Quality Concrete: How Does the Owner Obtain It?

by B.E. Weinberg

Synopsis: An owner can do much to achieve quality concrete construction. He has the most at stake in a project, must live with the results of others' efforts, but knows the least about how to achieve the desired results. His roles and responsibilities are discussed. Guidelines are given for the hiring of the designer and contractor. What must the owner demand from them? What must he do for them? Two essentials for success are a comprehensive quality control program by the contractor and quality assurance program by the designer. The owner must involve himself in the project continuously to make certain that these programs are fully implemented and monitored.

Keywords: concrete construction; contractors; quality assurance; quality control; responsibility; structural design

Bertold E. Weinberg, P.E., F.A.C.I., is Chief Project Manager, New York State Dormitory Authority, Elsmere, N.Y. He has also worked in private consulting and construction. A member of Committees 311, Inspection of Concrete, 362, Parking Structures, and E-902, Certification, he chairs Committee E-901, Scholarships.

INTRODUCTION

This paper addresses what the owner must do to achieve quality concrete construction, to end up with a facility with which he will be satisfied, not only when construction is completed, but also throughout its expected useful life. We will not discuss the many technical aspects involved, for two reasons. First, most technical questions are being addressed in other papers of this symposium. And, second, the owner is usually the least qualified person to address them.

THE OWNER

His Concerns

For perspective, consider a few general comments about the owner. First, if he is an occasional owner (not a government agency or developer) he knows the least about concrete of everyone involved in producing it. This includes the owner, the designer, the contractor, the material suppliers, the testing laboratories, government agencies, etc. The owner knows that he wants a good end product, but usually does not know how to get it. Second, the owner pays all the other parties involved, either directly or indirectly. If there were no owners who wanted facilities built, every school of architecture and engineering, every construction company, every building material supplier, every testing laboratory, every contractor might as well close. Finally, the owner has to live longest with the results of everyone else's efforts. Unless the designer or constructor wins an award, or unless there is litigation, all the other parties immediately move on to the next project. However, the owner must live with the results of all others' efforts for the next 30 or 40 years.

His Roles

What are some of the owner's specific roles in achieving quality concrete? First, he must define his needs concerning the type and quality of end product he requires. He must be quite specific in this. When does he need it? What is the expected useful life of this facility? To what kinds of loads and service requirement will the facility be subjected? And, finally, what are the owner's financial resources? If the owner wants a quality end product he must clearly define all these needs.

The other major role that the owner has is the hiring of a competent architect or engineer designer: (1) both to achieve an appropriate design and, (2) even more important in the early stages, to help the owner define the needs discussed above. Very few owners are qualified to specify their needs with the precision required if the project is to be a success. The hiring of a competent designer is critical for the owner to end up with quality construction, be it in concrete or any other material.

His Responsibilities

What are the owner's responsibilities? The most important one is to give the designer adequate resources to do his job properly, both in time and money. Quality work cannot be rushed, be it in surgery, in preparing a legal brief or in designing a facility. Also, dollar for dollar the money spent on design fees will have a far greater impact on the quality of the end product than any money spent later on materials, construction or operation and maintenance of the completed facility. Not even the best material supplier, contractor, or maintenance organization can overcome the effects of improper design.

The owner should not require a higher level of quality than he needs or can afford. He must match his expectations with his needs and his budget. Lastly, he has no right to expect more quality in either design or construction than all parties have agreed upon. At the same time, he must accept no less.

THE DESIGNER

Selection

What should an owner consider in selecting a competent designer? What is the designer's recent experience with this type of project? Does he have qualified staff available to meet the owner's time schedule? What is his track record in keeping projects within budget? What are the experience and quality of his proposed consultants? Is he able and willing to perform acceptance inspection? What do previous clients say about his completed facilities? Is he or has he been subject to disciplinary proceedings?

What Must He Do For The Owner?

In achieving quality concrete what must the owner demand from his designer? As said before, the owner must demand a design that fits both his needs and his budget. He must work closely with the designer in order to reconcile the two. The owner must demand that the designer furnish him with a clear, complete design and specifications. There is no room for ambiguity. Considering the diverse financial interests of the owner, designer and contractor, the designer's responsibility to the owner in this regard is quite clear.

Equally important, the owner has the right to demand that the designer develop a constructible design, with constructible details. This means a design constructible in the area where the project will be built, and details with which the construction crews are familiar. Special or unusual construction methods, materials and details should be avoided, unless they are specifically needed. The designer must remember that he is not building a monument for his own glory or experimentation. Rather, he is designing a facility with which his client has to live for a long time. And, finally, the owner must demand that his designer assume full responsibility for acceptance inspection.

Absolutely essential for obtaining quality concrete are fully spelled out requirements for the contractor's quality control program. These must cover materials, off-site fabrication, batch plant operations, on-site work, testing, inspection, etc. Acceptance inspection, and the testing laboratory work connected with it, must never be made part of the contractor's responsibility. The owner must insist that the designer develop the construction documents accordingly.

In developing the acceptance inspection program, the testing laboratory should be hired on the same professional basis as the designer, whether it works for the designer or directly for the owner. It should not be hired on a low-bid basis. And its technicians should hold ACI or equivalent certification.

What Must The Owner Do For Him?

If the above outlines some of the things the owner has the right to expect or demand from his designer, what are the owner's responsibilities to the designer? First, as mentioned, he must furnish his designer with a fee and time adequate to do the assigned task. Then the owner must make timely decisions, for some of which he will need his designer's advice. And, finally, the owner must support his designer as needed in dealings with all other parties involved in the project--contractors, suppliers, government agencies and so forth. Without that support the designer is a sitting duck for all the other parties.

THE CONTRACTOR

Selection

Next, what can the owner do to assure himself quality work in selecting his contractor? If it is a public project, the work is usually subject to public bidding. Where permitted, the owner should carefully prequalify the bidders. Where this is not permitted, he should include a detailed post-bid qualification questionnaire in the bid documents, to be completed and submitted by the apparent three low bidders within a stated, short time after bid opening.

If it is a private project, the owner must carefully check out the contractors being considered. The lowest priced proposal is not always the best one. What is the contractor's experience with this type of project? What are the qualifications of his proposed subcontractors and major suppliers? What is his track record with timely completion? How often has he been sued by clients? Why? Is he financially stable? Is he claim happy? What is his overall reputation?

What Does He Owe The Owner?

What can the owner demand from his contractor? Most important of all is full compliance by the contractor with all requirements of the contract documents. As stated before, the owner has no right to expect more than what the contract documents call for. Yet he must accept no less. The owner must demand that the contractor at all times fully implement a proper quality control program. Just as no one other than the designer is qualified to execute a proper acceptance inspection (quality assurance) program, nobody other than the contractor is as qualified to implement a proper quality control program.

What Does The Owner Owe Him?

In return, what must the owner furnish the contractor? Obviously, the most important is timely payment. An owner who thinks he can delay payments to his contractor, and thereby reduce his total costs, is only fooling himself. A contractor can do far more, and far more lasting, damage to an owner than the other way around. And nothing will keep a contractor as happy on a project, and encourage him to do his best, as knowing that he will be paid promptly.

Also, the owner must deal with the contractor fairly. While their interests diverge, not every complaint by a contractor is unjustified. Quality construction depends on cooperation. And cooperation depends on fair dealing.

SELFHELP

Now that we have talked about some specific relationships in the owner's obtaining quality concrete, what are some of the specific steps the owner should take to help himself? In doing these he should feel free to call on his designer to act as his agent. First, the owner must recognize the varying interest of all the different parties involved in the project. He should clearly understand the roles of each. At the same time, he should stress the common interest all parties have in the project's success. The owner is more likely to have a quality end product if all parties involved are satisfied and make a reasonable profit. Implicit in this is to avoid an adversarial tone unless specifically necessary. Be tough when you have to be, but no tougher than you need to be.

A most useful tool to help achieve a quality project is to hold a pre-construction conference involving all parties, the owner, the designer, contractor, testing laboratory, subcontractors and suppliers. An early meeting of the minds concerning what the major problems are or are likely to be is important. Lines of responsibilities and communications should be spelled out. A clear understanding must be achieved of who has to make what decisions, and when, what kind of reports and test will be required, what needs to be inspected, at what point and by whom, and who has the right to stop the work. These and other questions should be answered at the very beginning, because all parties should remember that the least costly problems are the ones that are avoided. In any major undertaking no matter who pays directly for a specific problem, indirectly all parties pay.

As mentioned, the owner must insist on the implementation of full quality control and acceptance inspection programs. However, there is no point in calling for tests and reports unless the test results and reports are monitored on a continuous basis. Reports and test results have a diminishing time value. So, it is important that prompt corrective action is taken for all errors, improper test results and deviations from normal test results.

CONCLUSION

Some of the above will appear utopian. And yet, very few of us know of any successful concrete projects where most of the above has not held true. Most owners are not familiar with what is expected of them. So, this places an added responsibility on the designers whom they hire. Major government agencies or private owners, such as hotel, department store and supermarket chains or utilities, frequently have staff that can handle many of these problems. It is the occasional owner of a facility who knows the least and is most dependent on his design professionals.

In conclusion, for the owner to obtain quality concrete he must be involved in the project at all times, he must clearly define his requirements, including quality needed, he must be able and willing to pay for this quality and he must continuously and actively, directly or through his design consultant, assure himself that he is obtaining the agreed upon level of quality.

SP 104-2

Effects of Construction Practice on Concrete-Steel Bond

by D. Darwin

Synopsis: Construction methods and concrete properties affect the bond strength between concrete and reinforcing steel. Research on the effects of concrete slump, consolidation practice, bar position, concrete cover, and bar spacing is summarized. The research shows that the use of high slump concrete reduces bond strength. An increased density of vibration increases bond strength. Vibration is especially important for high slump concretes, both with and without superplasticizers. Revibration is of greatest benefit to top-cast bars in high slump concrete. Revibration may damage bond in initially well consolidated, low slump concrete. Top-cast bars show reduced bond strength with as little as 6 in. [150 mm] of concrete below the bars. Bond strength decreases with increased concrete depth below bars, decreased cover, and decreased bar spacing. Monolithic cover provides a higher bond strength than laminar cover of the same total thickness.

Keywords: bond (concrete to reinforcement); bridge decks; concrete construction; consolidation; cover; moving loads; plasticizers; pullout tests; reinforced concrete; reinforcing steels; repairs; resurfacing; structural engineering; vibration; water-reducing agents; workability

David Darwin, FACI, is a Professor of Civil Engineering and Director of the Structural Engineering and Materials Laboratory at the University of Kansas. He is a member of ACI's Technical Activities Committee and Past-President of ACI's Kansas Chapter. He is also a member and past-chairman of ACI Committee 224, Cracking. He is a member of ACI Committee 408, Bond and Development of Reinforcement, ACI-ASCE Committee 445, Shear and Torsion, ACI Committee 446, Fracture Mechanics, and the Concrete Materials Research Council. Darwin received the ASCE Walter L. Huber Civil Engineering Research Prize in 1985 and the ACI Delmar L. Bloem Distinguished Service Award in 1986.

INTRODUCTION

Construction methods and concrete properties play an important role in determining the bond strength between concrete and reinforcing steel. Changes caused by construction-related variables can exceed the modification factors that are used in development length design (ACI 318-83).

The key variables are concrete slump, consolidation practice, bar position, concrete cover, and bar spacing. In most cases, the effects of these variables are interrelated. For instance, the negative impact on bond strength of high slump concrete is magnified with a lack of consolidation, increased depth of concrete below a bar, and decreased cover.

This paper presents a survey of research on the effects of the key construction-related variables on concrete-steel bond strength. Most of the work pertains to horizontal deformed bars. Recent work concerning the use of superplasticized concrete and the use of revibration is of special interest. The role of transverse steel, an important design consideration, is not covered.

Lewis H. Tuthill has made "quality concrete construction" the major theme of his professional life. The research presented in this paper strongly emphasizes the importance of construction practice in determining concrete-steel bond strength.

CONCRETE SLUMP

The workability of concrete, generally measured by slump, affects the bond strength between concrete and reinforcing steel. After concrete is cast, it continues to settle and bleed. Settlement leaves a void below rigidly held bars. Bleed water collects below bars, whether rigidly held in place or not. The higher the concrete slump, the greater the tendency to settle and bleed.

Properly consolidated, low slump concrete provides the best bond with reinforcing steel. High slump concrete, used primarily when it is desirable to use little or no consolidation effort, results in decreased bond. Top-cast bars (bars near the upper surface of a concrete placement) appear to be especially sensitive to slump. Top-cast bars may or may not be "top reinforcement," defined as "horizontal reinforcement so placed that more than 12 in. of fresh concrete is cast in the member below the reinforcement" (ACI 318-83).

Menzel (1952) studied the effect of slump on bond strength for top-cast bars. Using specimens shown in Fig. 1, he observed a marked reduction in bond strength as the height of top-bars was increased from $2\frac{1}{8}$ in. to $33\frac{1}{8}$ in. (54 to 841 mm) when using 5 to 6-in. (127-152 mm) slump, hand-rodded concrete. The rate of decrease in bond strength with increasing height of the top-bars was greatly reduced by decreasing the concrete slump to a range of 2 to 3 in. (51 to 76 mm).

Zekany, Neumann, Jirsa, and Breen (1981) studied the effect of concrete slump on top-cast and bottom-cast splices. They found that the bond strength of both top-cast and bottom-cast bars decreased with increasing slump. The effect was most pronounced for the top-cast bars. Luke, Hammad, Jirsa, and Breen (1981) studied the influence of casting position on development and splice length using a 72-in. (1.83-m) deep wall specimen (Fig. 2). As shown in Fig. 3, the bond of top-cast reinforcement was reduced significantly with $8\frac{1}{2}$-in. (216-mm) slump concrete, as compared to 3-in. (76 mm) slump concrete. The bond strength of these bars decreased 40 to 50 percent due to the increase in slump alone.

Donahey and Darwin (1983, 1985) studied the bond strength of top-cast bars in bridge decks. The bars had different amounts and types of cover. These included two monolithic covers, $\frac{3}{4}$ and 3-in. (19 and 76-mm) thick, and a laminar cover consisting of a $\frac{3}{4}$-in. (19-mm) monolithic cover topped with a $2\frac{1}{4}$-in. (57-mm) high density concrete overlay. Eight in. (203 mm) of concrete was used below the reinforcement. As shown in Fig. 4, increasing slump resulted in decreased bond strength.

High slump concrete can be obtained in a number of ways. It can be obtained by the addition of water, in which case the strength of the concrete is reduced. It can be obtained by the addition of water and cement, in which case the strength of the concrete can be maintained approximately constant. Or, it can be obtained by the addition of a high-range water-reducer or superplasticizer, in which case the strength is usually increased.

A number of recent investigations have specifically considered the bond of reinforcement to superplasticized concrete. Brettmann, Darwin, and Donahey (1984, 1986) used modified cantilever beam specimens (Fig. 5) and concretes varying in slump from $1\frac{3}{4}$ to 9 in. (44 to 229 mm). Three specimen depths were used. The key variables were degree of consolidation, concrete slump with and without superplasticizer, concrete temperature, and bar position. Based on their work, Brettmann et al. (1986) concluded that, if cast at a relatively high temperature (resulting in a short setting time), properly vibrated (ACI 309-72) high-slump superplasticized concrete and its low slump nonsuperplasticized base concrete provide approximately the same bond strength. The equal bond strength is due largely to the increased concrete strength obtained with the high-range water-reducer. However, for the <u>same concrete strength</u>, high slump concrete made with a high-range water-reducer has a lower bond strength than low slump concrete. Brettmann et al. also observed that if the high slump, superplasticized concrete is cast at a low temperature (resulting in a longer setting time), or if high slump, high cement factor, nonsuperplasticized concrete is used, bond strength decreases regardless of concrete strength. The results of Brettmann et al. for both superplasticized and nonsuperplasticized concrete, normalized for concrete strength, are illustrated in Fig. 6. In this case, the bond strengths are normalized to a concrete strength, f'_c, of 4000 psi by multiplying the experimental results by $\sqrt{4000/f'_c}$.

Musser, Carrasquillo, Jirsa, and Klingner (1985) and Zilveti, Sooi, Klingner, Carrasquillo, and Jirsa (1985) also studied the effect of high slump, superplasticized concrete on bond strength. Specimens were consolidated using an internal vibrator in both investigations. Musser et al. considered the anchorage of deformed bars in wall specimens. Bond was tested by a straight pull-out procedure (Fig. 7). Zilveti et al. used modified cantilever beam specimens similar to those used by Brettmann et al. (1984, 1986) (Fig. 5). Of the two test methods, modified cantilever beam tests provide a more realistic comparison to bond in structural members than do pull-out tests, since the test places both the concrete and the steel in tension. Pull-out tests of the type used by Musser et al. place the concrete in compression around the test bar. Musser et al. found little effect, with or without a correction for concrete strength. Zilveti et al. concluded that the addition of a superplasticizer simply to improve workability has no effect on bond strength. Additional analysis of Zilveti's results, however, reveals that when corrected for concrete strength, the bond strength obtained with high-slump, superplasticized concrete is lower than the bond strength obtained with low slump concrete. This agrees with Brettmann's results. Also like Brettmann et al., Zilveti's tests show that high slump is more detrimental to bond strength when the temperature of the concrete is initially low. The lower temperature provides a longer period during which the concrete remains plastic and, thus, a longer period during which settlement and bleeding occur.

CONSOLIDATION

It is generally agreed that adequate consolidation is a key factor in quality concrete construction. The role of consolidation is usually described in terms of removing entrapped air. In terms of bond, adequate consolidation, usually in the form of high frequency internal vibration, plays the additional role of reducing the effects of settlement and bleeding, which result in the accumulation of bleed water and low density, weak concrete just below horizontal reinforcement. By disturbing the concrete, vibration helps restore local uniformity. Both the removal of entrapped air and the restoration of local uniformity appear to play an important role in improving bond strength.

In the following sections, the effects of initial vibration, delayed vibration, and revibration are discussed.

Vibration

Davis, Brown, and Kelly (1938) studied the effects of delayed vibration and sustained jigging on bond strength. Using 4-in. (102-mm) slump concrete, vibrations were applied 0 to 9 hours after the placement to specimens consisting of deformed bars held vertically in cylindrical specimens. Delayed vibration up to 9 hours improved bond strength compared to initial vibration. Increases in bond strength of up to 62 percent were recorded. This improved bond strength has been used as evidence of the positive effect of revibration (Tuthill 1938, 1977). However, since the specimens were not initially vibrated, the improved bond strength must be attributed to delayed vibration, not revibration.

Using similar specimens for sustained jigging tests, Davis et al. obtained increases in bond strength as the period of jigging increased from one-half hour to two hours, after which there was no significant change up to a maximum of 6 hours.

Robin, Olsen, and Kinnane (1942) compared bond strengths of horizontally cast bars consolidated with external vibration and