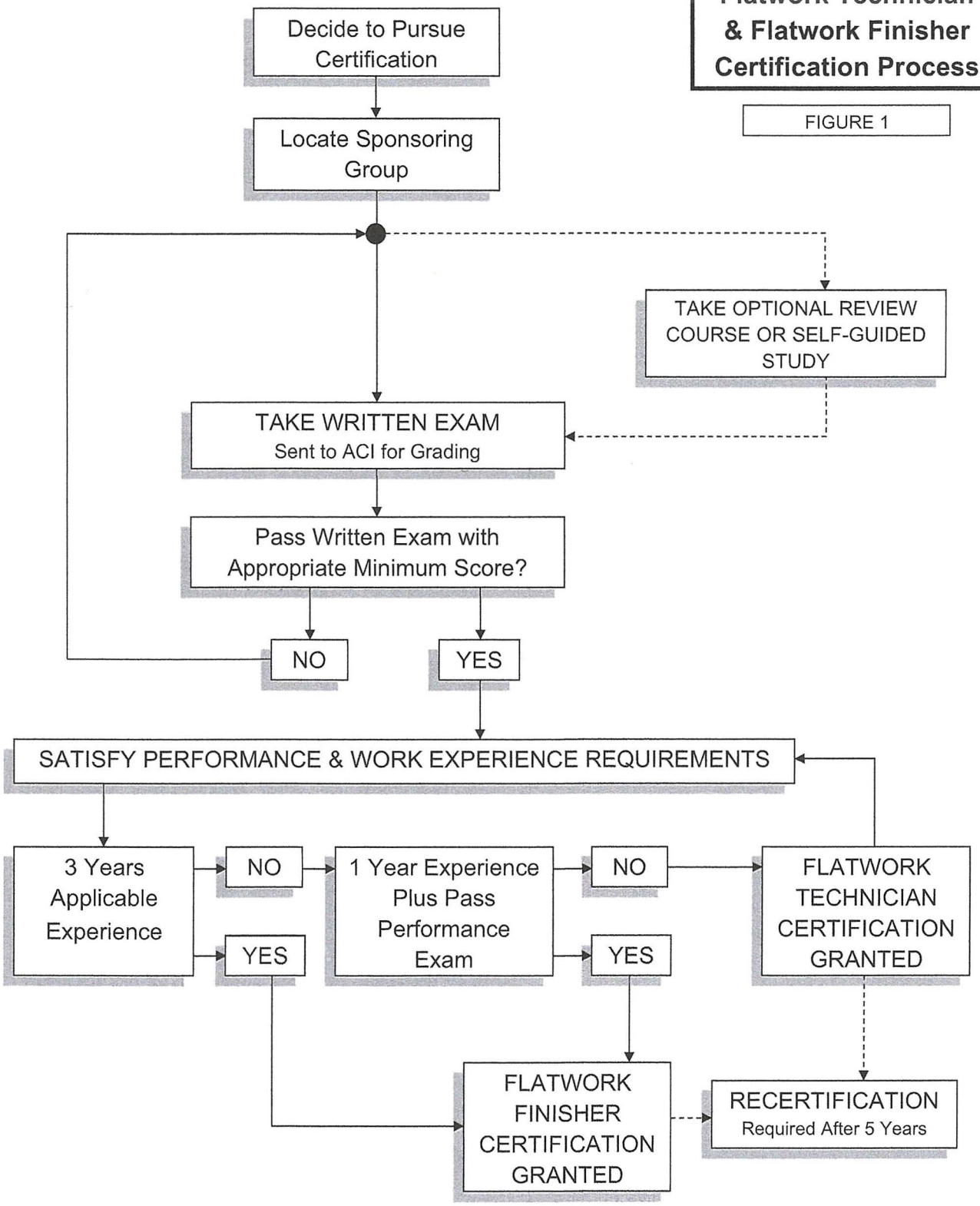
ACI — The American Concrete Institute (38800 Country Club Drive, Farmington Hills, Michigan 48331) which developed and published the instructional materials and examinations used in this program, and which certifies individuals who satisfy all requirements of the this program.

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ACI Concrete Flatwork Technician & Flatwork Finisher Certification Process

FIGURE 1



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ACI Certification — A formal recognition, valid for fa specified period of time, which shows that a person has satisfactorily completed the certification requirements.

ACI Certification Department — The department within ACI that manages the certification programs.

ACI Concrete Flatwork Finisher — A person who has demonstrated proficiency in and an understanding of proper procedures and techniques for placing, finishing, jointing, curing, and protection of concrete flatwork by passing the ACI written examination and by meeting the performance evaluation and work experience requirements.

ACI Concrete Flatwork Technician — A person who has an understanding of proper procedures and techniques for placing, finishing, jointing, curing, and protection of concrete flatwork by passing the ACI written examination.

Applicant — A person who has submitted work experience information and intends to become an examinee.

ASTM — ASTM International (100 Barr Harbor Drive, West Conshohocken, Pennsylvania 19428), which developed and published technical standards used in this program.

Concrete Construction Publications, Inc. — (World of Concrete Center, Addison, Illinois 60101) Publishers of *Guide to Finishing and Related Problems* by J.C. "Skip" Yeager, one of the resource materials used in the Training Course.

Examinee — A person who is participating in the ACI certification examination(s).

Examiner — A person knowledgeable in concrete finishing who is approved by ACI and authorized to evaluate the qualifications of applicants and conduct the examinations locally.

Recertification — A process, undertaken every five years after original certification, by which a certified individual renews certification by successfully completing the then-current certification requirements.

Respondent — A person, usually a present or former employer of an applicant, who verifies information concerning work experience submitted by the applicant.

Sponsoring Group — The local organization (such as an ACI chapter, trade association, public agency or private company in the construction industry) which takes responsibility for conducting the certification examinations in its locality and, as a recommended option, for conducting a review course.

Supplemental Examiner — A person knowledgeable in concrete finishing who is chosen by the Examiner to assist in conducting the performance evaluation.

Trial — In the performance examination, one of two attempts allowed for the examinee to successfully perform each step of the procedure.

PCA — The Portland Cement Association (5420 Old Orchard Road, Skokie, Illinois 60077), which co-produced the video training *Finishing Concrete Flatwork* used in this program.

Proctor — A person who is chosen by the Examiner to assist in conducting the written examination.

Resource Materials

This technician workbook is the primary resource for Concrete Flatwork Finisher and Technician certifications and contains the essential resource material you need to prepare for the examinations.

The **Program Information** section contains general information about this ACI certification program and describes all policies, procedures, and requirements in detail.

The resource materials are divided into eight **Sections**, containing technical material taken from the required course text, *Slabs on Grade* (ACI Publication CCS–1). These sections also contain study questions for the written examination and the performance evaluation (Sections 5, 6, and 7 only).

Preparation for the Examinations

ACI recommends that you attend a review course prior to the examinations, if offered by the sponsoring group. Sponsoring groups typically have access to resources (laboratory equipment and time, video training materials, etc.) that an individual does not. Course content and instructional time varies between sponsoring groups depending upon local needs.

Your success on the ACI examinations will ultimately depend on your willingness to invest an adequate amount of time studying before and after a review course. It is recommended that you allow 6 to 8 hours before the course reviewing background information on concrete testing and technology and reading through the relevant resources. Then, after you have completed the review course, allocate another eight to ten hours reviewing the resources and practicing the methods.

Examinees are not required to participate in a review course, but preparing for the examinations without the benefit of the review course is not recommended. If a review course is not offered, or if you choose not to enroll in the course when offered, you should prepare a course of self-study.

Remember that your individual study, with or without the training course, can mean the difference between passing and failing the ACI examinations.

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Written Examination

The written examination consists of approximately fifty (50) multiple-choice and/or true-false questions. The passing grade is 70%. The examination is closed-book; you may not have access to any publications or notes during the examination. All examinees are expected to finish the examination within two (2) hours.

In the written examination, you are expected to demonstrate a basic knowledge of concrete flatwork construction, including:

1. Basic concrete technology
2. Concrete materials and mix proportioning
3. Concrete control tests
4. Proper use of placing and finishing tools
5. Placing, finishing, and jointing
6. Curing and protection

THE EXAMINATION MAY BE GIVEN TO YOU VERBALLY IF NECESSARY. All requests for verbal examinations must be made directly to the Examiner. The Examiner will then decide when and how to arrange the examination.

Performance Examination

During the performance evaluation, you will be expected to place, finish, edge, joint, and begin curing a concrete slab. During the performance examination, you are required to perform the correct procedures for each procedure in the direct presence of the examiner or a supplemental examiner. You may not refer to notes or any other written material during the trial. Talking is not prohibited during the examination, but it is not necessary. The examiner is not allowed to respond to any questions which would serve to assist you in performing the tests. You must therefore refrain from asking for or accepting coaching or advice while the examination is in progress.

Immediately following completion of each trial, the examiner will tell you whether you passed or failed that trial. If a failure has occurred, the examiner will tell you which particular part of the method was performed or described (for verbal questions only) incorrectly. The examiner will not stop the trial at the point that an error is made, nor will the examiner express approval or disapproval, either verbally or nonverbally. If, during a trial, you feel that you have made an error, you may request to suspend that trial and begin the procedure over. If a trial is suspended voluntarily, it will not be counted as a failure of the trial. You may voluntarily suspend one trial per procedure.

The performance exam is physically demanding. If you feel you are risking personal injury in performing, or are unable to perform the procedures in the performance examination due to diminished physical capacity or physical disability, please inform the sponsoring group in advance of the examination date so alternative arrangements may be made.

Re-Examination

Failure of a performance examination on one or more of the required procedure will require re-examination on the entire performance examination, not just on the failed procedure(s). All procedures must be passed at the same time.

A re-examination on either written or performance exam may be taken at any time, together or independently of one another; however, both exams must be passed within one year to be considered for certification.

It is your responsibility to request re-examination. To do so, contact the examiner and/or sponsoring group to arrange a convenient time, location, and appropriate fee. If you require further assistance, contact the ACI Certification Department.

Performance Examination: Work Experience Alternative

The performance examination may be waived if you have met additional work experience requirements and equivalent work performance requirements. These requirements are as follows:

1. Two additional years (3000 hours) of experience in concrete flatwork finishing [3 years (4500 hours) total] including experience in placement, consolidation, finishing, jointing, curing, and protection of concrete flatwork
2. Proven abilities that are equivalent to those listed in the Performance Examination Checklists

The Work Experience Form for Flatwork Finisher is used to prove the amount and level of your work experience as well as your work performance abilities.

Challenges

If you encounter a test question that appears to be unclear, incorrect, or unfair, please describe your complaint on the Question Challenge Form included with your examination.

You must mark a response on your answer sheet that best answers the question. All questions

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have been formulated from the ACI standard; any challenge based on a reference from an outside document will not be considered unless the reference agrees with the ACI standard. If your explanation is found to be valid, scores will be adjusted accordingly.

All questions for the written examination and checklists for the performance examination are developed by the Craftsman Certification Committee and maintained at ACI Headquarters by the ACI Certification Department. Neither the examiner nor the sponsoring group have any jurisdiction over the content or the scoring of the written and performance examinations. However, since the performance examination is slightly more subjective in nature than the written examination, the examiner or supplemental examiners do have the authority to interpret some of the procedures on the performance examination.

Appeals

All ACI certification policies, procedures, requirements, and examination materials have been developed through the voluntary consensus process and carefully reviewed for accuracy and fairness. However, an appeal process is available in the event that you feel that some aspect of the examination administration is unclear, incorrect, or unfair (see **Challenges** for examination content disputes). If a complaint is found to be valid, ACI will adjust grades accordingly.

The first level of appeal rests with the examiner. This person is a registered professional engineer with sufficient education and experience in concrete testing and inspection to be approved by ACI as their local representative for this program.

If the examiner cannot satisfy your complaint, appeals are handled in order by the following people or groups:

1. Sponsoring Group
2. Director of Certification
3. Certification Appeals Committee
4. Committee C640—Craftsman Certification
5. Certification Programs Committee

Note: Members of the Certification Appeals Committee include the Director of Certification, the Chair of the Certification Programs Committee, and the Chair of Committee C640.

Appeals submitted directly to ACI must be received, in writing, within 60 days of the receipt of the examination at ACI Headquarters. Appeals that are not made during the examination session will not be considered.

Work Experience

In order to be approved as a Concrete Flatwork Finisher, you will need to complete the Work Experience Form for Flatwork. Approval of this form will exempt the applicant from the performance examination requirement.

Typical work histories are often a succession of different jobs, each covering different time periods and different employers. Because of this, it is possible that more than one past employer's reference will be necessary to verify overall work experience. If so, each time period corresponding to a particular job or work situation must be identified on a separate Work Experience Form.

If you are seeking Flatwork Technician Certification, you may take the written examination without submitting the Work Experience Form.

If you apply for a waiver of the performance evaluation requirement:

- The procedure for showing that the *additional* work experience requirement is met is the same as the procedure for showing that the *minimum* work experience requirement is met. You will simply need to show that you have at least three years of experience instead of one.
- The procedure for establishing that the work performance requirement is met involves having a qualified respondent (or respondents) complete Client Affidavit for Flatwork Finisher as if they were each an Examiner evaluating your skills.

If you have shown satisfactory abilities in all Parts of the evaluation while in one job, and one respondent can verify all of these abilities, then only one completed Client Affidavit Form will be required. In all other cases, more than one Client Affidavit Form must be completed.

NOTE: You have the responsibility for providing the respondent(s) with the necessary Forms. It is also recommended that you provide copies of the instructions along with the sample completed forms.

Qualifications of Respondents

In order to prove that you have met work experience requirements, one or more respondents are needed to verify the information that you give on the Work Experience Form for Flatwork Finisher. The person who is best suited to be a respondent is the owner or chief executive officer from a company where you have been employed in concrete finishing-related work. Also acceptable in verifying the minimum experience requirement are other co-employees, such as supervisors, providing

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they have a direct knowledge of your work history during the time period in question.

More strict requirements apply to respondents verifying performance abilities and additional experience for waiver of the performance evaluation requirement. In order for a Work Experience Form for Flatwork Finisher and/or a Client Affidavit for Flatwork Finisher to be considered a satisfactory substitute for taking the performance evaluation, the respondent(s) must:

1. Be the equivalent of a Project Superintendent, Project Engineer, or higher (i.e. company owner or executive officer).
2. Have had recent experience in concrete construction (especially placing, finishing, and curing concrete flatwork).
3. Be adjudged qualified by the Examiner and/or ACI.

Recertification

Your ACI certification as a Concrete Flatwork Finisher or Technician expires five years from the date that you complete the certification requirements.

A Flatwork Technician who becomes a Flatwork Finisher at any time during the five-year certification period will be recognized as a Flatwork Finisher for the remainder of that certification period. The five-year certification does not reset when the Finisher requirements are met. Your original certification and subsequent recertification periods run concurrently, not consecutively.

Recertification is granted to a Flatwork Finisher or Technician who successfully completes the then-current qualifications.

Americans with Disabilities Act (ADA)

If you have a disability and require special accommodations, please contact ACI Headquarters for further information on how to proceed. All requests for special accommodations under ADA are handled on a case-by-case basis and must be made allowing enough time for evaluation and appropriate action by ACI.

If you require additional help in completing the application and submitting the necessary documentation, contact the ACI Certification Department at (248) 848-3790.

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SECTION 1

Chapter 1—Planning for slab-on-ground placement

Introduction

Specification requirements

Determining the size of concrete placements

Ordering concrete

Concrete delivery

Equipment

Size of placing and finishing crews

Preconstruction meeting

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CHAPTER 1—PLANNING FOR A SLAB-ON-GROUND PLACEMENT

Introduction

Specifications are written to help ensure that the contractor constructs a slab-on-ground that satisfies the owner. This manual supplements specifications by presenting basic information about slab-on-ground placing and finishing practices for commercial, industrial, and institutional projects. Most of the information can also be used to improve the quality of flatwork for residential projects. In the field, concrete placements are often referred to as concrete pours. In this manual, the preferred term *placement* will be used in place of the term *pour*.

Specification requirements

Just as project specifications may require the contractor to use certified ACI Flatwork Finishers, they also may contain much more information on the specific requirements for the slab-on-ground placements. It's important that the finisher foreman read and understand the specifications (Fig. 1.1) because they convey the owner's requirements. Typical project specifications contain requirements related to:

- Material properties;
- Concrete strength and durability;
- Mixture proportions;
- Vapor retarders or barriers;
- Reinforcement;
- Slab flatness and levelness;
- Joint spacing and depth, and timing of the joint forming (whether by grooving the fresh concrete or sawing with an early-entry or conventional saw); and
- Curing and protection.

If the specifications or drawings do not address these issues, it's best to address them at the preconstruction meeting before starting any slab-on-ground placement.

Determining the size of concrete placements

Slab-on-ground placements can range from very small to more than 50,000 ft^2 (4650 m^2) in a single placement (Fig. 1.2). Refer to the sidebar for the factors to consider when determining the appropriate size of the concrete placement. The concrete delivery rate should be matched with the placing equipment capability and production capabilities of the placing and finishing crews. If a concrete producer is told to deliver 300 yd^3/hour (230 m^3/hour) to a job on which a crane and bucket can place only 50 yd^3/hour (38 m^3/hour), placement delays can cause fresh concrete properties to vary from truck to truck. Inconsistent concrete properties make the finishers' job more difficult.

Many contractors make a small first placement on every project to ensure smooth coordination between the concrete producer, the placing equipment, and the placing and finishing crews. After confirming that all activities are coordinated, placement size can be increased. Construction schedules and contractor economics typically dictate daily concrete placements of 10,000 to 20,000 ft^2 (900 to 1800 m^2) unless a laser-guided, wheel-mounted screed is used, in which case daily placements from 30,000 to 50,000 ft^2 (2800 to 4600 m^2) are possible.

Specifications for Structural Concrete
An ACI Standard

Reported by ACI Committee 301

W. Calvin McCall, Chair — Colin L. Lobo, Secretary

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This specification is a Reference Specification that the Engineer or Architect can make applicable to any construction project by citing it in the Project Specifications. The Architect/Engineer supplements the provisions of this Reference Specification as needed by designating or specifying individual project requirements.

The document covers materials and proportioning of concrete; reinforcing and prestressing steels; production, placing, finishing, and curing of concrete; and formwork design and construction. Methods of treatment of joints and embedded items, repair of surface defects, and finishing of formed and unformed surfaces are specified. Separate sections are devoted to architectural concrete, lightweight concrete, mass concrete, prestressed concrete, and shrinkage-compensating concrete. Provisions governing testing, evaluation, and acceptance of concrete as well as acceptance of the structures are included.

Keywords: admixture; aggregate; air entrainment; architectural concrete; cement; cementitious materials; cold weather; compressive strength; concrete; concrete construction; concrete durability; concrete slab; consolidation; conveyor; curing; density; exposed-aggregate finish; finish; floors; formwork; grout; grouting; hot weather; inspection; joint (construction, contraction, and isolation); lightweight concrete; mix; mixture proportion; placing; prestressed concrete; prestressing steel; reinforced concrete; reinforcement; repair; reshoring; sharing; shrinkage-compensating concrete; specification; subgrade; temperature; test; tolerance; water-cementitious material ratio; welded wire reinforcement.

NOTES TO SPECIFIER

This specification is incorporated by reference in the project specifications using the wording in P3 of the preface and including the information from the mandatory, optional, and submittal checklists following the specification.

PREFACE

P1. ACI Specification 301 is intended to be used by reference or incorporation in its entirety in the Project Specification. Do not copy individual Parts, Sections, Articles, or Paragraphs into the Project Specification, because taking them out of context may change their meaning.

P2. If Sections or Parts of ACI Specification 301 are copied into the Project Specification or any other document,

ACI 301-05 supersedes ACI 301-99 and became effective April 20, 2005.

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Fig. 1.1—ACI 301, "Specifications for Structural Concrete," requires at least one finisher or finishing supervisor to be a certified ACI Flatwork Concrete Finisher/Technician or a certified ACI Flatwork Technician.

Factors to consider when determining appropriate placement size

- Concrete delivery rate, yd^3/hour (m^3/hour);
- Placing equipment rate, yd^3/hour (m^3/hour);
- Placing crew production, yd^2/hour (m^2/hour);
- Finishing crew production, ft^2/hour (m^2/hour);
- Availability of equipment or manpower in case of a breakdown or shortage;
- Ability to install an emergency construction joint;
- Ability to handle problems that may arise due to cold or hot weather;
- Concrete setting time;
- Experience of equipment operators and placing and finishing crew;
- Floor flatness and levelness requirements;
- Specialty surface finishes, toppings, or dry-shake hardeners required;
- Construction schedule; and
- Economics

Ordering concrete

Concrete is sold by volume—in cubic yards or cubic meters—while in a freshly mixed or hardened state and as discharged from the truck mixer. The next sidebar contains

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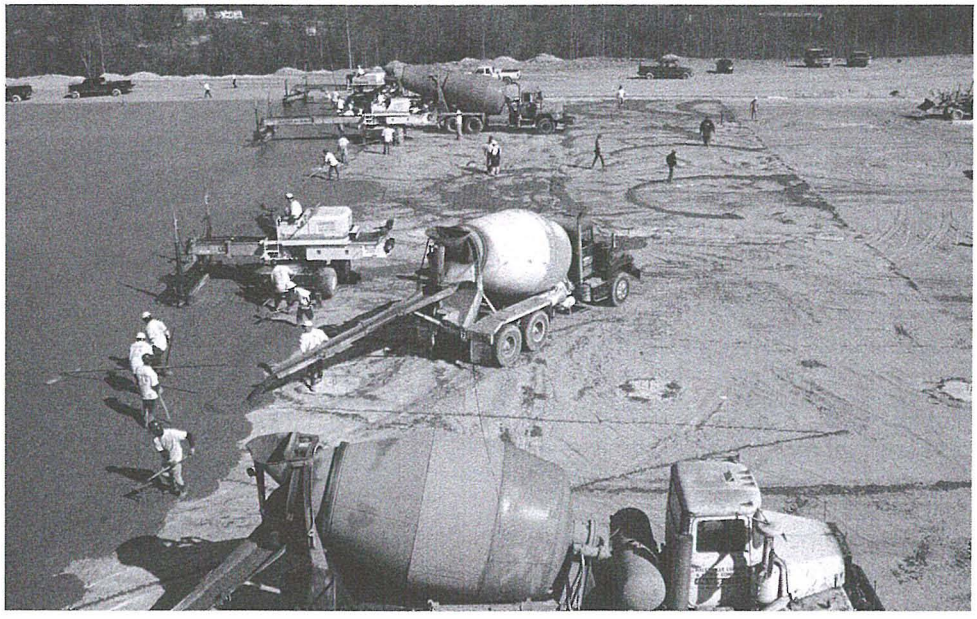


Fig. 1.2—Construction schedules and contractor economics typically require concrete placements of 10,000 to 20,000 ft^2 (900 to 1800 m^2) or from 30,000 to 50,000 ft^2 (2800 to 4600 m^2) when a laser-guided, wheel-mounted screed is used. This figure shows a 300,000 ft^2 (27,900 m^2) placement that was completed within 24 hours.

an example of how the volume of concrete needed for a slab placement is calculated.

In addition to the volume of concrete needed, the concrete producer needs to know who is ordering the concrete, what properties are required, where the concrete will be delivered, and when it is needed. Be prepared to provide an accurate delivery address, date and time of delivery, quantity, and mixture properties desired. The items in the following checklist should be given to the concrete producer when ordering concrete.

Checklist for ordering concrete

- Volume of concrete;
- Who is ordering;
- Where to deliver;
- When to deliver;
- Delivery rate; and
- Mixture properties:
  - Strength;
  - Water-cementitious material ratio;
  - Slump;
  - Air content; and
  - Maximum aggregate size.

Concrete delivery

Because fresh concrete properties start to change as soon as the concrete is mixed with water, finishers should be prepared for concrete delivery. First, make sure the truck has adequate space to enter the site and reach the placement area. This may require the use of a flagger to direct traffic and keep all other traffic out of the way when the concrete truck arrives. Other construction materials can sit for hours and

How is concrete quantity calculated?

Consider as an example a 10,000 ft^2 (900 m^2) strip concrete placement measuring 200 ft (60 m) long x 50 ft (15 m) wide and 5 in. (125 mm) thick. First, convert all measurements (length, width, and thickness) to feet (meters) and then multiply them together. This gives the volume of concrete in ft^3 (m^3). For the example, convert the 5 in. to feet by dividing by 12 to obtain 5/12 ft = 0.42 ft (convert 125 mm to meters by dividing by 1000 to obtain 125/1000 m = 0.125 m). Because all the other measurements are in feet (meters), multiply the length times the width times the thickness, or 200 ft × 50 ft × 0.42 ft to get 4200 ft^3 (60 m × 15 m × 0.125 m to get 112.5 m^3). Because there are 27 ft^3 in 1 yd^3, divide the volume in ft^3 by 27 to obtain the volume in yd^3. For this example, 4200/27 = 155.6 yd^3.

It's common to add 10% or 15% to small loads and 5% to 10% to larger orders to compensate for subgrade settlement, uneven subgrade, spillage, and waste. In this example, add 5% of the total: 155.6 yd^3 × 0.05 = 7.8 yd^3 (112.5 m^3 × 0.05 = 5.6 m^3). The volume of concrete to be ordered for this placement would be 155.6 yd^3 + 7.8 yd^3 = 163.4 yd^3 (112.5 m^3 +5.6 m^3 = 118.1 m^3). Usually, the order is rounded up to the nearest yd^3 (m^3), or 164 yd^3 (119 m^3). That would require 16 trucks carrying 10 yd^3 loads and one partial load of 4 yd^3 (15 trucks carrying 7.5 m^3 loads and one partial load of 6.5 m^3).

Some finishers mark locations on the forms where they should have placed a given volume of concrete. For this example, when the placement is halfway done, the amount of concrete used should be about 164 yd^3/2 = 82 yd^3 (119 m^3/2 = 59.5 m^3). For 10 yd^3 (7.5 m^3) trucks, about eight truckloads should have been placed at the halfway point of the placement. If more than eight trucks have discharged when the halfway point is reached, more concrete than originally anticipated may be needed to finish the placement. The concrete supply needs should be re-evaluated during placement, and any changes should be communicated to the concrete producer.

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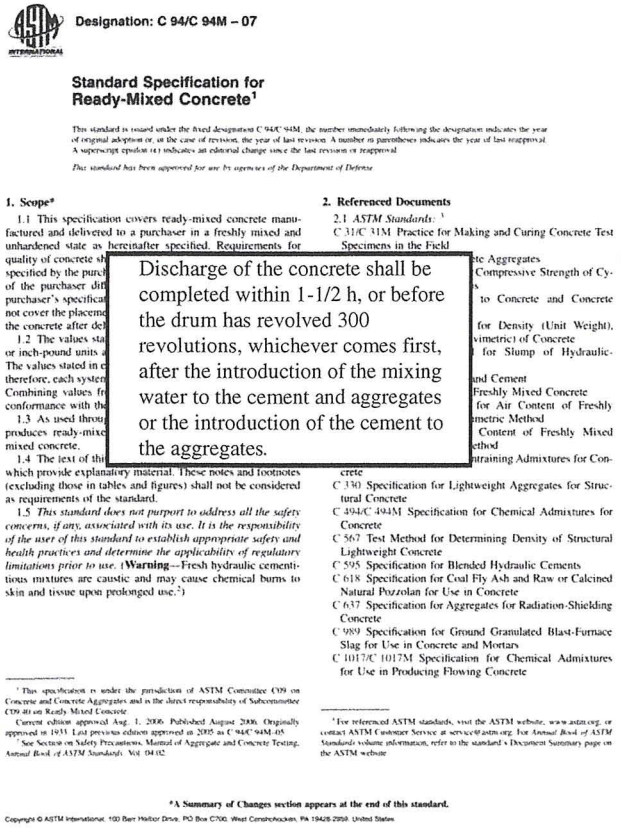
still be useable, but delays in concrete placement can result in concrete that is hard to transport, place, and finish.

Determine whether there is enough space for two or more concrete trucks to be on site and discharging concrete without truck-to-truck delays. For concrete placements using a pump, it's best to have access so that two concrete trucks can both be in position to discharge into the pump hopper. That way, as one truck is finishing, the other truck can already be backed in and ready to unload concrete so there is a continuous flow of concrete to the pump.

Most project specifications refer to ASTM C94, "Standard Specification for Ready-Mixed Concrete" (Fig. 1.3). This specification limits how long the truck can wait before the concrete is used. The concrete must usually be completely discharged within 1-1/2 hours after water has been added to the cement and aggregates or before the drum has reached 300 revolutions, whichever comes first. The truck driver's batch ticket lists the time that the concrete was loaded, so the end of the 1-1/2-hour time period can be determined. Trucks are equipped with a revolution counter that records the number of times the drum revolves. An inspector looks at the batch ticket and the revolution counter to determine if the concrete can still be used. Workers should be prepared before concrete is delivered so they can discharge the trucks before the time limit or drum revolutions is reached.

The number of trucks arriving for each placement will vary. Plan to get the trucks onto the site for discharge, then to a washout area and away from the site as quickly as possible.

A 10 yd^3 (7.5 m^3) load of concrete can be completely discharged from a concrete truck in about 4 to 5 minutes, but trucks are unlikely to discharge that quickly on most jobs. Typically, it takes about 15 to 20 minutes to empty a truck, depending on whether it can discharge completely in one spot or must be moved to different areas before the mixing drum is empty. Because of the time limit on discharging concrete, limited space at most construction sites, and congestion at the point of truck discharge, most finishers prefer concrete truck arrivals to be spaced about 15 minutes apart, especially when concrete will be discharged from the chute and onto the slab base course. This usually allows enough time for the first truck to be about empty when the next truck has arrived on site. The new load of concrete can be checked or tested, and the new truck can be positioned when the preceding truck pulls away.



Designation: C 94/C 94M – 07

Standard Specification for Ready-Mixed Concrete[1]

This standard is issued under the fixed designation C 94/C 94M; the number immediately following the designation indicates the year of original adoption or, in the case of revision, the year of last revision. A number in parentheses indicates the year of last reapproval. A superscript epsilon (ε) indicates an editorial change since the last revision or reapproval.

This standard has been approved for use by agencies of the Department of Defense.

1. Scope*

1.1 This specification covers ready-mixed concrete manufactured and delivered to a purchaser in a freshly mixed and unhardened state as hereinafter specified. Requirements for quality of concrete sh... specified by the purch... of the purchaser dif... purchaser's specifica... not cover the placeme... the concrete after del...

1.2 The values sta... or inch-pound units a... The values stated in e... therefore, each syster... Combining values fr... conformance with th...

1.3 As used throug... produces ready-mixe... mixed concrete.

1.4 The text of thi... which provide explanatory material. These notes and footnotes (excluding those in tables and figures) shall not be considered as requirements of the standard.

1.5 *This standard does not purport to address all the safety concerns, if any, associated with its use. It is the responsibility of the user of this standard to establish appropriate safety and health practices and determine the applicability of regulatory limitations prior to use.* (**Warning**—Fresh hydraulic cementitious mixtures are caustic and may cause chemical burns to skin and tissue upon prolonged use.[5])

Discharge of the concrete shall be completed within 1-1/2 h, or before the drum has revolved 300 revolutions, whichever comes first, after the introduction of the mixing water to the cement and aggregates or the introduction of the cement to the aggregates.

2. Referenced Documents

2.1 *ASTM Standards:* [3]

C 31/C 31M Practice for Making and Curing Concrete Test Specimens in the Field

...te Aggregates

...Compressive Strength of Cy-...

... to Concrete and Concrete ...

... for Density (Unit Weight), ...vimetric) of Concrete

... for Slump of Hydraulic- ...

...and Cement

...Freshly Mixed Concrete

... for Air Content of Freshly ...metric Method

... Content of Freshly Mixed ...ethod

...ntraining Admixtures for Con-crete

C 330 Specification for Lightweight Aggregates for Structural Concrete

C 494/C 494M Specification for Chemical Admixtures for Concrete

C 567 Test Method for Determining Density of Structural Lightweight Concrete

C 595 Specification for Blended Hydraulic Cements

C 618 Specification for Coal Fly Ash and Raw or Calcined Natural Pozzolan for Use in Concrete

C 637 Specification for Aggregates for Radiation-Shielding Concrete

C 989 Specification for Ground Granulated Blast-Furnace Slag for Use in Concrete and Mortars

C 1017/C 1017M Specification for Chemical Admixtures for Use in Producing Flowing Concrete

[1] This specification is under the jurisdiction of ASTM Committee C09 on Concrete and Concrete Aggregates and is the direct responsibility of Subcommittee C09.40 on Ready Mixed Concrete.

Current edition approved Aug. 1, 2006. Published August 2006. Originally approved in 1933. Last previous edition approved in 2005 as C 94/C 94M-05.

[5] See Section on Safety Precautions, Manual of Aggregate and Concrete Testing, *Annual Book of ASTM Standards*, Vol 04.02.

[3] 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.

*A Summary of Changes section appears at the end of this standard.

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Fig. 1.3—Most project specifications refer to ASTM C94, "Standard Specification for Ready-Mixed Concrete."

Equipment

Required equipment for each placement varies, but some general equipment is required on each job. Spare equipment, such as vibrating screeds, power trowels, or curing compound sprayers, may be needed in case of breakdowns. Materials for installing emergency bulkheads (forms for closing a section of the slab and creating a construction joint) should also be available. Emergency bulkheads may be needed if concrete delivery is interrupted or if placing equipment breaks down and can't be replaced.

The productivity of each piece of equipment varies greatly depending on the experience of the placing and finishing crews and the concrete properties. Some average production rates to assist finishers in selecting the needed equipment (Fig. 1.4) for a placement include:

- Walk-behind power trowel: 1000 to 3000 ft^2 (90 to 280 m^2) daily;
- Ride-on trowel: 3000 to 6000 ft^2 (280 to 560 m^2) daily; and
- Laser-guided, wheel-mounted screed: 30,000 to 50,000 ft^2 (2800 to 4600 m^2) daily.

For comparison purposes, an experienced hand-finishing crew can finish about 1000 to 2000 ft^2 (90 to 190 m^2) of slab in a day.

Size of placing and finishing crews

The size of each crew affects the labor cost for the placement. Although keeping placing and finishing crew size to a minimum reduces labor costs, it might not provide enough labor to handle some possible job-site contingencies, such as:

- Workers who call in sick or are injured during the placement;
- Concrete that sets faster than expected due to weather changes;
- Inconsistent fresh concrete properties that delay finishing;
- Equipment breakdowns; and
- The need for early sawing to prevent cracking on windy days.

Overlapping placing and finishing crews provides some flexibility. If the finishing crew needs more help, some

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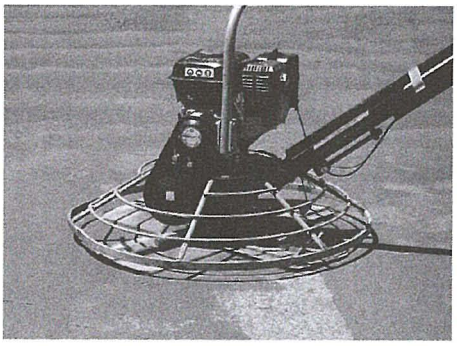
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(a)



(b)



(c)

Fig. 1.4—(a) Laser-guided, wheel-mounted screeds; (b) ride-on power trowel; and (c) a walk-behind trowel are all common equipment for slab-on-ground placements.

laborers or finishers from the placing crew can be pressed into overtime service. But what happens if the placing crew is shorthanded? One solution is to slow the concrete delivery rate to match worker output.



Fig. 1.5—The needed size of the placing crew will depend on the concrete delivery rate, the length and width of the placement, and the type of strike-off equipment used. This photo shows four workers using a truss screed to place concrete. The worker on the left turns a crank that advances the screed, the person in the middle is adjusting the screed, and the others will be using shovels or comealongs to level concrete in front of the screed.

Finishing foremen are the decision makers, and remain on site at all times. For them, 12- to 14-hour days are common. Their day starts with the placing crew and ends with the finishing crew.

Placing crew

Figure 1.5 shows a four-person crew placing concrete and describes the role of each crew member. If the concrete is pumped, requires extensive anchor bolt or other insert placement, or has other special requirements, crew size may have to be increased. Crew members or roles are as follows:

Finishing foreman—Supervise crew, review batch tickets and testing, check slump, and make decisions regarding water additions. Responsible for all activities of the placing crew;

Discharging concrete—One to two laborers to direct concrete trucks, handle chute discharge and truck movement, assist in getting concrete for testing, direct trucks to washout area, and provide general help;

Spreading concrete—Two to four laborers to level concrete in front of the screed; probably three to five laborers when using a laser-guided, wheel-mounted screed;

Screed operators—One to operate a wheel-mounted screed and one or two to operate a vibratory backpack-screed or a vibratory truss-screed. Two people are required for hand screeding;

Finishers—One to handle the bull float, one for the highway straightedge (if needed), and one to work slab edges and use a walk-behind power trowel for concrete loads that set before the finishing crew starts; and

General assistance—Two laborers are needed to provide gasoline for screeds and riding trowels, lift equipment into place, replace broken parts or shovels, provide water or bathroom breaks to other workers, lay vapor retarders, relevel subgrade, watch or fix edge forms (a carpenter may be needed if it's a union crew), reset reinforcing bar or mesh (an ironworker may be needed if it's a union crew), and other tasks as needed.

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Finishing crew

When selecting a finishing crew size, it's essential to know the characteristics of the concrete being placed and the weather conditions. Fortunately, if the concrete starts setting too fast, you can call on the finishers from the placing crew to work a little overtime so the concrete doesn't get away from you. Here's the basic finishing-crew size:

- Two or three edge finishers to work edges by hand, with machines, or both;
- One walk-behind finisher to start floating fast-setting truckloads and assist other finishers;
- Two finishers for riding trowels equipped with pans or combination blades for power floating;
- Two finishers for finish riding trowels to provide a hard-troweled finish; and
- Two laborers to help fill machines with gasoline, get evaporation retarder, saw and cure the concrete, and clean up.

Checklist for placing and finishing

The placing and finishing crews need to ensure that concrete can be placed and finished correctly and without unnecessary delays. Here are some things that should be considered to help ensure a smooth job:

- *Volume of concrete*—Ordering too little concrete can delay completion of the placement and increase cost because partial loads cost more per unit volume than full truckloads;
- *Concrete delivery rate* — A delivery rate that is too fast results in concrete trucks waiting to unload, along with a possible reduction in concrete quality and variations in setting time. A delivery rate that is too slow results in workers waiting for concrete and possible pumping problems, cold joints, and finishing difficulties;
- *Haul time*—Specifications usually require concrete to be discharged from the truck within 1-1/2 hours or 300 revolutions after water has been added to the dry ingredients. A long haul time makes it more difficult to meet this requirement, may affect the rate at which concrete can be delivered, and may cause concrete to stiffen excessively before it's discharged;
- *Truck spacing*—When concrete slabs are placed inside a building, several trucks arriving at once can result in traffic safety problems and difficulty in promptly doing the required testing;
- *Concrete placing equipment*—The delivery capabilities of the placing equipment should match the delivery rate of the concrete. Concrete pumps, conveyors, or buckets must also be spotted so trucks can approach them as easily as possible, discharge the concrete, and exit the site without causing congestion;
- *Equipment*—Having spare equipment available in case of breakdowns is prudent, if possible. At a minimum, emergency bulkheads should be available. Equipment productivity rates should be matched to placement size; and
- *Crews*—Minimize placing and finishing crew sizes, but make sure workers are available for job-site contingencies. Overlap the placing and finishing crews. Assign the proper number of workers to each necessary task and make sure each knows his or her responsibilities.

Suggested preconstruction conference agenda items

It's important that all of the relevant topics are covered during the preconstruction conference. These topics include:

- Project information and schedule;
- Project participants;
- Construction sequence and process;
- Base/subgrade preparation and acceptance;
- Site access;
- Power, lighting, and water sources;
- Concrete placing equipment and procedures;
- Vapor retarder/barrier placement;
- Concrete consolidation;
- Concrete finishing equipment and procedures;
- Floor flatness and levelness requirements;
- Jointing and sawing procedures;
- Concrete curing and protection;
- Hot and cold weather precautions;
- Concrete materials and mixtures;
- Ordering concrete;
- Concrete delivery schedule;
- Job-site adjustments to the concrete;
- Concrete test procedures;
- Distribution of test reports;
- Acceptance of concrete quality;
- Acceptance of surface finish;
- Job-site waste management;
- Job-site safety;
- Corrective actions if concrete is not acceptable; and
- Dispute resolution processes.

Preconstruction meeting

Prior to the start of a job, a concrete preconstruction conference, often called a preplacement conference, is held to define the responsibilities of the entire construction team. All members of the team meet to establish the responsibilities of the concrete producer, concrete contractor, general contractor, testing lab and inspectors, architect, engineer, and owner. A lead finisher or finisher foreman should also attend this conference. This meeting is held well in advance of the first placement so there is time for all parties to prepare to meet the assigned tasks.

Because no two jobs are ever the same, even when working with the same companies and personnel, a preconstruction conference is always needed. The conference can help sort out the details such as:

- What finisher or finishers can request the addition of water on site?
- Who at the ready mixed concrete plant receives requests from the field?
- Who is responsible for reporting results of fresh concrete tests, and to which parties?

After the preconstruction meeting, the placing and finishing crews can meet to determine their assigned tasks and how they fit the overall project goals. The sidebar provides suggested agenda items for discussion at a preconstruction conference.

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STUDY QUESTIONS

Chapter 1—Planning for slab-on-ground placement

1. It is important that the _____ _____ read and understand project specifications.

2. If the crew can place and finish 100 yd^3 (m^3) of concrete per hour, the producer's delivery rate should be about _____ yd^3 (m^3) per hour.

3. Concrete is sold by the ton. *True or False?*

4. Delays in discharging concrete trucks can result in the concrete being hard to:

   A. Pump
   B. Place
   C. Finish
   D. Pump, place, and finish

5. A) Inch/Pound:
   For a concrete floor slab that is 6 in. thick, 200 ft long, and 100 ft wide you should order _____ yd^3 of concrete, assuming a 10% waste factor.

   B) Metric:
   For a concrete floor slab that is 150 mm. thick, 60 m. long, and 30 m. wide you should order _____ m^3 of concrete, assuming a 10% waste factor.

6. When there is room for two concrete trucks ready to discharge into a pump hopper, placement is faster because:

   A. Both trucks must be discharging at the same time to keep the hopper full
   B. As one truck is finishing, the other is ready to unload concrete
   C. One driver can discharge both trucks at the same time
   D. The pump operator can discharge both trucks so drivers can take a break

7. Concrete from a ready mix truck must usually be completely discharged within _____ hours after water has been added at the plant.

8. You can tell when water was added to the concrete truck by looking at the:

   A. Bbatch ticket
   B. Revolution counter on the truck
   C. Truck number
   D. Time the concrete was ordered

9. When concrete for a slab placement will be discharged from the truck chute, truck arrivals should usually be spaced at about:

   A. 5 minutes
   B. 15 minutes
   C. 45 minutes
   D. 90 minutes

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STUDY QUESTIONS

10. When finishers get behind because the concrete is setting faster than expected and the placing crew is also shorthanded, one solution is slowing the concrete delivery rate to match worker output. *True or False?*

11. In deciding how much concrete to order for a floor placement, you should calculate the number of cubic yards (cubic meters) needed to fill the forms, then order two to three cubic yards (cubic meters) less so you don't waste concrete that is not needed. *True or False?*

12. The question, "What finisher or finishers can request addition of water to the concrete truck on site?" should be answered at the _____ _____.

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SECTION 2

Chapter 2—Concrete materials, mixture proportioning, and control tests

Portland cements

Supplementary cementitious materials

Blended cements

Aggregates

Maximum size of aggregate

Aggregate grading

Harmful substances in aggregate

Mixing water

Admixtures

Mixture proportioning

Control tests

Documents
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CHAPTER 2—CONCRETE MATERIALS, MIXTURE PROPORTIONING, AND CONTROL TESTS

Concrete is made of cement, water, and aggregates such as sand and gravel. It often contains one or more admixtures—materials that modify concrete properties. The quality of these ingredients, their proportions, and the way they are mixed all affect properties of the freshly mixed and hardened concrete.

This chapter briefly explains concrete materials, how they are combined in mixture proportioning to obtain fresh and hardened concrete properties, and how to measure those properties with control tests.

The principal ingredients that make up a concrete mixture are:

- Portland cement, other cementitious materials, or both;
- Fine aggregate;
- Coarse aggregate;
- Water; and
- Admixtures.

Concrete slabs may also contain reinforcing bars, welded wire reinforcement (also known as welded wire fabric or wire mesh), or fibers of steel, polypropylene, or other materials. Slabs that are prestressed by tightening strands placed in the slab are called post-tensioned.

Portland cements

Portland cements are hydraulic cements, which means they set and harden by reacting chemically with water, and they are able to do so under water. During the reaction, which is called hydration, they give off heat as they form a stone-like mass that binds the aggregate particles together. Most of the concrete's hydration and strength gain take place in the first month. After that there may be slow strength gains over long periods, sometimes 50 years or more. In massive structures such as dams and large piers, and in hot weather, the heat that is generated can cause cracking and strength loss. In most concrete work, however, the heat helps concrete harden and gain strength faster, particularly in cold weather.

Types of portland cement (ASTM C150)—ASTM C150, "Standard Specification for Portland Cement," defines the principal types of portland cement used in the United States:

- *Type I, normal or ordinary use*—A general-purpose cement used where the special properties of the other types are not required. It is widely used in slabs-on-ground, reinforced concrete buildings, bridges, and elsewhere when concrete is not exposed to aggressive sulfate environments;
- *Type II, moderate sulfate resistance*—Used where moderate sulfate exposure from the soil or groundwater must be resisted. It usually generates heat of hydration more slowly than Type I. Gains strength more slowly than Types I and III;
- *Type III, high early strength*—Used when high early strength is desired. It is similar to Type I, but more finely ground. It usually develops, in a week or less, the strength that Type I would produce at 28 days. It is useful when forms need to be removed early or a structure must be put into service quickly;



Fig. 2.1—Supplementary cementitious materials can be used to replace cement or improve the properties of concrete. From left to right, fly ash (Class C), metakaolin (calcined clay), silica fume, fly ash (Class F), slag cement, and calcined shale.

- *Type IV, low heat of hydration*—Used previously to control heat in mass concrete structures, like dams. Type IV cement is no longer manufactured in the United States because the use of other cementitious materials offers a less expensive way to control temperature rise; and
- *Type V, high sulfate resistance*—Used only in concrete exposed to severe sulfate action, principally where the soil or groundwater has a high sulfate content.

Type I portland cement is usually carried in stock and is supplied when the cement type is not specified. Type II is also widely available, particularly in areas with saltwater exposure or moderate sulfate content in the soil. Some cements meet the requirements for both Type I and Type II and are referred to as Type I/II cements. Types I, II, and I/II make up 90% of the cement shipped from U.S. plants.

Supplementary cementitious materials

Supplementary cementitious materials (Fig. 2.1), such as fly ash, metakaolin, calcined shale (ASTM C618), silica fume, and slag cement (ASTM C989), are used in relatively large amounts, generally replacing 10% to 50% of the portland cement. These cementitious materials are stored at the batch plant and added to the concrete similar to portland cement. Fly ash and slag cement may also be blended with portland cement by a manufacturer and stored in a single silo for addition into the concrete truck.

Slag cement has cement-like properties, meaning that it can set and harden in the presence of water. Pozzolans are materials that have little cementitious action when used alone, but when used with portland cement, they react with products of cement hydration to develop additional cementing action.

Today the most commonly used pozzolan is fly ash, a finely divided residue that is the by-product of coal-burning power plants. Fly ash particles are spheres that are somewhat finer than most portland cement particles. Class F fly ash is pozzolanic and Class C fly ash has both pozzolanic and cementitious properties.

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Silica fume (ASTM C1240), sometimes called microsilica, is a pozzolan with particles only 1/100 the size of fly ash particles. Silica fume is a by-product of induction arc furnaces in the silicon metal and ferrosilicon alloy industries. Silica fume concrete is often used to improve the durability of concrete slabs in parking structures and bridge decks.

Pozzolans, as replacement for part of the portland cement, improve the workability of fresh concrete and reduce thermal cracking in massive structures because they reduce the heat of hydration. By reducing the permeability of concrete, they also improve its durability.

Blended cements

A different ASTM standard, ASTM C595, "Standard Specification for Blended Hydraulic Cements," defines classes of blended hydraulic cements for both general and special applications. They are produced by blending two or more of the following materials:

- Portland cement;
- Slag cement;
- Fly ash;
- Other pozzolans; and
- Preblended combinations of the above materials.

The cement types produced in this way are: Type IS, portland blast-furnace slag cement; Types IP and P, portland-pozzolan cement; and Type S, slag cement. Blended cements may be used in construction when specific properties of other types of cements are not required. The concrete may not gain strength as fast as with ASTM C150 cements.

Aggregates

The sand, gravel, crushed stone, slag, and similar materials that are mixed with cement and water to make concrete are called aggregates. These materials make up 60% to 75% of the absolute (solid) volume of concrete and represent 70% to 80% of its weight. A cubic yard (cubic meter) of normalweight concrete may contain 2600 to 3200 lb (1500 to 1900 kg) of fine and coarse aggregates.

Fine aggregate—If all of the particles are smaller than 3/8 in. (9.5 mm), the aggregate is called fine aggregate. Fine aggregate is either natural sand or manufactured sand produced by crushing rock.

Coarse aggregate—If most of the particles are larger than about 1/4 in. (6 mm), the aggregate is called coarse aggregate. It may be either gravel or crushed material. Gravel usually has smoothly rounded particles, whereas crushed stone has rough, angular surfaces. Some gravel pieces, however, may be crushed to size from large pieces of gravel.

Concrete that is made without coarse aggregate is usually called mortar or grout. Most concrete used in building construction has a maximum aggregate size from 3/4 to 1-1/2 in. (19 to 38 mm).

Natural gravel and sand are usually taken from a pit, river, lake, or seabed. Aggregates from saltwater areas must be used with caution because of problems with seashell and salt content. Crushed aggregate can be made from natural gravel, quarry rock, cobbles, or boulders. Air-cooled blast-furnace slag is also crushed to make both fine and coarse aggregate. Recycled or waste concrete can also be crushed to make satisfactory aggregate. Whether the aggregate is crushed or natural, the mixture of particle sizes is not always ideal for making concrete. The aggregate producer may pass aggregate over screens that sort out particles of various sizes, then recombine them in proportions given in standard specifications.

The most common aggregates, such as sand, gravel, crushed stone, or crushed slag, make concretes weighing from 135 to 160 lb/ft^3 (2200 to 2600 kg/m^3). Structural lightweight concrete weighing from 90 to 120 lb/ft^3 (1400 to 1900 kg/m^3) is made with aggregates of expanded shale, fired clay, slate, or slag.

Normalweight aggregate should meet the requirements of ASTM C33, "Standard Specification for Concrete Aggregates," and lightweight aggregate should meet ASTM C330, "Standard Specification for Lightweight Aggregates for Structural Concrete." A number of tests can be made to determine if an aggregate can be used to make strong, durable concrete. Some important aggregate properties that affect the quality of the concrete are:

- Maximum size;
- Grading;
- Particle shape;
- Hardness;
- Organic impurities;
- Silt and clay content;
- Amount of coarse and fine aggregate in the mixture; and
- Surface or absorbed moisture in the aggregate.

Maximum size of aggregate

The largest aggregate that can be used depends on the size and shape of the member to be constructed and on the spacing and location of reinforcing steel in it. In slabs, the largest aggregate must not be more than 1/3 the slab thickness. The designer typically chooses the largest economically available aggregate that will meet this limitation because larger aggregate helps reduce cement and water content of the mixture, thereby reducing potential shrinkage.

Aggregate grading

Aggregate is made up of particles of many different sizes. To make consistent concrete batches, the aggregate amount and distribution of particle sizes must be controlled. To measure the particle sizes, a dry sample of the aggregate is passed through a number of standardized sieves starting with the largest openings and using smaller and smaller openings in successive sieves. The grading can then be precisely defined by the total weight passing each sieve. This is called sieve analysis, and ASTM C136, "Standard Test Method for Sieve Analysis of Fine and Coarse Aggregates," explains how to do it.

Standard sieves have square openings. When inch-pound units are used and the openings are 1/4 in. or larger, the sieve size is given as the opening size, such as 3/4 in. or 3/8 in. Sieves with openings smaller than 1/4 in. are named in terms of the number of openings per linear inch. For example, a No. 8 sieve has 8 openings per inch in both directions, or 8 × 8 = 64 openings per square inch.

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There are several reasons why ASTM C33 specifies grading limits and defines maximum aggregate sizes. Ease of placement, pumpability, finishability, and other fresh concrete properties can be affected by grading and aggregate size. Variations in grading can also affect the uniformity of concrete from one batch to the next. Too many small particles will increase the amount of water needed to make the concrete workable. If more water is added without also adding cement, the concrete will be weaker. If more water and cement are added in the same ratio of water to cement, the concrete won't be weakened, but it will cost more and will shrink more when it dries. This increases the chances of cracking. In general, aggregate that does not have a large deficiency or excess of aggregate passing each of the sieves will produce the best results. These aggregates are said to have a smooth grading curve. The specific grading selected is less critical than the need to prevent variation from batch to batch.

Although ASTM C33 requirements for aggregate are acceptable for floor slabs, ACI 302.1R, "Guide for Concrete Floor and Slab Construction," recommends using material near the upper limits specified for material passing the No. 50 and No. 100 (300 μm and 150 μm) sieves.

Harmful substances in aggregate

Most specifications limit the amount of potentially harmful substances in aggregates. A primary concern is that poor aggregates will harm the durability of concrete. Where there is more than 5% of a sand sample passing the No. 200 (75 μm) sieve, more water may be needed as well. Table 2.1 shows some harmful materials and the problems they may cause.

In addition to the items in Table 2.1, organic impurities such as peat and humus may delay setting and hardening of concrete and reduce its strength gain.

Many impurities can cause popouts (Fig. 2.2) (the breaking away of small parts of a concrete surface due to localized internal pressure). Typically, popouts are caused by freezing of moisture in unsound aggregates or excessive expansion of aggregate due to moisture gain, chemical reactions, or both. Popouts typically leave cone-shaped holes in the concrete surface.

Mixing water

Water quality is a concern because chemicals in it, even in very small amounts, sometimes change the setting time, strength, or durability of the concrete. Almost any natural water that is drinkable can be used to make concrete. Treated city water (tap water) is also suitable for making concrete. Some water that is not drinkable, including recycled washout water from concrete trucks, may also be used, but tests should be made of such water before use. Mortar cube tests (ASTM C109, "Standard Test Method for Compressive Strength of Hydraulic Cement Mortars (Using 2-in. or [50-mm] Cube Specimens)") made with the proposed water can verify the effect on concrete strength, but possible adverse effects on other properties such as shrinkage and setting time should be considered.

Table 2.1—Harmful substances in aggregates (from ASTM C33)

Item	Fine aggregate	Coarse aggregate
Clay lumps and friable particles	Unsound particles may affect durability and workability, cause popouts, increase water demand of mix	
Coal and lignite	Affect surface appearance; cause popouts and difficulty in air entrainment	
Material finer than No. 200 (75 μm) sieve	Affects bond of paste to aggregate and increases the mix water demand	Can cause trouble when it exists as a coating on coarse aggregate
Soft particles	—	Reduce durability and surface hardness
Lightweight chert (specific gravity less than 2.40)	—	Reduces durability; a main cause of popouts



Fig. 2.2—Popouts are caused by freezing of moisture in unsound aggregates or excessive expansion of aggregate due to moisture gain, chemical reactions, or both.

Admixtures

Any material deliberately added before or during the mixing of concrete other than cementitious materials, water, aggregate, and fiber reinforcement is called an admixture. There are many kinds of admixtures, including:

- Air-entraining admixtures;
- Accelerating admixtures;
- Retarding admixtures;
- Water-reducing admixtures;
- High-range, water-reducing admixtures (superplasticizers); and
- Miscellaneous specific-purpose admixtures, such as colors, corrosion inhibitors, pumping aids, and latex modifiers.

The following ASTM standards provide additional information on admixtures:

- ASTM C260, "Standard Specification for Air-Entraining Admixtures for Concrete;"
- ASTM C494, "Standard Specification for Chemical Admixtures for Concrete;" and
- ASTM C1017, "Standard Specification for Chemical Admixtures for Use in Producing Flowing Concrete."

Air-entraining admixtures (ASTM C260) Air-entraining admixtures create microscopic air bubbles in concrete. The bubbles are formed by the mixing action, and the air-

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entraining agents keep the bubbles from breaking up. Entrained air should not be confused with entrapped air, which consists of ordinary, larger air bubbles trapped in the concrete during mixing and placing. The purposely entrained air bubbles are uniformly distributed throughout the concrete, giving it greatly improved ability to withstand damage caused by freezing and thawing cycles.

If hardened concrete is wet and then freezes, moisture in the concrete expands as it turns into ice. As the moisture expands, it is forced to move through the pores in the cement paste. If the moisture must move very far, pressures high enough to crack the concrete can develop. The entrained air bubbles act as empty chambers into which the expanding water can flow, thus relieving the otherwise disruptive pressure. Entrained air also makes concrete more workable for a given water content and helps reduce bleeding and segregation. All concrete that will be subject to freezing when moist or be exposed to deicing salts should contain entrained air.

Accelerating admixtures (ASTM C494)—Accelerating admixtures speed up the setting and hardening of concrete. They are especially useful in cold weather because concrete hardens slowly at temperatures below about 50°F (10°C). In the past, the most common of these admixtures was calcium chloride. Calcium chloride in concrete, however, increases the potential for corrosion of reinforcing steel and some other metals. When required by the specifications, non-chloride accelerating admixtures are available for use.

Retarding admixtures (ASTM C494)—Retarding admixtures slow down the initial setting of the concrete. They are often used in hot weather to keep the concrete from setting before it can be placed and finished. Most retarding admixtures are also water-reducing admixtures. They do not reduce slump loss—an increase in concrete stiffness with time—which is caused by a combination of evaporation and hydration reactions. Slump is a measure of concrete's stiffness or consistency and is described in more detail later in this chapter.

Water-reducing admixtures (ASTM C494)—Water-reducing admixtures, as the name suggests, reduce the amount of water needed to produce concrete of a given slump. If they are put into a mixture without reducing the amount of water, water-reducing admixtures will increase the slump of the concrete. Some water-reducing admixtures contain calcium chloride. Mid-range water-reducing admixtures have been on the market for some time but are not yet covered in ASTM C494. They reduce the water requirement more than normal water-reducing admixtures, and usually don't affect the set time as much. They can, however, entrain air above the 3% level that ACI 302.1R recommends as the maximum for slabs requiring a hard-trowel finish.

High-range water-reducing admixtures (ASTM C494 and C1017)—High-range water-reducing admixtures are commonly called superplasticizers. They reduce the water requirement for concrete dramatically. They can be used to temporarily increase the slump or flowability of normal or stiff concrete to make it more flowable and easier to place in areas of congested reinforcement. They can also be used to reduce the water needed while improving workability of concretes that are consolidated by vibration. High-range water-reducing admixtures maintain slump for only an extended period that varies depending on the product and concrete temperatures; the concrete may then stiffen rapidly. They are usually added at the batch plant but can be added on site to prolong the concrete's effective slump. Their use does not necessarily reduce shrinkage.

Mixture proportioning

Concrete mixtures for commercial or industrial slabs-on-ground are usually proportioned by laboratories that specialize in concrete testing and proportioning. Standard guidelines for proportioning are given in ACI 211.1, "Standard Practice for Selecting Proportions for Normal, Heavyweight, and Mass Concrete."

The ideal amount of cement, water, aggregates, and admixtures needed to produce a volume of concrete are selected based on a combination of experience and trial batches. The goal is to meet four objectives:

1. The hardened concrete will have the strength, wear resistance, and durability called for by the job specifications;
2. The fresh concrete will be workable enough for the job;
3. The mixture will be economical; and
4. Shrinkage will be minimized.

Strength depends largely on the water-cement (or water-cementitious material) ratio. For any given set of materials, there is a certain water-cement ratio that will result in a given strength. This ratio can be estimated from tests of concretes made with different water-cement ratios. Increasing the amount of water without increasing the amount of cement generally results in lower strength.

Wear resistance depends on concrete strength or water-cement ratio at the concrete surface and on the hardness of the aggregates. Because wear resistance is also affected by finishing and curing, the mixture should be proportioned to take into account the type of finishing and curing expected. If the floor will be used for severe traffic, hard aggregates and high strength will be needed. Oversanded mixtures (mixtures with more fine aggregate than needed) are likely to produce floors with poor wear resistance and excessive shrinkage.

Durability usually means resistance to damage caused by freezing and thawing. Air-entrained concrete is able to withstand freezing and thawing much better than non-air-entrained concrete. Air entrainment should be used for all concrete that will be exposed to cycles of freezing and thawing in service.

Workability of concrete is the ease with which concrete can be placed, consolidated, and finished without causing harmful segregation. It's difficult to measure workability, but finishers who work with concrete can judge if one mixture is more workable than another. Proportioning a concrete mixture is an art as well as a science. Concrete with a water-cementitious material ratio of 0.5 and a slump up to 6 in. (150 mm) has been routinely used for slabs with good results, when good construction and curing practices are followed.

To produce concrete that is economical (but still has the required strength, wear resistance, durability, and workability), laboratory technicians and engineers use the least amount of cement that will give the required water-cement

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ratio and the greatest amount of coarse aggregate that will result in a workable and finishable mixture.

Low shrinkage is important in concrete slabs because it helps reduce cracking and curling. To minimize shrinkage, use aggregate with low shrinkage; use as much coarse aggregate as possible and the largest economical size without sacrificing workability; reduce the total water in the mixture, not just the water-cement ratio; and use admixtures that have been verified by test to produce low-shrinkage concrete.

Mixture proportions are frequently governed by specifications for slump, air content, and strength as well as the broader objectives discussed previously. A limit on the water-cement ratio and density (weight per unit volume) of the concrete may also be specified.

After developing a mixture that will meet all of the specifications, the proportions can be described as shown in Table 2.2.

After appropriate testing, the laboratory proportioning the mixture could also report the properties shown in Table 2.3.

The amounts shown in the mixture proportions are not necessarily the same as the amounts used to batch the concrete. The amount of water added will need to be adjusted depending on the moisture content of the coarse and fine aggregates.

Table 2.2—Example mixture proportions

Material	Quantity
Cement, Type I (brand name), lb/yd^3 (kg/m^3)	565 (335)
Water, lb/yd^3 (kg/m^3)	270 (160)
Fine aggregate (source), dry weight, lb/yd^3 (kg/m^3)	1215 (720)
Coarse aggregate (maximum size and source), dry weight, lb/yd^3 (kg/m^3)	1790 (1060)
Air-entraining admixture (brand name), fl oz/yd^3 (mL/m^3)	13 (500)

Table 2.3—Example mixture properties

Property	Range of results
Slump	3 to 5 in. (75 to 125 mm)
Unit weight	142 to 145 lb/ft^3 (2275 to 2320 kg/m^3)
Air content	4 to 6.5%
Strength at (n) days	3600 to 4100 psi (24.8 to 28.3 MPa)
Temperature	55 to 70°F (13 to 21°C)



Fig. 2.3—Truck-mixed concrete is sampled by taking two or more portions from the middle third of the batch, then remixing the portions before tests are conducted. Sample size should be at least 1 ft^3 (28 L) if strength test specimens are to be made.

Control tests

Concrete control tests are generally performed by inspection personnel, but concrete finishers should be familiar with these tests and understand what the results mean.

Some test results determine whether the concrete meets the job specifications. They are called "acceptance" tests because concrete that fails to meet the specifications can be rejected. Because such tests determine whether concrete should be accepted or rejected, they must be performed precisely as specified in the test standards. For example, the standard method for performing a slump test requires the use of a special steel tamping rod. If a piece of reinforcing bar or a wooden rod is used instead, the results of the test are not valid for accepting or rejecting the concrete.

Most control tests for concrete have been standardized by ASTM International (formerly the American Society for Testing and Materials). Such tests are identified by a number and title; for example ASTM C143, "Standard Test Method for Slump of Hydraulic-Cement Concrete." The following descriptions explain the test methods, but anyone who must do the testing should get full details from the referenced standards and should be a certified ACI Field Testing Technician–Grade I.

Sampling fresh concrete (ASTM C172)—Concrete used for control tests is assumed to represent the entire batch. For ready mixed concrete and concrete from stationary mixers, two or more portions are taken from the middle third of the batch (Fig. 2.3), combined, and remixed with a shovel to form a composite sample. The size of the sample should be at least 1 ft^3 (28 L) if strength test specimens are to be made. Tests for slump, temperature, and air content are started before molding specimens for strength tests.

Specifications typically require testing at the point of placement. If concrete is pumped, additional checking at the point of delivery may be needed because pumping can change concrete properties such as slump and air content. Sometimes, concrete is tested at both the delivery point (end of the chute of the concrete truck) and at the point of placement so the amount of slump and air lost during pumping or other placing methods can be estimated, and the rest of the testing can be at the point of delivery. It's easier and safer to test concrete at the delivery point because of all the activity occurring at the point of placement.

Slump test (ASTM C143)—A slump test (ASTM C143) is used to measure the consistency (stiffness) of concrete. Stiffer concretes are generally more difficult to place and consolidate. In concrete mixtures, changes in slump most often reflect changes in the amount of water in the mixture, but might also reflect changes in the air content, aggregate grading, and sand content. Water-reducing admixtures are

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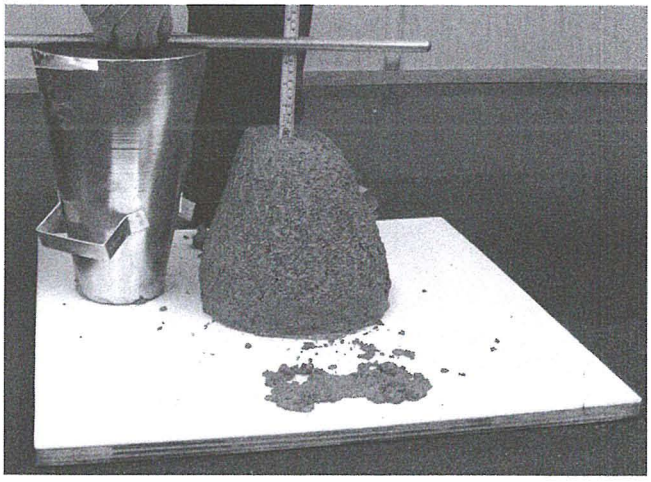


Fig. 2.4—Slump tests should be run on a flat, horizontal, nonabsorbent, rigid surface.

often used to increase slump without increasing water content. Because these admixtures are so commonly used, the slump test may not be a good indicator of the amount of water in the mixture. It can, however, be used to measure the uniformity of the mixture from truck to truck, which might reflect changes in the water content.

The essential equipment for a slump test (Fig. 2.4) is a flat, horizontal, nonabsorbent, rigid surface; a standard slump cone; a standard tamping rod; a scoop; and a ruler. A slump cone is made of sheet metal and is 12 in. (300 mm) high with a 4 in. (100 mm) diameter opening at the top and 8 in. (200 mm) diameter opening at the bottom.

To perform a slump test, dampen the inside of the cone, and place it on the dampened testing surface. Fill the cone with concrete in three layers of approximately equal volume, rodding each layer 25 times with the tamping rod. For the bottom layer, the rod should penetrate to the bottom of the layer. The tamping rod should penetrate through each new layer and roughly 1 in. (25 mm) into the previous layer. After the three layers have been rodded, strike off and smooth the concrete at the top, and clean away excess concrete around the base of the cone. Then slowly lift the slump cone vertically without shaking or twisting it. It should take about 5 seconds to raise the cone 12 in. (300 mm). Immediately place the cone upside down next to the slumped concrete, and measure the vertical distance between the top of the cone and the center of the displaced top surface to the nearest 1/4 in. (5 mm).

The result of a single slump test should not be the basis for rejection of concrete because the test itself is subject to considerable variation. ASTM C94, "Standard Specification for Ready-Mixed Concrete," requires two unacceptable slump tests to reject concrete. If the required slump is stated as a single number, say 5 in. (125 mm), a tolerance of ±1 in. (±25 mm) is normally considered acceptable; that is, the slump could be from 4 to 6 in. (100 to 150 mm). Specifications often give the maximum permitted slump, such as: "the slump shall not exceed *n* in." In this case, a lower slump, such as 2-1/2 in. (65 mm), may be acceptable, but slumps greater than the given value are not permitted.

Air content tests—Air-entrained concrete contains many extremely small air bubbles. These bubbles are so small that there are millions of them in each cubic inch of air-entrained concrete. These air bubbles improve concrete workability by acting as frictionless ball bearings. More important, these air bubbles improve the concrete's resistance to damage from freezing-and-thawing cycles.

The air content of freshly mixed air-entrained concrete should be checked regularly because too little air will not provide resistance to freezing and thawing and too much air will result in low strength. For steel-troweled concrete, there are potentially serious finishing problems such as blistering or delamination when concrete contains too much entrained air. ACI 302.1R recommends no more than 3% total air in concrete to receive a hard-trowel finish. Some water-reducing admixtures entrain air. Therefore, even the air content of concrete intended to be non-air-entrained should also be checked at the beginning of each placement and occasionally thereafter. ASTM International has two standard methods for checking air content:

- Pressure method (ASTM C231, "Standard Test Method for Air Content of Freshly Mixed Concrete by the Pressure Method"); and
- Volumetric method (ASTM C173 "Standard Test Method for Air Content of Freshly Mixed Concrete by the Volumetric Method").

The pressure method is useful for checking air in most types of concrete, but it can give misleading results for lightweight concrete and for concrete that contains porous aggregates. For these, the volumetric method should be used. Changes in air content for a specific mixture may result from variation in mixture components such as the amount and type of air-entraining admixture, sand, or cement.

Air content by the pressure method (ASTM C231)—A pressure meter works on the principle that a change in air pressure results in a change in the volume of concrete. The change in volume is assumed to be caused by compression of air voids in the fresh concrete. The pressure method works best for concrete with dense aggregates; it is not used for lightweight concrete or concrete with porous aggregate because the air pressure may push water and paste into the aggregate pores, providing a misleadingly high air content reading. ASTM C231 gives detailed instructions for placing concrete in the bowl of the pressure meter and consolidating by rodding or vibration. Concrete is then carefully struck off and smoothed level with the top of the bowl before the cover assembly is clamped on (Fig. 2.5).

Air content by the volumetric method (ASTM C173)—The volumetric method (ASTM C173) requires removal of air from a known volume of concrete by agitating the concrete in an excess of water. Commonly referred to as the roll-a-meter test, it works for all concretes, but it's used mostly for lightweight aggregate concrete. The air meter consists of a bowl and a top section. The bowl is filled with concrete in three layers and each layer is rodded 25 times. After the top layer is struck off and smoothed, the top section of the meter is clamped on. The top section is then carefully filled with water or alcohol to the zero mark and the top cap is screwed

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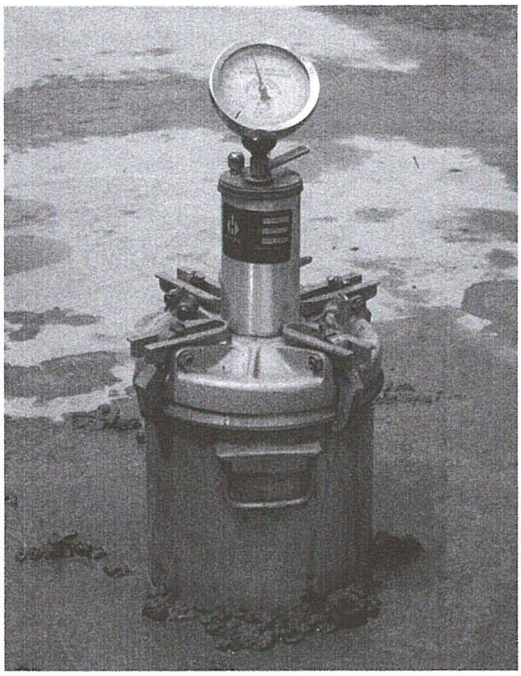


Fig. 2.5—The pressure meter is used to measure air content for normalweight concrete. It should not be used to measure air content of lightweight concrete.

on. The air meter is then rolled and agitated (Fig. 2.6) until all of the bubbles break and the air has escaped from the concrete. The drop in the water level shows the air content that has been agitated free from the fresh concrete and risen to the top. To read the drop in water level, a defoaming agent is usually added.

Sometimes an erroneous reading occurs if the meter has not been rolled long enough to remove all of the air. To ensure an accurate air content result, the bowl is checked after the test to make sure all the concrete was dislodged. If the all the concrete in the bowl is not free, more air is still trapped in the fresh concrete, and the air content reading will be low.

Unit weight and yield (ASTM C138)—Yield is the volume of freshly mixed concrete produced from a mixture of known quantities of the component materials. Yield computations can be used to verify that the batched weights provide the contractor with the purchased volume. ASTM C138, "Standard Test Method for Density (Unit Weight), Yield, and Air Content (Gravimetric) of Concrete," uses the unit weight (density) method for determining yield.

This unit weight test is simple but requires an accurate scale and a sturdy unit weight container. To perform the test, fill the container and consolidate the concrete by either rodding or internal vibration, depending on the concrete slump and size of the container. After consolidation, strike off the top surface, smoothing it carefully with the strike-off plate, and wipe the sides of the container clean. Then weigh the full container (Fig. 2.7) to the nearest 0.1 lb (45 g). Subtracting the weight of the empty container gives the net weight of the concrete. Divide the net weight of the concrete by the volume of the container to get the unit weight of the concrete.

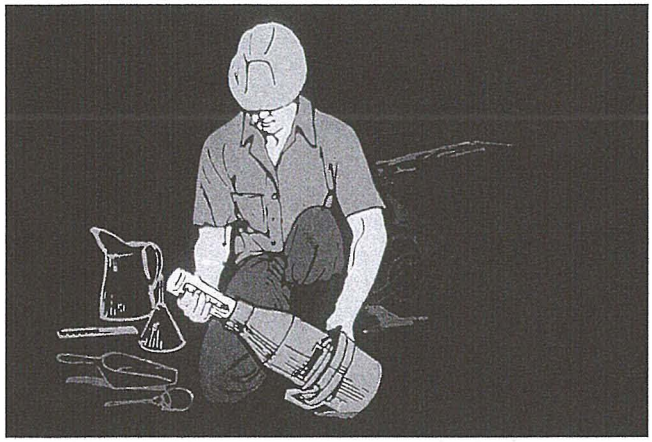


Fig. 2.6—When determining air content by the volumetric method, the air meter must be rolled and agitated until all the concrete in the bowl is dislodged and all of the air has escaped from the concrete. Concrete remaining in the bottom of the bowl after testing indicates that the measured air content may be too low.

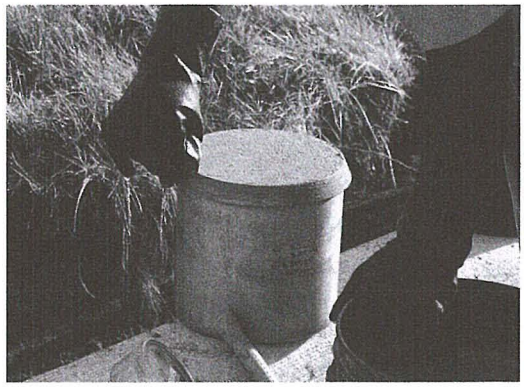


Fig. 2.7—The weight of concrete in a container of known volume (called unit weight or density) is used to verify that the batched weights provide the purchased concrete volume. The test can also be used for acceptance of lightweight concrete.

Changes in unit weight usually indicate changes in air content but may reflect changes in materials or mixture proportions. The unit weight test is often used as a check for the air content test.

When the total weight of materials in a batch is known, the yield of the batch can be calculated by dividing the total batch weight by the unit weight of the concrete. For example, if the total weight of cement, aggregates, water, and admixture in a batch is 31,450 lb (14,270 kg), and if the concrete unit weight is 145.6 lb/ft^3 (2332 kg/m^3):

$$\text{yield} = \frac{31{,}450 \text{ lb}}{145.6 \text{ lb/ft}^3} = 216.0 \text{ ft}^3 \qquad \text{(in.-lb units)}$$

$$\text{yield} = \frac{14{,}270 \text{ kg}}{2332 \text{ kg/m}^3} = 6.1 \text{ m}^3 \qquad \text{(SI units)}$$

Divide 216.0 ft^3 by 27 ft^3/yd^3 to calculate the batch yield of 8 yd^3.

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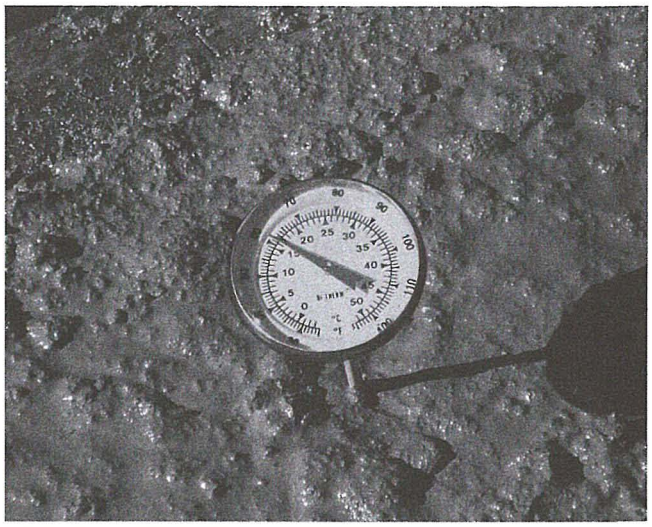


Fig. 2.8—Dial type metal thermometers with ranges between 0 and 180°F (–20 and 80°C) are generally used to measure concrete temperature. Changes in temperature affect the concrete setting time, air content, and slump.

To determine if the purchaser is receiving the correct amount of concrete by volume, ASTM C94 requires that yield be determined as the average of at least three measurements, one from each of three different concrete trucks, sampled in accordance with ASTM C172.

Temperature (ASTM C1064)—Changes in temperature affect the concrete setting time, air content, and slump. Admixtures are less effective at higher temperatures and more effective at lower temperatures. Because of this, concrete producers use the temperature of the fresh concrete to adjust admixture dosage and the amount of water added. Specifications may also set maximum or minimum limits for the temperature of the delivered concrete. ASTM C1064, "Standard Test Method for Temperature of Freshly Mixed Hydraulic-Cement Concrete," provides a standard method of measuring the temperature of fresh concrete. The test uses a calibrated metal-shielded or liquid-in-glass thermometer accurate to ±1°F (±0.5°C) that is inserted into a representative sample of the concrete (Fig. 2.8). An average of two or more readings is suggested.

Dial type metal thermometers with a range of 0 to 180°F (–20 to 80°C) are generally used for concrete, although ASTM C1064 permits some thermometers with a range of 0 to 120°F (–20 to 50°C).

Making, curing, and testing cylinders (ASTM C31 and C39)—Specifications require compressive strength values from at least two cylinder breaks to be averaged and reported as one "test." If tests are to be made at 3 days, 7 days, and 28 days, at least six cylinders must be made. In addition, one or more hold cylinders may be called for as backups in case the 28-day cylinders are damaged or do not come up to strength.

Nearly all concrete test cylinders made in the United States are 6 in. (150 mm) diameter and 12 in. (300 mm) high (called 6 x 12 cylinders) or 4 x 8 in. (100 x 200 mm). There are several kinds of cylinder molds, including heavy steel molds, sheet metal molds (tin can molds), plastic molds, and

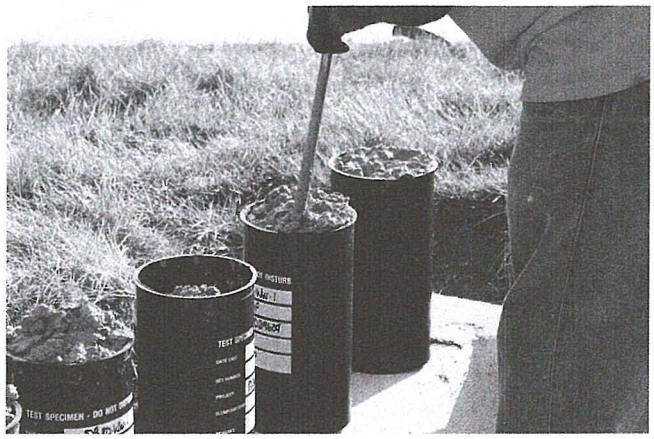


Fig. 2.9—Concrete cylinders used for compressive strength tests are molded on a solid level base. For slumps greater than 3 in. (75 mm), compaction is by rodding. Note that the technician has marked the date and concrete properties on each cylinder mold.

waxed cardboard molds. The tin can, cardboard, and plastic molds can be used only once. The heavy steel molds are reusable, so they must be cleaned and oiled after each use.

After obtaining a representative sample of concrete (ASTM C172), ASTM C31, "Standard Practice for Making and Curing Concrete Test Specimens in the Field," provides the following procedure for making test specimens:

1. Place the cylinder molds (cleaned and oiled if required) on a solid level base such as a concrete slab;
2. For slumps greater than 3 in. (75 mm), fill each mold in three equal layers. Use a standard tamping rod to rod each layer 25 times (Fig. 2.9). The rod should penetrate all the way through each layer and into the previous layer about 1 in. (25 mm). Tap the sides of the mold lightly after each layer has been rodded to close any voids left by rodding;
3. For slumps less than 1 in. (25 mm), fill the mold in two equal layers. Use an internal vibrator with a diameter of 3/4 to 1-1/2 in. (19 to 38 mm), and insert the vibrator into the concrete at three locations. Leave the vibrator in the concrete each time long enough to allow entrapped air to escape, then raise the vibrator slowly, and tap the sides of the mold lightly;
4. For slumps between 1 and 3 in. (25 and 75 mm), fill the mold and compact either by rodding or vibrating, as in Step (2) or (3);
5. Strike off and smooth the surface. Cover the top surface of the cylinders with a plate or sheet of impervious plastic; and
6. Mark each cylinder mold so it can be matched with the concrete in a particular part of the project. Also record the time and date.

Curing and protecting test cylinders—Cylinders are made and tested for two reasons:

- To determine if the concrete meets the specified compressive strength (design) requirements;and
- To determine if concrete, in place, has the strength needed to remove the forms or to put the concrete into service.

Cylinders made to check design strength (less than 6000 psi (41 MPa) should be stored for no more than 48 hours in a moist environment where the temperature is 60 to 80°F (16

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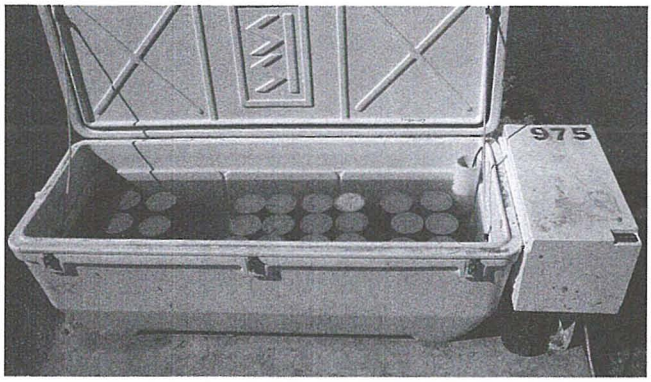


Fig. 2.10—Cylinders used to check design strength must be kept moist and at a temperature of 60 to 80°F (16 to 27°C) for up to 48 hours before being cured further under standard conditions at the testing laboratory. This storage box can be used in the field, but many times, the cylinders are covered and stored in a temperature-controlled job trailer.

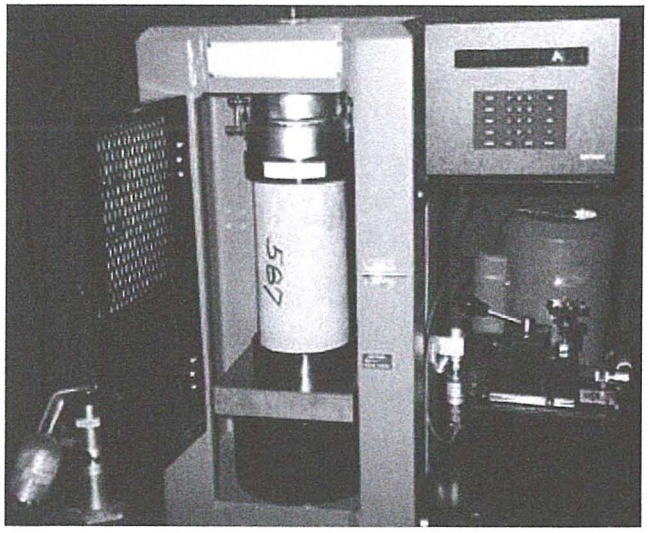


Fig. 2.11—At the age specified for testing, cylinders are placed in a calibrated hydraulic testing machine that applies load at a uniform rate. The load is increased until the cylinder fractures. Compressive strength is the maximum load divided by the cross-sectional area of the cylinder, usually expressed in psi (MPa).

to 27°C). Care in handling, shipment, and storage of cylinders is very important for accurate test results. Cylinders should not be transported until at least 8 hours after final set. A good rule of thumb is not to transport any cylinders less than 12 hours old.

During transportation, cylinders should be protected from freezing and moisture loss and cushioned to prevent jarring. Wrapping the specimens in plastic or surrounding them with wet sand or wet sawdust is suggested. Travel time should not exceed 4 hours. Any cylinders that are prematurely moved, accidentally dropped or kicked, or left in the field too long at the wrong temperature should be discarded.

Cylinders made for construction site control (the second reason for testing cylinders) should be kept at the job site and cured under conditions similar to the curing conditions for the concrete they represent (Fig. 2.10). Specimens made to determine when a structure can be put into service should be removed from the molds at the time of formwork removal. They are tested in the moisture condition resulting from job-site storage. The same careful handling and transportation to the test laboratory for testing are important for these cylinders too.

Testing the cylinders (ASTM C39)—Compression tests of concrete cylinders are performed after the ends of the test cylinders are ground or capped. The end of the cylinder must have a smooth, plane surface to ensure uniform loading and accurate test results. Unbonded caps may be used in accordance with ASTM C1231, "Standard Practice for Use of Unbonded Caps in Determination of Compressive Strength of Hardened Concrete Cylinders." Remember that building codes define a strength test as the average result from breaking two cylinders made from the same sample and tested at the same designated age.

Most job specifications give a specified compressive strength, for example 3000 or 4000 psi (21 or 28 MPa), or some other strength at 28 days. This specified compressive strength is commonly referred to as f'_c, and a 28-day strength test is always used unless a different test age is specified. Cylinders made, cured, and transported in accordance with ASTM C31 and tested in accordance with ASTM C39, "Standard Test Method for Compressive Strength of Cylindrical Concrete Specimens," are used to verify that the strength specification has been met.

At the age specified for testing, the cylinders are placed in a calibrated hydraulic testing machine (Fig. 2.11) that applies load at a uniform rate. The load is increased until the cylinder fractures. The maximum load divided by the cross-sectional area of the cylinder is the strength of the concrete in psi (MPa).

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STUDY QUESTIONS

Chapter 2—Concrete materials, mixture proportioning, and control tests

1. Concrete made with portland cement will set and harden while under water. *True or False?*

2. If a concrete slab on ground won't be exposed to sulfates, the cement used is most likely to be:

   A. Type I
   B. Type II
   C. Type III
   D. Type IV

3. Fly ash may be added to concrete from a fly ash silo at the batch plant or from a silo containing a _____ cement.

4. Most concrete used in slabs on ground has coarse aggregate with a maximum size of:

   A. 3/8 to 1/2 in. (9.5 to 13 mm)
   B. 1/2 to 3/4 in. (13 to 19 mm)
   C. 3/4 to 1-1/2 in. (19 to 38 mm)
   D. 1 to 2 in. (25 to 50 mm)

5. Sand for concrete used in slabs on ground is easier to finish when it has close to the largest allowable amount of material passing the No. 50 and No. 100 sieves. *True or False?*

6. Increasing the amount of sand in a concrete usually decreases the amount of water needed to make the concrete workable. *True or False?*

7. All concrete that will be subject to freezing when moist or be exposed to deicing salts should contain:

   A. An accelerating admixture
   B. An air-entraining agent
   C. Calcium chloride
   D. An antifreeze agent

8. Strength of normal weight concrete depends mainly on:

   A. Strength of the aggregate
   B. Mixing time
   C. Purity of the mixing water
   D. Water-cement ratio

9. Oversanded concrete mixtures are likely to produce floors with poor wear resistance and excessive shrinkage. *True or False?*

10. To minimize shrinkage and reduce cracking and curling:

    A. Use as much coarse aggregate as possible
    B. Use as little mixing water as possible
    C. Use aggregates with low shrinkage
    D. All of the above

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STUDY QUESTIONS

11. Changes in concrete slump most often represent changes in the amount of _____ in the mixture.

12. Air-entrained concrete is **not** recommended for use in concrete slabs:

    A. Exposed to freezing and thawing
    B. Exposed to deicing chemicals
    C. Finished by repeated steel troweling passes
    D. Finished by bullfloating and brooming

13. Changes in concrete temperature affect:

    A. Setting time
    B. Air content
    C. Slump
    D. All of the above

14. To determine if concrete, in place, has the strength needed to put it into service, test cylinders should be stored:

    A. For no more than 48 hours in a moist environment at a temperature of 60 to 80 °F (16 to 27 °C), then stored at 73 °F (23 °C) until they are tested.
    B. In water at 73 °F (23 °C) immediately after casting and tested before putting the concrete into service.
    C. In a temperature-controlled job trailer.
    D. At the job site and cured under conditions similar to the curing conditions for the concrete they represent.

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SECTION 3

Chapter 3—Preparation before placing concrete

Subgrade preparation

Compaction around buried pipes and excavations

Establishing grades

Placement sequence

Setting side forms and screed guides

Vapor retarders or barriers

Reinforcement for shrinkage control

Bulkheads and jointing

Checklist of tools and materials

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CHAPTER 3—PREPARATION BEFORE PLACING CONCRETE

Proper preparation before the concrete arrives is important because even the best finishing methods can't compensate for placing concrete on soft ground, setting edge forms too high or low, failing to install a vapor retarder or required reinforcement, or marking the wrong location for joints. The following steps must take place before concrete arrives on the job site:

- Prepare the subgrade;
- Compact the subgrade over utility lines and pipes;
- Establish grades (elevation control);
- Determine the placement sequence;
- Set side forms, temporary bulkheads, and screed guides;
- Install vapor retarder or barrier, if required;
- Install reinforcement, if required;
- Lay out and mark joint locations on forms; and
- Have tools and materials ready.

Subgrade preparation

Slabs-on-ground are supported by the subgrade on which they are cast. Subgrades should provide uniform support throughout. There should not be any hard spots or soft spots. If the subgrade is not uniform, the concrete slab will be supported only by the hard spots and will have to bridge over the soft spots. This is likely to result in cracking of the slab and unequal settlement.

If the subgrade is not uniform, a subbase of sand, gravel, crushed stone, or other granular material should be placed over it. If possible, slope the area around a slab-on-ground so that water will drain away from the slab rather than toward it.

Remove organic and foreign material completely, exposing the natural ground. If the soil is highly plastic and absorbs a lot of water, it may be expansive. Slabs supported by expansive soils should be designed to withstand or accommodate swelling and shrinking of the subgrade.

All subbases or subgrade material should be compacted to uniform bearing capacity, and to meet any specific requirements of the job specifications. Compaction provides a consistent strength to the subbase and subgrade and helps limit the amount of settlement. The compaction requirements presented in the project specifications or soils report determine the appropriate soil moisture and density expected on the project. A testing laboratory normally makes measurements to ensure that these compaction requirements are met. If rain causes the soil or base to absorb too much water, recompaction and further testing may be needed.

Granular subbases and sandy soils can be compacted with vibratory compactors (Fig. 3.1). Clay or silty clay soils are compacted with a kneading action provided by sheepfoot rollers.

The subgrade must be free of frost before concrete placing begins. ACI 302.1R now recommends placing concrete on a dry subgrade or subbase so some of the mixing water will be absorbed. Under severe drying conditions that threaten plastic shrinkage cracking, water can be sprinkled on the subgrade or subbase before concreting (Fig. 3.2). The sprinkling, however, shouldn't result in puddles on the surface or soft, muddy spots.

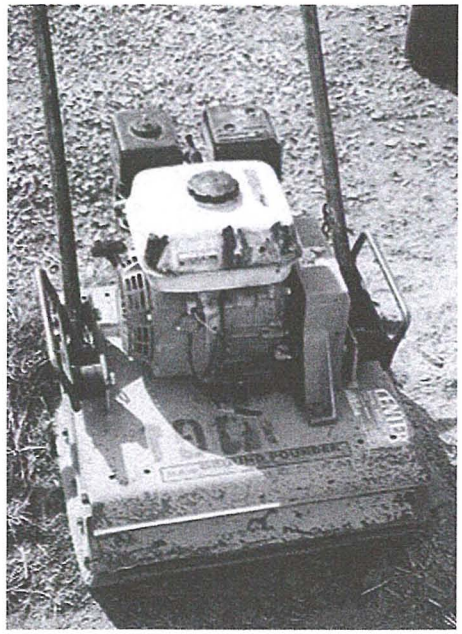


Fig. 3.1—Granular subbases and sandy soils can be compacted with vibratory compactors.



Fig. 3.2—Under severe drying conditions that threaten plastic shrinkage cracking, water can be sprinkled on the subgrade or subbase before concreting.

Compaction around buried pipes and excavations

Slabs-on-ground may be built over buried utility lines, water pipes, and sewers. Often, these lines and pipes are installed immediately before the slabs are built, and frequently, they are not covered until the subgrade and subbase are prepared. Electrical conduit and pipes should be covered with at least 2 in. (50 mm) of subbase so they do not cause cracking by restraining slab shrinkage or reducing slab thickness.

The backfill material should be compacted in layers so it will not settle and cause the slab to crack. An alternative to compacted backfill is a controlled density fill material—also called controlled low-strength material (CLSM). This low-strength mixture, generally consisting of water, portland cement, fly ash, and sand, hardens to prevent settlement of the slab.

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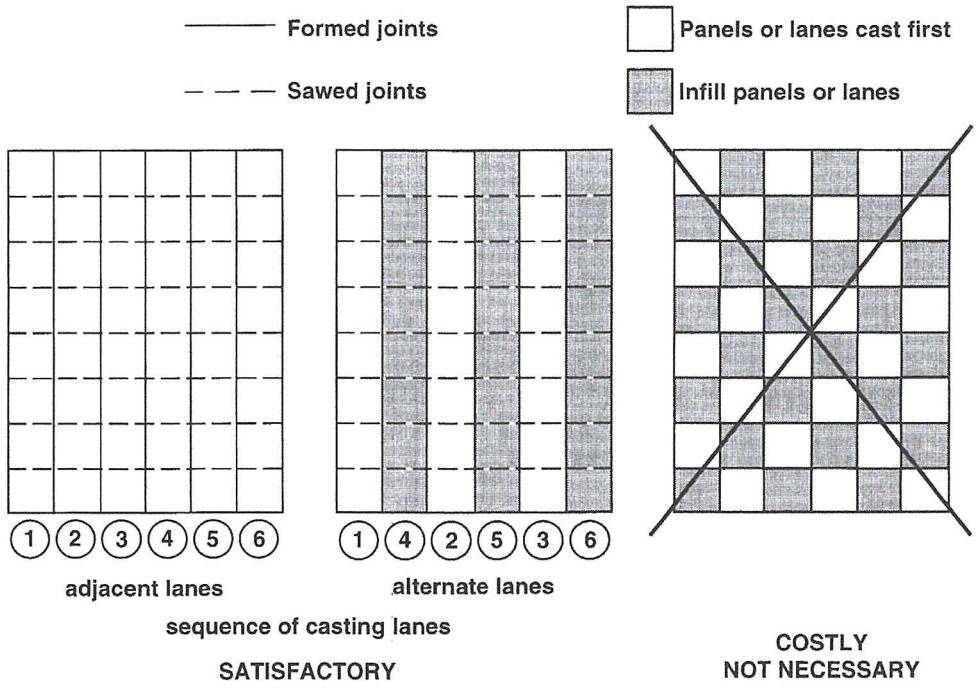


Fig. 3.3—Sequence for casting concrete slabs-on-ground.

Establishing grades

Positive drainage should always be provided for exterior slabs and is sometimes desired for interior slabs. The drawings for most projects show the important elevations of slabs-on-ground. In many cases, an engineer or surveyor sets grade stakes to the proper elevation using a surveyor's level (or a laser level) and rod. On other projects, the elevations of slabs are not clearly defined so the layout person must establish grades.

Before concreting, workers should check the elevation of the subbase by measuring down from a straightedge spanning between the side forms. High spots should be removed and low spots filled and compacted. If the surface of the subbase is 1 in. too low, it will take an extra cubic yard of concrete to fill each 18 x 18 ft section. (For a surface 25 mm too low, an extra cubic meter will be needed to fill each 6.3 x 6.3 m section).

Placement sequence

It's common practice to construct concrete floors in long strips or lanes starting at one side of the floor and then placing the adjacent lane after the first lane has hardened. With adjacent lanes, the first lane is usually next to a wall and only one line of side forms is needed. For the second lane, the side forms are removed from the first lane and moved over for the second lane. Alternate long lanes are effective (Fig. 3.3) but may require more side forms. Strip placement makes it easier for trucks to discharge concrete and for finishers to use bull floats and straightedges without walking in the fresh concrete. Contraction joints are installed or sawed to divide the strips into roughly square blocks.

Large block placements with interior contraction joints are acceptable if the contraction joints are installed soon enough and at the specified spacing. If the joints are sawed too late, cracks may form at locations other than at the sawcut joints.

In the past, many slabs were built in a checkerboard pattern instead of in lanes. It was hoped that this would permit the earlier placements to shrink so joints wouldn't open as wide. This is no longer recommended because experience has shown that the earlier placements shrink too slowly for the method to be effective, and more bumps at joints are likely. The checkerboard pattern also makes it difficult for trucks to discharge concrete in the desired location, thus increasing placement costs if pumps or conveyors need to be used.

Setting side forms and screed guides

Of all the floor placing and finishing operations, form setting and screeding have the greatest effect on floor levelness (the tilt or slope of the slab surface). The screeding method should be appropriate for the flatness and levelness called for in the specifications. For small areas, striking off or screeding is done by drawing a straightedge along the tops of the forms. For larger slabs, additional reference points for the straightedge are needed. These are called screed guides, sometimes referred to simply as screeds. Screed guides may be 2 in. (50 mm) thick lumber (Fig. 3.4), pieces of pipe, or T-bars, with the top set to the finished concrete grade. Another alternative is to use grade stakes driven into the subgrade at predetermined intervals, usually in a square pattern, with their tops at the required finish elevation.

The previous types of screed guides are set during site preparation. Another kind of screed guide, the wet screed, must be placed during the concreting operation (see **Striking off [screeding] the concrete** in Chapter 7).

Side forms must be set accurately to achieve close surface tolerances. Also, side forms should be aligned accurately

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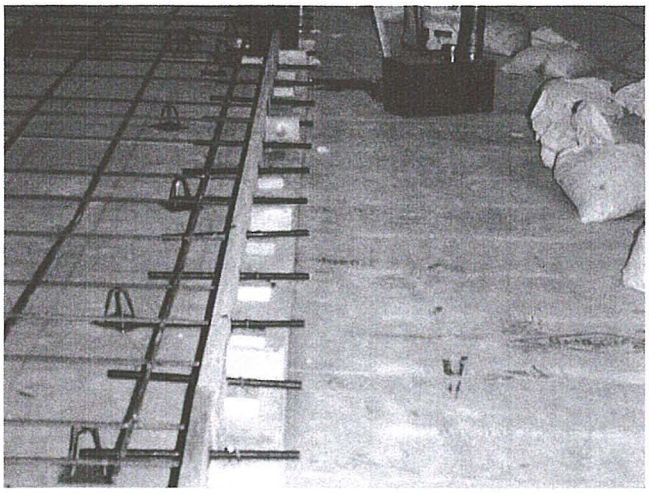


Fig. 3.4—Rigid screed guides can have openings for tie bars or smooth dowels.

with openings in the slab and with corners of diamond isolation joints around columns (see Chapter 8).

Vapor retarders or barriers

Water does not flow through good concrete, but a significant amount can pass through as vapor. Moisture collecting beneath a floor covering can cause adhesive bleeding, blistering, cupping, or other flooring failures. If a moisture-sensitive floor covering is to be installed on the concrete slab, ACI 302.1R recommends placing concrete directly on a vapor retarder or barrier. If the slab will not receive a floor covering, a granular layer may be placed over the vapor retarder or barrier. Although they may be called vapor barriers, some of these products only reduce vapor passage instead of blocking it totally. Some materials are available that can almost totally block vapor passage and may sometimes be specified. The term "vapor retarder," however, is used in the rest of this manual.

One type of vapor retarder is heavy polyethylene sheeting. ACI 302.1R recommends a 10 mil (0.25 mm) minimum thickness. Some specifiers, however, require a thicker material—15 mil (0.4 mm) or higher—when concrete is placed directly on it. This heavier material is used to reduce the chance of construction traffic tearing or puncturing the vapor retarder. Sheets should be overlapped 6 in. (150 mm) at the seams and sealed so they are vapor tight. They should be carefully fitted around service openings. There should be no holes in the sheet because holes will expose the underside of the slab to moisture that can seep through any cracks or joints. If the granular subbase is coarse and harsh, the vapor retarder is at risk of being punctured by workers walking on it. To prevent this, a layer of sand is sometimes placed over the subbase and under the vapor retarder.

ACI 302.1R advises that placing concrete in direct contact with a vapor retarder may aggravate slab edge curling and plastic shrinkage cracking problems. Yet, specifications may require placing concrete in direct contact with a vapor retarder to minimize moisture movement through the floor slab. When the vapor retarder isn't required to be in direct contact with the concrete, placing a layer of granular fill over

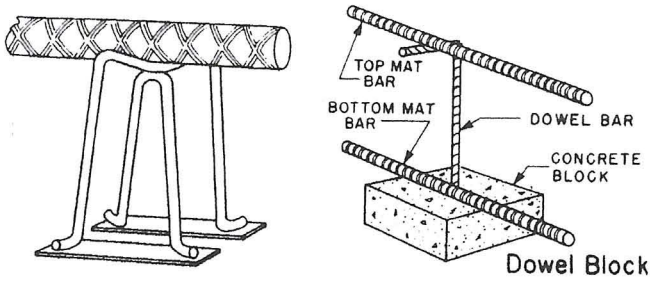


Fig. 3.5—The preferred method of positioning reinforcement in the slab is to use blocks or standard bar supports (chairs) to hold reinforcement at the proper elevation.

it may reduce potential problems of shrinkage cracking and curling and protect the vapor retarder from concrete truck traffic. This fill is typically a granular, self-draining, compactible material (NOT concrete-type sand) placed 3 in. (75 mm) thick if it's a manufactured sand containing rock dust or 4 in. (100 mm) thick if it's a crusher-run material with larger particles. The smaller manufactured sand particles are less likely to puncture the vapor retarder.

Reinforcement for shrinkage control

All required reinforcement (steel bars or welded wire reinforcement) should be precut to the proper dimensions. If the reinforcement is to be positioned at its proper elevation with prefabricated bar supports (Fig. 3.5), all of the necessary supports should be at the site and ready for use. Reinforcement should be at the proper location when it is needed so that no time is wasted during concrete placement.

Even though many slabs-on-ground contain some reinforcing steel, they are usually considered to be unreinforced because the only purpose of the reinforcement is to keep cracks closed tightly. Nearly all cracks in slabs-on-ground are wider at the top than at the bottom, which retains more moisture and shrinks less than the top. The reinforcement should be located at or (preferably) above mid-depth of the slab so it can keep any cracks closed (Fig. 3.6). Details on the project drawings will indicate the reinforcement location.

Do not "hook" or lift welded wire reinforcement from the subgrade as the concrete is being placed. Also, don't walk on the steel after it has been placed on supports at the proper elevation. Remember that mesh at the bottom of the slab won't help keep surface cracks closed.

The drawings should indicate if the steel is cut off before the joint or runs through the joint. The designer makes that decision based on what the joint is expected to do. If it is to be a working joint that is expected to open and provide relief for drying shrinkage, it is best to discontinue all steel at the joint. Some designers believe that a limited amount of steel can safely be continued across the joint. This is done so the joints won't open too wide. In wide joints, there is no interlocking of the crack faces and no ability to transfer load across the crack when vehicles drive across the joint. The risk of running some steel through the joint is that cracking will occur at a location other than the contraction joint. If the joint is expected to stay closed over time, steel may be

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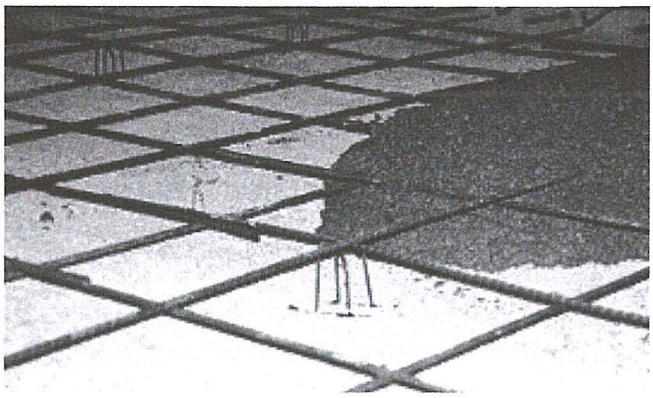


Fig. 3.6—High chairs with sand plates for soil bearing are available to hold reinforcement at the proper level in or near the top half to third of the slab.

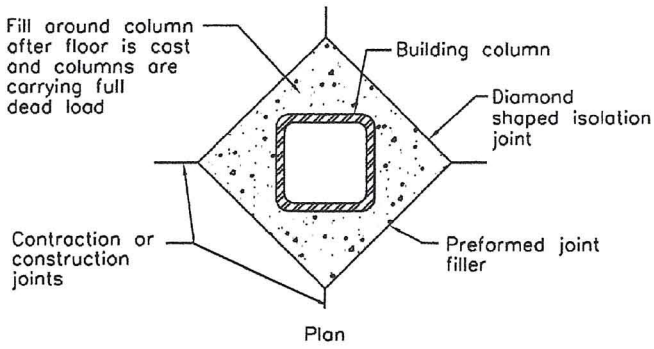


Fig. 3.7—Circular or square forms may be used to isolate columns. Place square isolation joint forms with their corners at the joints coming into the column.

continued through the joint. If load transfer is needed across the joint, the designer specifies smooth steel dowels or other types of load transfer devices.

Bulkheads and jointing

The locations of joints that are to be made with jointers (groovers) or to be sawcut should be marked ahead of time on the edge forms or bulkheads or on other permanent items such as walls or footings. Refer to Chapter 8 for detailed information on the purpose and spacing of joints in slabs.

Isolation joints (Fig. 3.7), used to separate the slab from walls, footings, columns, and other rigid structures, are made with asphalt-impregnated sheets or other suitable joint materials. All isolation joint (expansion joint) material should be in place before concrete placing begins.

Circular or square forms (see Chapter 8) may be used to isolate columns. Around columns, place square isolation joint forms with their corners at the joints coming into the columns. After removal of the forms around columns, preformed joint materials should be placed at the joint to the level of the floor surface. Then, the rest of the formed area is filled with concrete and finished.

Bulkheads at construction joints may have a small wood or metal key attached to the face to form a keyed joint, or a premolded or metal keyed joint form may be used. The metal keyed joint form is not recommended for slabs subject to heavy wheel traffic. Keyed construction joints are also not recommended for slabs less than 6 in. (150 mm) thick. Check the drawings, as they will indicate what the designer requires at the construction joints.

Checklist of tools and materials

Before concrete arrives, all of the necessary tools and materials should be ready. Valuable time can be wasted if the required tools are not at the site. One way to avoid last-minute delays is to prepare a complete list of all of the equipment, tools, and materials needed for each day's work, and then be sure that everything on the checklist is on hand and in good working condition. The list should include all tools that will be needed, as well as all miscellaneous items such as hoses, handsaws, hammers, extension cords, buckets, and testing equipment.

All of the materials, such as curing blankets, curing compounds, oil and fuel for engines, tape, chalk lines, and form oil, should be included on the list. The list should include items that might be needed in case of an emergency such as a sudden storm, drop in temperature, or power breakdown. If weather conditions are right for plastic shrinkage cracking, this is also a good time to get materials and equipment to prevent or reduce it (see Chapter 9). On some jobs, the foreman prepares the checklist and assigns one person to be sure that all of the items on the list are available. On other jobs, the foreman makes each person responsible for specific items on the list.

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STUDY QUESTIONS

Chapter 3—Preparation before placing concrete

1. Granular subbases for slabs on ground can be compacted with sheepsfoot rollers. *True or false?*

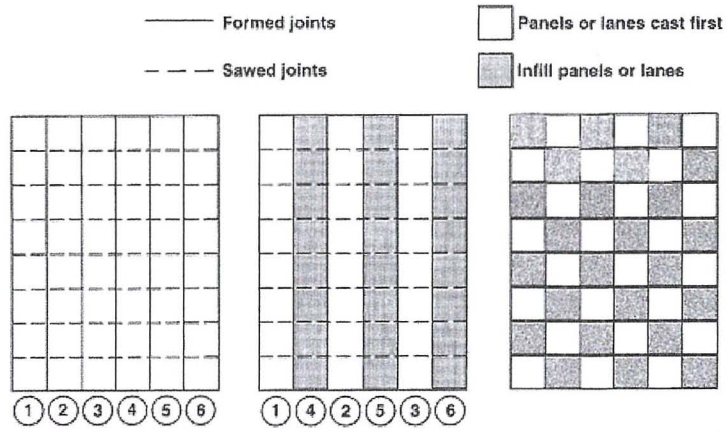
2. In cold weather, the subgrade soil must be free of _____ before concrete placing begins.

3. Before a concrete slab on ground is placed under severe drying conditions that threaten plastic shrinkage cracking, water should be sprayed on the subgrade until puddles are formed and the and the surface is soft. *True or False?*

4. Before concreting, workers should check the elevation of the subbase by:
   A. Measuring down from a straightedge spanning between the side forms
   B. Measuring the distance from the subbase surface to the top of both sets of side forms at 5-ft (1.5-m) intervals
   C. Using a surveyors level to measure the subbase elevation at the beginning and the end of the placement.
   D. Calculating the average elevation of the highest and lowest spots on the subbase surface and comparing that with the design elevation.

5. If the surface of the subbase for a concrete slab on ground is too low, the slab is likely to be too thin. *True or False?*

6. Which one of the following placing sequences for casting slabs-on-ground is **not** recommended?



A. adjacent lanes B. alternate lanes C. checkerboard

7. Which of the following have the greatest effect on floor levelness?
   A. Compaction of the subgrade and base
   B. Concrete slump
   C. Form setting and screeding
   D. Hand troweling slab edges

8. When concrete will be placed directly on a vapor retarder, finishers should use a margin trowel to punch holes in the vapor retarder and thus decrease waiting time before the concrete can be finished. *True or False?*

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