contractor. When one assumes that a problematic contractor may be involved with the construction, there are certain loss-prevention measures that the designer should use during design to minimize liability exposure:

- There can be no obvious flaws in the specifications that the contractor can use as justification for claims. This step requires considerable experience in specification writing. There should be no technical inaccuracies (see Section 15.2). No ambiguous language should be used that will allow the contractor to take liberties in his or her own interpretation. There should be no conflicts within the documents (specifications and drawings) that the contractor can use to his or her advantage.
- Clearly spell out the duties and responsibilities of the contractor, such as submittal contents and schedule, quality control testing and frequency of testing, utility clearance, progress meetings, all safety issues, and progress payment requests.
- State all minimum qualifications and experience for specialty construction, such as rock blasting, posttensioned anchors, roller-compacted concrete, and foundation improvement. This protects the owner from getting inexperienced contractors and subcontractors that get the job through low bid.
- Use the submittal process to check the contractor's means and methods for difficult construction, such as dewatering of a permeable foundation, or braced excavation in a deep cut in soft ground that is adjacent to buildings that need to be protected. The submittal should clearly list the method, sequence, materials, and equipment that demonstrate to the engineer that the work can be performed safely while meeting the requirements in the specifications. The submittal process allows a direct dialogue between the designer and the contractor before the construction starts to address as many of the anticipated problems and concerns as possible ahead of time. Sometimes the submittal process many require several iterations in the case of an inexperienced contractor before all the issues are addressed and the engineer is satisfied.

The precautions listed here are nothing more than what the owner normally expects from the design engineer in preparing a good set of specifications. By maintaining this defensive approach throughout the preparation of design documents, the designer can guard against potential problems that could manifest themselves during construction.

In spite of the defensive design approach against potentially poor contractors, there is great integrity, professionalism, and expertise among most construction contractors, who frequently have to deal with difficult working conditions and risks to complete the work. A designer can learn a great deal from competent contractors, and the design profession should value contractors as a great resource for design and construction issues.

Sharing the Risk

Another one of the engineer's responsibilities is to protect the interest of his or her client, usually the owner. In heavy civil construction, there are many times when the engineer and the contractor have to deal with unknown conditions, such as inclement weather, differing geology and foundation conditions, groundwater inflows, surface runoffs and flooding, and stream diversion. One apparent way to protect the owner in these situations is to shift all the risk to the contractor, as in the following specifications:

> The Contractor shall provide whatever is deemed necessary for cofferdam protection, stream diversion, and dewatering so that all construction along the stream channel is performed in the dry. Damages to permanent construction caused by flooding shall be repaired at no additional cost to the Owner. It shall be the responsibility of the Contractor to determine the height of the cofferdam and size of the diversion facilities for his or her protection.

In this particular example, the unspecified requirement is the level of flood protection during construction. A bidder can bid no protection, or a bidder can bid protection for a 10-year storm. Even when the engineer provides the bidders with historical streamflow records and seasonal precipitation records, there is still considerable risk for the contractor to work in the stream channel. Bidding on unknown conditions and risky situations is difficult, and, as part of the bidding strategy, potential claims may have been prepared already by bidders. In general, unknown factors increase construction costs. If the increased costs are not manifested in the initial bid, they will most likely be manifested in change orders and claims during construction. Contractors are known to take risks, and some accept more risk than others. There is undoubtedly a cost difference in favor of the contractor who takes more risk, but the owner is ultimately at risk if a flood destroys the work during construction.

It is unfair for the contractor to assume all of the risk for unknown or unanticipated conditions. The owner should share appropriate risk with the contractor, whom the owner hires to help build his or her project. When an owner agrees to share risk, the contractor feels that he or she is being treated fairly and that he or she is included as a partner in the team. It promotes a mutually acceptable working relationship between the owner and the contractor, and also between the contractor and the engineer during construction.

Both sharing the risk and treating the contractor fairly require compensating the contractor for the costs and losses he or she experiences as a result of unpredictable conditions. To handle unknown situations during bidding, the bid documents can ask the bidders to put aside cost allowances, or some other uniform basis can be specified for bidding. In addition, the specifications should also allow the contractor to recuperate losses for documented unanticipated conditions through a negotiation process. When bidders enter their bids with the understanding that they will not

need to absorb unnecessary losses, there will be fewer risk costs, and the bids will be more uniform and consistent. When a contractor starts construction with the understanding that he or she will be protected from losses caused by unknown situations, there will be less adversarial confrontation and more cooperation during construction.

For the example given above, the specifications can be rewritten to provide a more uniform basis for bidding and an avenue to compensate the contractor:

> The Contractor shall provide temporary cofferdam protection and stream diversion for construction in the stream channel. The required level of protection is elevation 362.0 feet. Temporary protection shall be earthfill cofferdams, sheet piles, bulkheads, or other approved water-retention barriers to prevent flooding of the new structure during construction. The Contractor shall provide a temporary diversion conduit with a shutoff valve under the cofferdam to drain the work area after flooding. Design and sizing of the conduit and valve shall be the responsibility of the Contractor.
>
> Damages to the permanent construction and temporary protection facilities caused by inadequate protection below elevation 362.0 feet shall be the responsibility of the Contractor. The Owner will negotiate with the Contractor in accordance with provisions in the contract documents to compensate for damages for floods that overtop the cofferdam above elevation 362.0 feet.

In the rewritten specifications, the owner and the contractor share the risk of flood protection. The engineer estimates that El. 362.0 ft is an acceptable level of protection for this construction, based on the duration of the construction work, and all bids for flood protection will be based on this level of protection. In fact, a bidder that provides no flood protection will be ruled nonresponsive and thus cannot use this tactic for cost advantage. Instead of specifying the frequency of the storm for flood protection, such as a 10-year storm, the engineer specifies a specific floodwater elevation, thus eliminating a common controversy on what sized storm actually occurred during the construction. When the bidders realize that they do not need to put aside any risk cost for large storms, the bids become more uniform, and the contractor's responsibilities are more clearly defined.

Fairness to All Parties

A fair specification treats all parties on the same basis. Each party has a certain responsible role, whether it is financial, design, testing, or construction. As designers, the engineer should take a lead technical role to provide the owner with the most cost-effective product that meets the project requirements. To the maximum extent possible, all of the design decisions and technical decisions should be made during the design phase, and not delayed until construction. One of the most common complaints from contractors is that they are asked to do too much engineering.

With some exceptions of specialty contractors, most contractors think that their main contribution to construction is to build, and not to design, for the owner. At the same time, owners pay engineers for their technical and design expertise, and a decision to delay a design issue to construction or to shift the design to the contractor should not be made, except under special circumstances. Special circumstances may include the following:

- Temporary construction features, which are usually designed by the contractor, such as dewatering, braced excavations, flood protection, stream diversion, access roads, and safety provisions;
- Need for additional foundation grouting, which is typically decided during construction, based on the geology, observed grout takes, and specified closure requirements; and
- Rate of fill loading on a soft clay foundation, which is controlled by the dissipation of excess pore-water pressure in the foundation, as monitored by piezometers.

The following are examples of some unfair and fair specification requirements. A commentary is provided (within brackets) for each example to further clarify the intent.

- Fair to all—"The Contractor shall submit test samples from proposed source for testing by Owner. If the test fails, the Contractor may submit a recheck sample for additional testing by the Owner. If the recheck sample fails, then the stockpile or proposed source shall be rejected. Testing for recheck sample shall be at the expense of the Contractor." (Commentary: The owner carries a testing budget to check whether the proposed material from the contractor's source meets specifications. However, when the first test fails, the specifications allow for a second test to account for variability but at the expense of the contractor. Both the owner and the contractor share the cost of testing—a fair arrangement.)
- Unfair to the contractor—"The Contractor shall be responsible for providing adequate quantities of structural fill from on-site borrow areas furnished by the Owner." [Commentary: It is the responsibility of the owner to ensure that the owner-furnished source has adequate material (see Section 3.4). A shortage of materials in the owner's borrow area should be considered a changed condition, and the contractor should not bear the additional cost of importing the material from off-site sources.]
- Fair to the contractor—"The Contractor agrees that, should he or she or any of his or her employees in the performance of this contract discover evidence of possible scientific, prehistoric, historic, or archaeological data, he or she shall notify the Contracting Officer immediately. Where appropriate by reason of a discovery, the Contracting Officer may order delays in time of performance, or

changes in the Work, or both. If such delays, or changes, or both, are ordered, the time of performance and contract price will be adjusted in accordance with the applicable clauses in the Contract." (Commentary: The discovery of buried archaeological artifacts during construction is considered an unforeseen field condition, even though the site has been surveyed and is known to contain these artifacts. If the discovery affects the construction, then the contractor is entitled to compensation for changes in contract price and schedule, which is allowed in the contract. These contract provisions are common in federal construction specifications.)

- Unfair to the contractor—"The Contractor shall perform all concrete and field density testing at a frequency as deemed necessary by the Engineer." (Commentary: The testing frequency is an open target, and it is impossible for the contractor to budget the testing cost in his or her bid.)
- Fair to all—"The Contractor shall perform concrete testing at a frequency of every 30 cubic yards of concrete placed. Field concrete tests shall include slump, temperature, and air content. The Engineer will perform all field density tests at least once every lift of earthfill placed, or more frequently, as deemed necessary by the Engineer. The test location in the fill will be determined by the Engineer." (Commentary: The contractor is responsible for testing the concrete, and the owner is responsible for testing the in-place earthwork. At a prescribed rate of 30 cubic yards per test, the contractor can estimate the number of tests required, and hence the testing cost. The contractor knows that the owner will test every lift of the earthfill placed, so there will be allowance for access by the testing personnel and work stoppage before the next lift is placed. The test location is not a cost burden for the contractor. If more earthwork testing is needed for each lift, that cost will be the responsibility of the owner, and not an open target for the contractor.)

15.4 Technical Correctness and Quality Control

The first responsibility of a specifier is technical correctness of the specifications. A set of specifications can be written in the most clear and concise language, but if the wrong materials or products are specified, or if the wrong standard references are cited, the specifications are defective. Examples of technical inaccuracies are illustrated in Section 15.2. Technical inaccuracies are considered design errors. Problems associated with design errors may or may not be readily revealed during construction.

Ensuring technical correctness is one of the main functions of the lead design engineer and represents part of the engineering process in a design. Regardless of what engineering discipline (e.g., structural, mechanical, or geotechnical) is involved, and without going into technical details in a particular discipline,

there are a number of things a lead design engineer can do regarding technical correctness in specifications:

- The design analysis, whether hand-calculated or computer-assisted, should be checked for correct assumptions, criteria, methodology, and mathematics. Unchecked analysis is a poor engineering practice, and the direct implications of an error in specifications caused by unchecked analysis can be serious.
- When an old specification is to be reused for a current project, the engineer should try to understand what design criteria, site conditions, and other project-related background are associated with the old specification before it is marked up for the next project. Requirements in specifications were put in the previous project for a reason, and that reason may be different for other projects.
- Only factual field and laboratory data (such as drill logs, laboratory soil test data, concrete mix design study, and borrow-area test pit logs) should be included in the construction documents. The engineer's interpretation and evaluation, used in reports to his or her client, should not be used in construction documents. The contractor should provide his or her own conclusions and interpretations of these data.
- Heavy civil construction often involves many different engineering disciplines, and a designer of a particular discipline should resist practicing beyond his or her area of expertise without consulting with engineers from other disciplines (see Chapter 12). For example, a structural engineer should not prepare a foundation preparation specification of a clay shale foundation that has slaking deterioration potential if it is not adequately protected. A geotechnical engineer should not prepare a specification of mechanical gates and valves, especially for special applications, such as pinch valves, free-discharge valves, and radial gates.
- Specifying new products, new materials, and new construction methods that do not have adequate performance history or adequate testing should be resisted. An engineer should always be innovative and look for ways to reduce construction costs and to advance the state of the practice. On the other hand, a design engineer has a responsibility to minimize liability exposure for his or her company and himself or herself, and it is natural to take a fundamentally cautious approach in design. These two opposing considerations should be balanced on a case-by-case basis. A good example of being innovative in design is the use of articulated concrete block revetments to provide erosion resistance in hydraulic channels; this revetment system has been adequately tested in the laboratory, in full-scale models, and in actual applications. On the other hand, gabions (rock-filled wire baskets) have been promoted by manufacturers to provide the same erosion resistance in hydraulic channels, yet there are numerous failures reported for this application; in those cases, using the more traditional riprap is a more conservative approach.

- The designer should make it a habit to review the standard reference specifications referred to in the project specifications, especially when using a new or revised version in which subtle differences may exist (see Section 17.4). When products are specified from standard reference specifications, the availability of that product should first be verified with manufacturers and distributors.

The first responsibility of an in-house design reviewer is to check on the technical correctness of the specifications. If the primary role of the project manager of a design project is administrative because of a lack of design experience, that manager should not be the technical reviewer of the specifications (or the construction drawings). The same can be said about principals without design and construction experience. The review by a qualified technical reviewer is the last line of defense for quality control before the project goes into bidding and construction. According to the Construction Specifications Institute (2011), in addition to obvious graphical, dimensional, and typographical errors, the design reviewer should check the construction documents to eliminate the following problems:

- Omissions;
- Overlaps and duplications between disciplines;
- Noncompliance with laws and regulations;
- Conflicts and discrepancies with locations of equipment and components;
- Incompatible materials and components;
- Difficult or impossible construction methods;
- Inconsistent terminology and abbreviations;
- Inconsistent units of measure;
- Incorrect or unspecified materials, components, or equipment;
- Errors in defining areas of construction phasing;
- Errors in defining limits of work;
- Errors in identifying work by the owner or work not in contract;
- Errors in designating work of separate contract; and
- Inaccurate or unnecessary cross-referencing.

Typographical errors are another overlooked aspect of quality control of specifications. Typographical errors, if undetected, may result in serious problems in construction. An extra word (e.g., “shall not” versus “shall”) or different numbers may have significant cost implications associated with the error. Typographical errors, even though committed by the clerical staff, are the responsibility of the lead design engineer in the same way that technical errors committed by junior engineers are the lead engineer’s responsibility. Regardless of time constraints caused by a tight specification production schedule, it is the responsibility of the lead specifier to back-check all changes typed by the clerical staff and all cross-references to other specifications and drawings. This problem is particularly

prevalent when an old specification from a previous project is used as a starting point, and the text is so voluminous that there is a tendency not to carefully read or understand all of the text.

15.5 Contractor's Means and Methods

The conventional approach in construction, whether civil or architectural, is to allow maximum flexibility to the contractor's means and methods that are not specified, as long as the final product or final results comply with the specifications. The reasons for this approach include the following:

- It allows the contractor to adapt his or her own equipment, crew, and procedure for the project.
- It encourages the contractor to be innovative and use his or her own experience and background.
- It alleviates the designer's liability on the construction method and allows the field quality control personnel to focus on the end product instead of the construction method.

A well-known application of this principle is site safety provisions, which are the sole responsibility of the contractor. Site safety is discussed in more detail in Section 15.12.

It is within the realm of the designer, however, to put restrictions on acceptable means and methods because of technical reasons or specific project requirements. These restrictions should not be considered a problem if they are known during bidding and construction. The following examples illustrate how limiting the contractor's means and methods actually results in a better product or performance, or improved safety, in some situations:

Soil compaction

- "Only vibratory rollers are allowed to compact the clean filter sand and gravel."
- "Only sheepsfoot rollers are allowed to compact the cohesive embankment fill in the dam. Smooth drum rollers are not allowed."

Drilling method

- "To avoid hydraulic fracturing, only drilling with hollow-stem augers and without drilling fluids is allowed in the embankment dam."
- "To avoid damaging the dam, only diamond-bit coring in the concrete dam shall be allowed."

Dewatering method

- "Well-point dewatering shall be required for excavation in the clean sand and gravel foundation. Foundation dewatering by sump-pumping alone shall not be considered adequate."

Construction sequence restriction

- "The Contractor shall first construct the new access road to allow local residents continuous access across the construction site."
- "To allow uninterrupted streamflow downstream, the Contractor shall install the new culverts before placing the temporary cofferdam."

In the examples above, the geotechnical designer has determined—based on the anticipated subsurface conditions, his or her understanding of material behavior, and his or her judgment—that certain construction methods are not acceptable. This engineering decision can be made during design or during construction. To the extent possible, the decision should be made during design to minimize changes in conditions and disputes during construction. By specifying these restrictions in the bid documents, the bidders can accommodate these restrictions in their bids. By delaying this decision until construction, the contractor may argue that these restrictions will result in additional costs to him or her. Both approaches may end up increasing the cost of the project (in the original bid or in change orders), but handling the changes during construction could lead to other problems, including delays or impacts to other related work, which then leads to additional cost increases.

15.6 Specifying Materials and Products

Even if the specifications are prepared by nontechnical personnel (e.g., in-house specifiers who are not professional engineers), the selection of a specified material or product should be the responsibility of the design engineer (see Section 15.1). Many factors—functional characteristics, practical concerns, material and installation costs, code requirements, compatibility with existing facilities, past performance, maintenance requirements and costs, and availability—contribute to the selection of a particular material or product. The Construction Specifications Institute has an excellent reference on product evaluation (2011).

The potential problems associated with product substitution are discussed in Section 15.2. In particular, the specification provision "or equal" is the center of most disputes regarding product substitution. Removing the "or equal" provision, as proposed by Rosen et al. (2010), is not the solution to this problem. In fact, for federal projects, this provision is mandated if proprietary products are used. Rather, if used appropriately, the provision "or equal" is an acceptable provision to allow a contractor to substitute a named product for another one.

Let us approach the problem from the standpoint of a contractor preparing his or her bid on a certain brand-name product with an allowance for substitution. Other than the brand name, no other properties and acceptance criteria are given in the specifications. To gain an advantage, the bidder does not use the specified brand name, but substitutes a less costly product. This bidder later is selected as the

contractor, and when the contractor submits the cheaper product to the engineer for approval, the product is rejected on the grounds that it is an inferior product and is not equal to the specified brand name. Because the specifications for this product do not contain any other technical requirements and characteristics, the contractor chooses to argue with the engineer on the rejection, leading to delays, disputes, and claims.

Let us consider another scenario. This time, the specified brand name is accompanied by a list of relevant properties and performance criteria that are used to determine product equivalence. Under these conditions, the avenues of controversy are removed. Let us also assume that the contractor, in preparing his or her bid, has identified a cheaper product that satisfies all of the specified properties and criteria and has used that cheaper product in preparing his or her bids. During construction, the contractor submits a request for substitution, and the engineer accepts the substitution because it meets all required properties and criteria.

The latter approach contains two strategies in the use of the "or equal" provision:

1. It encourages competition, while it gives the engineer a contractual basis to compare equivalent products.
2. When a set of characteristic properties and criteria are specified with a named product, the additional information allows the bidder to look for equivalent, less expensive products for use in his or her bid. Without this information, the bidder is risking that his or her substitution will be rejected later.

Two examples of appropriate use of the "or equal" provision are provided below:

1. "Geotextile erosion protection mat shall consist of polymer nettings, with a fused, three-dimensional mat of sufficient thickness and void space to allow for soil filling. The material shall be ultraviolet stabilized with a minimum of 2 percent carbon black to resist sunlight degradation when exposed. The mat shall be resistant to biological and chemical degradation. Geotextile erosion protection mat shall be Tensar Erosion Mat TM3000, or approved equal."
2. "Steel sheet piles shall conform to ASTM A328-93 and shall have a minimum yield strength of 39,000 pounds per square inch. The minimum section modulus for each single section shall be 90 cubic inches, and the weight per square foot of pile shall be 35 pounds. The sheet piles shall be PZ35 as manufactured by Bethlehem Steel, or approved equal."

In these examples, the requirement of uniform bid basis is used to encourage competition. The characteristic properties given in the specifications allow the engineer to approve or reject any substitution without having to deal with any potential for claims.

Finally, the engineer should check on the availability of a brand-name product that is specified. Failure to do so during design may be justification for the contractor