the pavement thickness required to carry the design loads.

Tie bars

Tie bars are bars that are deformed to provide better bond with the concrete and prevent the joint from opening. This is just the opposite of the doweled joint, where the intent is to allow the joint to open.

Tie bars are not recommended for any joints in interior slabs-on-ground and would never be used at contraction joints or isolation joints. They are often used in longitudinal joints in pavement and driveways to prevent the panels from gradually separating but are not typically recommended for transverse joints. They are also used to tie the outer or perimeter lane in large paved areas, such as parking lots. Typically, they may be No. 4 or No. 5 (No. 13 or No. 16) bars, 30 in. (760 mm) long, and placed at approximately 30 in. (760 mm) on center.

Fiber reinforcement

Numerous fibrous materials are now available and are being used to reinforce concrete for various purposes. The materials from which fibers are made include steel; glass; carbon; and a number of plastics such as nylon, polypropylene, and polyester.

Fibers in concrete have a different character and purpose from the primary steel reinforcing bars, bar mats, and WWR. The term "secondary reinforcement" is often used to describe their application so that fibers are not confused with structural reinforcement. In general, their use does not affect the recommendations for jointing concrete slabs-on-ground, but they have been used at appropriate dosages in extended-joint slab design systems.

Fibers improve tensile strength, reduce the effects of fatigue, decrease shrinkage, and enhance durability. The amount of strength added by fibers is related to the material of the fibers and to the dosage rate (pounds of fiber per cubic yard of concrete). Plastic (polypropylene) microfibers primarily reduce plastic shrinkage and settlement cracks and provide no significant structural strength. Macrofibers can be included at higher dosages to help control drying shrinkage crack widths. The finishability of fiber-reinforced concrete depends on the fiber design, and sample slabs can be used to evaluate the finish of fibers from different manufacturers. Steel fibers (Fig. 8.24),

Fig. 8.21—Sheets of WWR with larger wire sizes spaced a minimum of 12 in. (300 mm) on center provide space for construction foot traffic. They also make it much easier to maintain the required depth of the reinforcement as compared to rolls of WWR with closely spaced wires. (Photo courtesy of Wire Reinforcement Institute.)

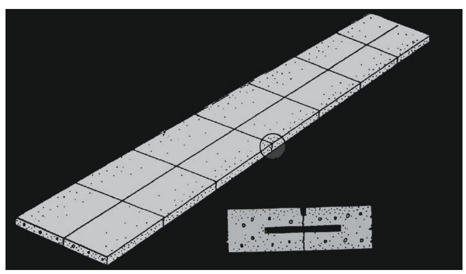

Fig. 8.22—A pavement with dowels. The contraction joints are spaced closely together to control shrinkage cracking; there is no need for reinforcement between joints. Heavy wheel loads make the dowels necessary for load transfer at the joints.

Fig. 8.23a—Dowels and welded wire reinforcement are supported in place. A contraction joint will be sawed above the dowels in the background of the photo that are located perpendicular to the construction joint. The welded wire reinforcement is stopped short of the joint.

Fig. 8.23b—Dowels sticking out of concrete cast on one side of the joint.

Fig. 8.24—Examples of steel fibers that can be used in slabs to reduce crack widths.

approximately 2 in. (50 mm) long, in dosage rates of about 60 lb/yd^3 (36 kg/m^3), can significantly reduce cracking. Steel fibers used in exterior slabs will cause rust spots on the surface but no other significant problems. Some manufacturers and engineers have used fibers made of steel or FRP to replace secondary reinforcement in nonstructural building elements. Recent advancements in optimizing fiber shape and aspect ratio have expanded the use of fibers. Some applications include underground concrete utility boxes and precast wall panels. Other uses include replacing WWR on metal decks and slabs-on-ground. The use of fibers is gaining acceptance but is not currently recognized in ACI 318 except as a replacement for minimum shear reinforcement under specific circumstances.

SUMMARY

Restraint to volume changes in concrete can cause cracking. Proper curing reduces cracking by enhancing strength gain before the concrete experiences the tensile stresses caused by shrinkage.

Proper jointing and construction practices can greatly reduce uncontrolled cracking in concrete slabs. Potential shrinkage cracking is only one condition requiring joints. The three basic types of joints for slabs-on-ground, and the conditions for which they are required, are contraction, isolation, and construction joints.

The purpose of contraction (control) joints is not to prevent cracks. They are intended to cause cracks in the places you want them to occur. The joints are placed closely together so shrinkage cracking will occur in, but not between, the joints. Sawcutting should be performed before the cracks have formed, typically once the concrete can support the weight of the saw (within 1 to 4 hours after finishing). Higher temperatures and stiffer mixtures will shorten the waiting time. If the timing is right, expect to see a trace of raveling at the joint edge during sawing. A common guideline for spacing contraction joints is to space them in feet approximately 2-1/2 times the slab depth in inches (in SI units, space them about 30 times the slab depth).

Concrete placement interruptions should end in a construction joint. Ideally these are located where a contraction joint would normally have been placed. A bond breaker should be applied to the vertical face of the slab before continuing placement if the joint will serve as a contraction joint. Additionally, a load transfer device is needed.

Isolation joints separate slabs from adjacent structures. These joints are commonly found at the junction of a slab and wall, column, machinery base, or other item. Isolation joints are filled with joint material. This prevents bond and allows for independent movement of each element.

Reinforcement in a slab includes reinforcing bars, welded wire reinforcement (WWR), steel and synthetic fibers, smooth dowels, and tie bars. Only steel reinforcing bars can impart structural strength to a slab and only reinforcing bars or WWR can serve to control crack widths. WWR should be placed on concrete blocks or on chairs so that it cannot be displaced during concrete placement. WWR should be placed at 2 in. (50 mm) below the slab surface or within the upper one-third of the slab thickness, whichever is closer to the surface. Slab joint spacing can be increased when reinforcement is included in the slab, but the amount of opening at each joint will increase due to the increased joint spacing. Therefore, dowels are often used in conjunction with WWR to support the additional load transfer. One end of the dowel may be bonded to the concrete on one side of the joint, and the other end greased or fitted with a sleeve so that it is free to move as the joint opens and closes. The use of coated dowels to prevent bond with the concrete is also common.

Fibers in concrete have a different character and purpose from the primary steel reinforcing bars, bar mats, and WWR. The term "secondary reinforcement" is often used to describe their application so that fibers are not confused with structural reinforcement. In general, their use does not affect the recommendations for jointing concrete slabs-on-ground.

REVIEW QUESTIONS

1. What is the purpose of a contraction joint?
2. What is the proper timing for saw-cutting joints? What affects the timing?
3. How deep should a joint be made with a groover?
4. What should the contraction joint spacing be for a 6 in. (150 mm) slab?
5. What are some common locations for isolation joints?
6. How far below the slab surface should WWR be placed?
7. How do dowels transfer loads across joints?
8. How does a tie bar differ from a dowel?
9. What properties of concrete can be improved with the addition of fibers?

REFERENCES

American Concrete Institute

ACI 302.1R-15, Guide to Concrete Floor and Slab Construction

Chapter 9

Planning for Quality

The return on investment for a quality product is a satisfied customer, minimization of rework, increased profit and efficiency, a good reputation within the industry, and higher employee morale. The results of a quality management effort on a project stem from commitment to planning and organization. You can achieve good results by:

- Proper planning and development of the project execution strategy and goals
- Ensuring all personnel are trained and made aware of their responsibilities
- Making the necessary information readily available to those who need it
- Having adequate communication and coordination
- Selecting the right team members as employees, subcontractors, and suppliers
- Defining the rules of interaction

ELEMENTS OF QUALITY MANAGEMENT

The basic elements of quality management apply to all industries and companies. There are many sources that discuss these elements in a variety of ways, but they are mostly common sense and are often already part of construction daily operations. The following definitions present some of these elements within the frame of reference of the concrete industry:

Quality control—actions taken to provide control and documentation over what is being done and what is being provided so that applicable standards, good practices, and the contract documents are followed; control of the product.

Quality assurance—actions taken to provide and document that what is being done and what is being provided are in accordance with applicable standards, good practices, and the contract documents for the work; assurance that controls are in place.

Independent testing laboratory—a testing laboratory contracted to conduct acceptance testing of materials and workmanship that has no financial stake in the contractor's work and has no affiliation with any member of the contracted construction team.

MANAGEMENT RESPONSIBILITY

The quality of work can be optimized if management supports the effort and defines it as policy. If profit and schedule are emphasized at the expense of workmanship, then project engineering, field management, and skilled craftsmen will see this as the company standard. This can result in a reduction in the quality of work.

An investment of resources in quality management personnel, technicians, and testing equipment will be more effective if those responsible for the level of quality are supported and have a certain level of control over the work. Senior management should review periodic status reports and trends for signs of breakdown in the quality management system. Participation in regular meetings by all involved, including senior management, is essential. Senior management can move the job in the right direction and motivate others to value quality by maintaining awareness of staffing concerns and by supporting integration of quality and production.

QUALITY MANAGEMENT SYSTEM

The quality management system is composed of two elements: the site-specific quality plan (and the procedures referenced within it) and the organization that executes it.

Organization on each project

On the project level, the following gives some definition to the roles of each member of the construction team. Each one is considered a separate entity:

The Owner is the final decision-making authority for the entire project, except for overriding local building codes and regulations. All members of the construction team ultimately report to the owner. Most often, the owner will hire an architect or engineer to oversee production of the contract documents and a Construction Manager to oversee construction of the project. The owner may also act as the Construction Manager and hire a General Contractor directly to construct the project.

The Architect determines the design of buildings and writes the general specifications. For bridges and heavy construction projects, there may not be an architect; these functions would be performed by the engineer.

The Engineer prepares the structural designs for buildings, bridges, and other complex structures. This includes the structural frame and members, specifications, and engineering drawings. The Engineer reviews submittals, including shop drawings, mixture designs, formwork, materials, construction joint locations, temporary structures, and repairs if necessary. The engineer is often called the structural engineer. For structural concrete, the engineer is required to conduct acceptance inspections per ACI 318 and most governing building codes.

The Construction Manager (CM) is hired by the owner to manage the project. The CM can be "at risk" in that they share in the profit or losses of the project, or "not at risk" in that the CM acts only as the owner's agent. The CM normally schedules inspections, coordinates the design work and changes, obtains permits and certificates of occupancy, issues change orders, and makes progress payments. Depending on the contract, the CM may hire and manage the subcontractors or award the project to a general contractor.

The General Contractor (GC) is responsible for construction of the project and supervises the work of the specialty contractors, which includes the concrete and reinforcing steel contractors if the work is not self-performed by the GC. The GC is responsible for the quality control but can assign specific inspection and testing duties to subcontractors in the agreements.

The concrete specialty contractor is responsible for planning and constructing the concrete portion of the contract documents. This includes placing, consolidating, and finishing the concrete, and may also include the erection and removal of concrete formwork.

The reinforcing steel placing specialty contractor positions the reinforcing bars prior to the placement of concrete.

The ready mixed concrete supplier batches and delivers concrete to the jobsite. The supplier is responsible for the quality of what they supply.

The reinforcing steel fabricator fabricates the reinforcing steel and delivers it to the jobsite. This service generally includes the preparation of placing drawings (also referred to as shop drawings) for the reinforcing steel.

The reinforcing steel detailer prepares placing drawings and bar lists from engineering drawings.

The on-site workers include the carpenters, ironworkers, concrete finishers, and laborers.

The testing lab is hired by the owner, the contractor, or both. The owner is concerned with quality assurance and acceptance testing, and the contractor with quality control. For quality assurance and acceptance testing, the lab is required to be independent; meaning it must not be hired by the contractor or subcontractors. For quality control testing, the lab can be hired by the contractor or subcontractors.

The inspector can be one of three types—representing the owner for acceptance inspection, employed by the contractor for quality control, or employed by the local building department for code enforcement.

Organization within each company

All members of the project team should understand the organizational structure and the responsibilities of each team member.

The size of the quality management staff will vary with the size and complexity of the project.

Small projects may only require an ACI Concrete Field Testing Technician – Grade I to conduct field testing. Normally, a technician performs testing only and is not placed in a position of responsibility. They will likely be subordinate to a field manager responsible for quality control as well as other duties.

Large projects may require a site quality manager in charge of inspectors and office personnel (refer to the *Inspection and Testing* section of this chapter for a description of their roles). In this case, site quality management personnel should report to senior management, not to field supervisors, to avoid a conflict of interest. This structure needs to be reflected in the organization chart for the project.

Production personnel can be given tasks related to first-level quality control such as inspection of their own work; work performed by their peers; or duties related to receiving inspections, preplacement checklists, damage reports, and repair procedures. These duties should be included in their job definitions or detailed in the site-specific quality plan.

To further the concept of organization and responsibility within the contractor's project team, there should be a clear definition of who works for whom, and who does what. A small, simple project does not necessarily need its own organization charts and job descriptions; the organization chart for the company may suffice. As the scale and complexity of a project grows, so does the need to document roles, responsibilities, and accountability, especially with regard to quality control.

THE SITE-SPECIFIC QUALITY PLAN

Site-specific quality plans are typically part of broader project management plans that are relied upon to manage all aspects of project execution. Site-specific quality plans are typically used to manage the quality of the in-place work, but some quality plans also include more performance-related procedures, such as continuous improvement processes, opportunities for improvement, practice documentation, or lessons learned.

Site-specific quality plans can be simple narratives or they can be a compilation of hierarchical documents. In the latter case, general requirements are typically defined in program-level documents, while increasing detail is provided in subordinate procedure level documents, work instructions, inspection and test plans, and individual forms.

It is important to apply a graded approach to formal quality plans and invoke requirements that are commensurate with the complexity of the work being completed.

The site-specific quality plan itself is no more than an expression of the goals of the project and the steps necessary to accomplish those goals. The criteria for these goals are often spelled out in the contract documents for large industrial projects and federally funded work.

The procedures referenced within the site-specific quality plan give the plan the strength of execution. These procedures, sometimes referred to as work instructions, are not for just the quality managers and inspectors. Any organization responsible for complex operations, personnel management, documentation and communication requirements, and a need for efficiency and continuous improvement can benefit from written procedures. Written procedures can help train new personnel quickly and accurately, communicate needs across department lines, develop uniformity of execution, and serve as the vehicle for continuous improvement.

Quality plans and procedures should also be developed for subcontractors and suppliers. Construction managers and general contractors can insist on their use by including them as a contract requirement and by following up with audits to ensure that the commitment is honored. Implementing a quality plan does not necessarily require an extreme amount of paperwork, but testing, inspection, and process control should be expected.

Written Quality Procedures should answer the following questions:

Scope—What are the boundaries of the procedure? Does a concrete testing procedure apply to field acceptance testing alone, or does it include batch plant inspection and testing of component materials?

Application—What does the procedure apply to? Does a concrete field acceptance testing procedure apply to prepackaged grout and concrete or only to ready mixed concrete?

References—Which specifications, codes, and standards apply?

Procedure steps—What steps are included in the test or inspection?

Acceptance/rejection criteria—What is and what is not acceptable? For example: a limit on air content of 1 percent over the specified value can be used as an upper value for acceptance and as a rejection criteria for anything more than 1 percent over.

Documentation—Which forms are used to record the information? This list can include report forms, logs, or checklists. The use of these documents will vary by project and will be discussed later in this chapter.

Authorities and responsibilities—Who has the authority to reject or accept a load of concrete? Who does what test or inspection? Who manages the concrete samples? Who writes the report/checklist for each concrete placement? Who countersigns the report/checklist? Who has the authority to shut down an operation? Who notifies the batch plant of all breaks? Do they provide all breaks or just those that fail to meet requirements?

The quality plan, along with the quality procedures, should be included in the project management plan at the same level of importance as the safety plan, schedule, manpower charts, cash flow forecasts, organization plan, and cost trending procedures.

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CONTRACT REVIEW

Contract review requires that you take the time to read contracts thoroughly before finalizing agreements. It applies to both the company bidding the contract and the company purchasing a service or product. For a bidder, the contract should be reviewed to determine the level of risk and the resources required to minimize that risk. For a purchaser, the review should judge the ability of a vendor to complete the work and fill the order.

When bidding, choosing the right job with the right location and team is essential if you are to run a profitable business. To determine the level of risk and to minimize the risk, several questions should be answered to ensure that the job meets these criteria:

- Can we do this job with the equipment and manpower we have on hand or readily available?
- Are the specifications and plans clear?

- Are the expectations realistic based on previous experience?
- Is the design buildable?
- Does it conflict with local codes and practices?
- Can we supply the level of workmanship at the specified schedule for a competitive price?
- Have we asked all the necessary questions and taken exclusions prior to signing contracts?

In other words, the main question to ask is: Are we able to recognize a potentially successful project, and have we identified standard criteria within the company to make this decision? It is best to document the answers to these questions and these decisions, so that successful projects can be repeated and unsuccessful ones can be avoided.

When purchasing, determine if your subcontractors and suppliers can complete the work or fill the orders. Several questions should be considered before contracting with subcontractors or suppliers:

- Is the procurement contract structured to assign more risk to one entity or the other?
- Is the vendor capable of the delivery as expected?
- Will they be able to make a profit? The failure of a vendor to profit can place extra costs for completion on the General Contractor.
- Have all the correct drawings and specifications been included in the agreement?
- Is everything included in the vendor's proposal so there are no surprises?

Therefore, when bidding or purchasing, a method of assessment and documentation needs to be in place, so one can later determine what went right or wrong and why. It is important to remember that the organization needs to assess its own capacity to perform the contract and to assess whether its subcontractors and suppliers are capable of completing the work or filling the orders.

DESIGN CONTROL

Aside from design-build contracts, permanent facilities are typically designed by the architect or engineer of record. Some jurisdictions allow the design professional to delegate permanent design work to the contractor, insisting on a professional seal to validate the design of details. Other types of design that may require a professional seal are formwork drawings (often only for placements over a certain height) and temporary shoring. Not requiring a professional seal, but still of importance for efficiency and quality of workmanship are reinforcing detail drawings, embed placement drawings, and the construction joint (lift) placement drawings that can show surface finishes, water stops, and concrete strengths. All of these documents are usually checked by the professional of record; however, it is good practice to have an internal review system in place to assure the information is correct and not be dependent on the review of the architect or engineer of record. It is recommended that this internal review system be defined in a procedure that includes a system of internal review, verification, and sign-off.

DOCUMENT AND DATA CONTROL

A system should be in place to track documents throughout the construction process. These documents include:

- Contract drawings
- Submittals
- Requests for information, sometimes called requests for interpretation (RFI)
- Notices of claim
- Change orders
- General correspondence
- Inspection reports
- Testing data
- Material certifications
- Owner and construction manager directives
- As-built drawings
- Cost data
- Extra work tickets

Lack of good documentation is often the weak link in the management system, especially at project startup. The people staffing the project are often brought together for the first time to discuss the tracking system. There can be questions as to how submittals are to be routed, what the most current drawings are, where they can be found, and how documents are to be tracked. This is where planning or having a system in place pays off by avoiding confusion, which can lead to building to the wrong revision, wasting time looking for submittals, or losing money by not documenting change orders.

You should assign the task of managing and tracking data to someone on-site. Audits of document and data control will ensure that everyone is working to the current revisions and documents are easily retrievable.

Keeping data management simple makes sense. Tracking items using software packages and databases are helpful, but simple spreadsheets are easy to use, quick to assemble, and take only a minimum of training to understand. The most important document tracking tools are the list of contract drawings and the submittals tracking log. The size and complexity of the project will determine the sophistication of software necessary for document control, but tracking can be completed in simple spreadsheets on many smaller jobs.

Using a documented, standardized, company-wide procedure is helpful, as it can be used on all projects, improved upon, and implemented on day one.

PURCHASING

The selection of subcontractors and suppliers can make the difference between success and failure. The selection is sometimes based on standing relationships between parties and at other times by price alone. Expecting to see a subcontractor's site-specific quality plan or some indication of procedures is within reason. When evaluating new subcontractors and suppliers, the following should be considered:

Batch plants

- Do they have a quality system, or a certification from the National Ready Mixed Concrete Association (NRMCA) or the State DOT?
- Is there a specific contact person for quality issues?
- Can you access their test sample histories and determine the variation you can expect in the results?
- Do they routinely test materials purchased from vendors?
- Do they consistently use the same vendors?
- Do they have enough trucks to service the job?
- What do their plant and delivery equipment look like?
- Do they have someone assigned to inspect and maintain the equipment?
- Is the plant inspected by any of their clients, such as the State DOT?

Testing labs

- Do they use a quality program that is reflective of how they operate? A visit to their lab is in order. Do not decide by price alone.
- Do they, as an entity, have the necessary qualifications? (Refer to the *Training and Certification* section of this chapter.)
- Do they have sufficient technicians and someone who will manage them?
- Are the qualifications of personnel adequate?

Rebar installation subcontractor

- Who will inspect the work?
- When will the inspections take place?
- How much time is required between requesting a rebar inspection and having the inspector on site? The rebar cannot be inspected once the concrete is placed. You cannot rely solely on the owner's acceptance inspection to guide the rebar installation. Failure of the owner's quality assurance inspection to detect defective work does not prevent rejection if a defect is discovered later. Rebar placement is arduous work and requires proper sequencing. Corrections can be costly. The best method of assessment of the rebar installation subcontractor is reputation, references, and past history. Audits of ongoing projects can also be helpful.

Rebar detailer, supplier/fabricator—Sometimes they are one and the same.

- Can you view audits of completed projects and review issues and problems?
- Do you have personal experience with the detailer? Otherwise, can you contact their references?

- Are sources of information (such as contract drawing numbers and RFIs directives) referenced on each shop drawing? Detailing and shop drawing preparation have to be systematic. Revisions need to be marked.
- Who completes the drawings? The Internet has given rise to the prevalence of detailing that is conducted outside the country in emerging economies where engineering work is competitively priced. This type of work is often subcontracted to overseas companies by the local suppliers, and direct links to the detailers are not always available.
- Is each drawing checked by a second person before final acceptance? This is standard practice in the industry, and most drawings include a "checked by:" entry in the title block.
- Does the supplier/fabricator provide material certifications for the steel and coatings, such as galvanizing or epoxy? The Concrete Reinforcing Steel Institute (CRSI) has a certification program for epoxy coaters.
- Do fabricators bend the bars in the plant before coating? Field-bent coated bars can require extensive touchup and will increase costs.

Forms and form materials supplier

- Does the form supplier provide the required engineering? Many form suppliers will supply the engineering when required.
- Who is responsible for managing and caring for formwork on the jobsite? Managing rentals will avoid additional costs from unused forms remaining on the site longer than necessary.
- Who will coordinate site-built wooden formwork? Grade stamps are printed on lumber produced in the United States and Canada and should be compared with the drawings to ensure that designs are validated. Miscellaneous materials such as isolation joint board, water stops, curing compounds, chemical anchoring material, sealers, and form oils should be certified by their appropriate agency, not past expiration, and in good condition. A visit to the warehouse to verify these items can help eliminate the added time and expense of replacing incorrect materials.

Concrete specialty contractor

- Does the subcontractor meet the quality management characteristics recommended in this chapter?

Product identification and traceability

Where the materials come from, and where they end up in the finished building, should be tracked. For example, one should know what mill produced what reinforcing bar shipment, the date of production, and where in the structure that rebar was placed. Most specifications require the submittal of rebar material certificates, so a supplier should be able to provide the source of the bar with the mill reports.

Keeping track of what concrete goes into what structure on what date is important in tracking performance of mixture designs and locating any material found to be deficient at a later date. The concrete supplier is responsible for knowing where the component materials (such as the cement, fine aggregate, and coarse aggregate) in the concrete mixture came from.

PROCESS CONTROL

Process control is the quality of having the right conditions to efficiently complete the work. Processes should be carried out under controlled conditions with respect to information flow, weather, access, logistics, communication, coordination of effort, sequences, testing, equipment, and documentation. Designs should be complete and clear, and approvals should be in place. Every person on the project team should know what is expected of them. Sequences and control points for inspections need to be defined. Results need to be reviewed for trending. In short, process control means that all aspects of the project are in order and running smoothly.

"*Every person on the project team should know what is expected of them.*

Communication

- It is important that a procedure be in place for preplanning, which includes a preconstruction conference. The NRMCA/ASCC *Checklist for the Concrete*