Effective Contract & Shop Drawings for Structural Steel

Pre-qualification, improved direct communication and greater emphasis on technical and professional conduct are key in producing high-quality, consistent shop drawings.

EMILE W.J. TROUP

During the past 15 years, the legal and insurance industries have increasingly influenced the way buildings framed with fabricated structural steel are designed, reviewed and constructed. Insurers and attorneys have been advising structural design professionals and contractors to limit their scope of service and write contracts that make the relationships among the project participants more confrontational and defensive – hardly the stuff of "partnering" or "team building." The term *approve* has all but disappeared from shop drawing review vocabularies.

For their part, since the fast-track construction process became popular during times of double-digit interest rates, owners and developers have come to expect that Rome *really can* be built in a day. Projects that sit on the shelf for two years suddenly must be designed in two weeks. This schedule-driven mentality provides design professionals insufficient time or fees for preparing complete Contract Documents and transforms the contractor bidding process into one of speculation rather than solid estimation of the work to be done. Speculation in bid preparation breeds uncertainty – and uncertainty increases bid prices. Incomplete design drawings also increase the chances that they will be misinterpreted. Not only is the public perhaps at higher risk, but the fast-track project can quickly become plagued with inflated costs and schedule – and offer greater potential for disputes, claims and litigation. Profits may be realized, but probably not by those involved at the level of structural design or steel fabrication. Ultimately, one way or another, the owner pays.

Higher quality and more consistency in the way contract drawings and shop drawings for structural steel are prepared must be encouraged. The recommendations herein are based primarily on "round table" discussions that have occurred during the past several years among members of the Structural Steel Fabricators of New England (SSFNE), New England Steel Detailers Association (NESDA) and the following state structural engineers associations: Boston Association of Structural Engineers (BASE), CEPP/Structural Engineers Coalition of Con-

necticut (CEPP/SEC), Structural Engineers Association of Maine (SEAM) and Structural Engineers of New Hampshire (SENH).

An attempt has been made to avoid the issues of legal responsibility and liability and rather to concentrate instead on the basic tasks that each discipline should perform, as part of the team, to help achieve the primary design objective – providing structural safety and reliability for occupants of the built environment.

Should Pre-Qualification of Structural Steel Fabricators Be Specified?

Background. In the interest of public welfare, the selection of firms for the design, detailing, fabrication and erection of structural framing systems for most building projects should be quality-based. At this time only the Architect and the Structural Engineer of Record (SER) are required to be professionally licensed, attesting to his/her education, experience and competency (by examination) for performing structural analysis and design. Although licenses for major building construction disciplines are required by some jurisdictions (for example, the state of Connecticut), qualifications for these "licenses" generally do not address technical expertise or product quality.

At the least, an unqualified steel fabricator can cause distress, added expense and dispute among the parties on the project and can jeopardize the construction schedule. At the worst, defects in the fabricator's or erector's work (if undetected) can jeopardize structural safety of both construction workers and the public at large.

Since the mid-1970s, the American Institute of Steel Construction (AISC) has administered a Quality Certification Program for structural steel fabricators. Fabricators that are AISC certified have been evaluated for their capability to perform work of the required quality for projects in various building and bridge categories. The program is recognized by the Building Officials and Code Administrators (BOCA) as fulfilling the purpose of the inspection of Fabrication Procedures (often referred to in New England as "Part A Inspection") under Special Inspections, Section 1705 of the 1993 BOCA National Building Code. The AISC Quality Certification Program recently underwent its first major revision that became effective during the summer of 1995. The revised program places greater emphasis on shop experience, training and quality of the fabricated product. The number of certified fabricators has grown steadily over the years, but only recently has AISC published a listing in the December 1995 issue of *Modern Steel Construction.*

Attempts by the SER to pre-qualify steel fabricators have sometimes been rejected by general contractors who convince owners that selection of structural fabricators should be solely by price. In addition, the limited number of certified fabricators in certain areas has restricted bidding on some projects. However, other criteria for fabricator pre-qualification have been successfully used. One such criterion, for example, is membership in a recognized, regional industry association having pertinent qualifications for membership – in New England, one such organization is SSFNE.

Currently, there are nearly 50 steel fabricators in New England that are AISC certified and/or SSFNE members. At this time, there is no formal certification program on which to base the selection of structural steel detailers or erectors. However, a pre-qualified fabricator should be expected to retain competent detailing (and erection, if included in the fabricator's contract).

Recommendation. At least for buildings above a threshold size, complexity or occupancy type, the Contract Documents should specify that the structural fabricators of any material be pre-qualified. Pre-qualification criteria for steel fabricators include AISC Quality Certification and, if available, membership in a regional fabricator association that has explicit qualifications relating to the capability of the fabricator to produce an acceptable product. Clients should be educated as to the financial (and other) risks involved in insisting on a non-pre-qualified structural subcontractor.

How Important Is Direct Communication Between the Fabricator, Detailer & SER?

Background. Direct communication between design professionals and structural subcontractors or suppliers is an avenue by which schedule-sensitive and technical questions are clarified in a timely manner. Obviously, when a

clarification results in a necessary structural change that increases project cost or affects an architectural detail, others in the normal chain of communication also must be informed.

During informal pre-design discussions, the SER should seek advice about the selection of connections from steel fabricators and erectors. Perhaps more important is a post-award discussion with the successful bidder of structural work to reach a consensus about typical connections and details. Agreement among members of the structural system team prior to placing mill orders and preparing shop drawings can avoid subsequent costly rework and delays.

Recommendation. Because of considerations for the public welfare and project cost and schedule, the structural steel fabricator and detailer should have an open line of communication with the SER during the preparation of shop drawings. Prior to the preparation of shop drawings, the SER and steel fabricator should agree as to what typical connections will be used. Direct contact between these parties serves the purposes of quality assurance, expediency and clarification. However, this is not a substitute for the normal chain of communication with other parties as required by contract.

Should Simple Shear Connections Be Selected by the SER?

Background. To remain competitive, fabricating shops are increasingly dependent on computer numerically controlled (CNC) equipment for more efficient production. Much of this equipment is designed for specific operations – *e.g.*, the punching and drilling of holes for bolting. Indeed, many shops consider themselves to be a "bolting" shop or a "welding" shop – meaning simply that they are more efficient in, *but not limited to*, one joining method over another. These shops much prefer to have the Contract Documents specify only the criteria and loading for simple shear connections (*e.g.*, beam end reactions greater than 10 kips) and to assign selection and design to the fabricator and detailer. Shops that are not so automated may have more flexibility and may accommodate a wider variety of simple shear connection types – but even these shops usually have preferences.

There is a significant difference between simple shear connection *selection* and *design*. There are only seven common simple shear connections, but many possible combinations of bolted or welded details and shop or field assembly. Of the seven basic types, perhaps four might be suitable connections on a given project. (Examples of "unsuitable" connections might be shear plates into column webs and stiffened beam seats into girders.) Of these four, two or three are probably better, and of these each fabricator would have a preference. The SER may know the four suitable connections but probably not the fabricators' preferences for connections from among the many possible combinations.

In addition to requiring knowledge of basic design concepts, the selection of connections requires knowledge of fabrication and erection practices and preferences, erection safety and local erection capabilities (experienced field welders are not always available in the local market). Simple shear connection design (assuming loads are given) can usually be accomplished by correctly applying the 1990 *AISC Allowable Stress Design or Load* and *Resistance Factor Design for Simple Shear Connection* handbooks. It is suggested that connection selection requires as much judgment and experience as design in order to determine how to adequately, safely and most efficiently assemble structural steel.

Rather than specifying that all simple shear connections be designed for the end reactions produced by maximum allowable uniform loads, showing calculated beam reactions will allow the detailer to more closely match connection capacity to design requirements. And, showing end reactions along with beam and girder sizes on Contract Drawings provides the SER with an intuitive check by "another set of eyes"; a beam that is inadvertently undersized may be detected by an astute fabricator or detailer. Software programs such as *RAM*STEEL automatically show design reactions (which can be modified at the SER's discretion) on the drawing printouts.

Specifying end reactions for a composite beam is especially important because there is no easy way for the detailer to calculate them. Some designers simply state that reactions should be some percentage of the non-composite allowable uniform load tabulated in the AISC *Manual of Steel Construction*. With the composite beam tables in the Load and Re-

sistance Factor Design (LRFD) Manual, the detailer can "back into" the LRFD end reactions for uniformly loaded simple beams. Both approaches become questionable, and perhaps unconservative, if concentrated loads are present (especially if they are not shown on the drawings).

Recommendation. Fabricators and detailers involved in structural steel work prefer the opportunity to select and design simple shear connections that are included in the AISC design aids. Contract Documents should provide selection and design criteria (including all end reactions) and note the connection types, if any, that are *not acceptable* on the project.

Should Connections for Lateral Load Resisting Frames Be Specified on Contract Drawings?

Background. With the fast-track construction process firmly ingrained in owners' minds, all projects today seem to be *schedule driven*. And structural design fees have been depressed (at least in the East), partly because clients erroneously assume that computers have substantially reduced design costs, and partly because of the lower "value" clients and the public place on structural engineering services (in contrast to electrical and mechanical design that is viewed as critical to "customer satisfaction"; *i.e.*, the *value* of the building). As a result, some SERs are hard pressed to complete designs on Contract Drawings for steel connections and joints in lateral load resisting frames. Since fabricators and detailers are usually under similar pressures from general contractors, insufficient information in the Contract Documents about moment or bracing connections, column strengthening (web doublers and stiffeners) and complex details often results in unrealistic or non-responsive bids and future claims for backcharges or "extras." Owners, architects, construction managers and design-build contractors must be educated that limiting the SER's scope of work, either by financial or time constraints, can generate either erroneous or inflated bids by structural suppliers and subcontractors and, simply stated, provides a *false economy*.

With many states adopting seismic code provisions and becoming more concerned about building performance during earthquakes, the SER must be involved in connection selection and design for lateral load resisting frames. Even if the prescribed seismic loads do not govern or even if the 1992 AISC Seismic Provisions for Structural Steel Buildings is not required to be followed (as for a Group II Building in Connecticut, A_v = 0.13, per the 1993 BOCA Code), there may be drift or other serviceability or performance considerations that are generally not conveyed to bidders. Moreover, it is already becoming evident that even states following BOCA and AISC specifications may not apply the respective seismic detailing provisions uniformly. In addition, joint design for moment-resisting steel frames, especially in high seismic risk areas, is in a state of rapid change as intense research and development continue in response to the 1994 Northridge Earthquake.

Recommendation. Most fabricators prefer that the Contract Documents show the connections and joints for lateral load resisting frames, especially those designed and detailed by seismic provisions for extraordinary strength and enhanced ductility. As an alternative, all criteria or procedures for selecting, designing and detailing such connections and joints (including column strengthening) should be clearly specified, and sufficient information provided to allow for the timely preparation of responsive bids and the subsequent construction of the project.

If Required to Strengthen Columns, Should Web Doubler Plates & Continuity Stiffeners Be Shown on Contract Drawings?

Background. Web doubler plates, a form of joint reinforcement (or, more precisely, column strengthening) in welded girder-to-column moment connections, have been a major source of difficulty for bidders of fabrication and detailing services. These doublers became an issue in Massachusetts when the first state building code, published in the mid-1970s, prescribed seismic detailing based partly on provisions in the 1973 Uniform Building Code for ductile moment resisting frames (now commonly referred to as "special moment-resisting frames"). The intent of the Massachusetts code is for girder-to-column connections to develop the "full plastic capacity" of the girders in flexure. Although this code differentiates between the *connection* (elements connecting the beam

to the column) and the *joint* (the entire girder-column assembly at the intersection), many engineers assume that all other elements in the joint must accommodate forces that can ultimately be developed in girder flanges. (Please note that the 1992 AISC Seismic Provisions reverse the above definitions for *connection* and *joint*.) In many cases, unstrengthened column webs, which are adequate for gravity and wind loads in low-rise buildings, are grossly inadequate to resist the net shears delivered by full capacity flange forces in deep girders. (Rarely do the panel zone shear strength or flexural strength of interior columns in low-rise buildings match the flexural capacity of two deep beams.)

The need for web doublers is symptomatic of an undersized column. Because doublers are very expensive to detail and fabricate, fabricators would prefer columns be designed by the SER in such a manner that doublers are eliminated. It is well-recognized that a "clean" column, heavier by 50 to 100 pounds per foot, can be more economical than a lighter one with stiffeners and doublers.

At the least, if bidders are not informed on the Contract Drawings as to the number of joints needing doublers, the preparation of a *responsive* bid becomes futile. In addition, as requirements for weld inspection tend to increase, another expensive by-product of column strengthening for beam-to-column joints is *shop weld inspection*. Considering the increased concern about the performance of highly restrained, heavily welded joints under seismic loading, it is difficult to rationalize a joint design philosophy requiring heavy column web strengthening, especially if the columns are relatively light.

If there is no way to avoid doublers, they should be shown designed on the Contract Drawings. Otherwise, notes on drawings – such as "Provide doubler plates as required" or "Design the connections for the full capacity of the beam" – are likely to generate bids that are erratic, are based on the expectation of future "extras" or attract ingenuous but unsuspecting fabricators. Structural engineers should note that software programs such as AISC's CONXPRT are a convenient way to check for and design doubler plates during the working drawing stage.

As an alternative, bidders could be given the option of substituting stronger columns to eliminate doublers, thereby offering a more economical structure by reducing detailing, fabrication, review (by the SER) and inspection costs. However, unless the larger columns are noted as suitable alternatives on the plans, this option puts a substantial burden on bidders during a normally tight bid schedule, and is more properly executed – once – during final design by the SER. This approach is much more efficient than having ten bidders all figuring doublers. The best alternative for all concerned is for the SER to check with one or two fabricators and have the most economical solution determined prior to the final design of the columns (as recommended above).

Continuity stiffeners are also employed for column strengthening. Some design firms simply require stiffeners at all moment connections. Although this is not an economical approach for detailing and fabrication (especially if full penetration welds are required by the SER), it levels the playing field for all bidders and is probably preferable to most fabricators than the note, "Provide stiffeners as required." Again, CONXPRT software facilitates determining the need for and design of continuity stiffeners and can be used to great advantage by the SER.

Recommendations. If web doubler plates and/or continuity stiffeners for columns are not designed, shown (located) or otherwise clearly indicated on the Contract Drawings, bidders may assume that none are to be provided. If column strengthening is necessary, the Contract Documents should show doubler plates and stiffeners where they are required, or, as a minimum, identify the joints where they are required and indicate the criteria and procedures by which all reinforcement is to be sized and detailed. The welding of stiffeners and doublers to the column should be by *fillet welds*. If feasible, increasing column sizes and material grade (from A36 to Grade 50) should be considered to eliminate or minimize the need for reinforcement.

What Documentation Can the Fabricator Provide to Establish the Competency of the Connection Selection & Design?

Background. Connections are critical elements

of the primary structural system. Without adequate connections, the structure's load paths and the safety of the building is in doubt, regardless of how well the primary members have been designed. If the fabricator is permitted to select connection types and is assigned the task of designing these connections, documentation should accompany the shop drawings signifying that this work is competent and meets the criteria set forth in the Contract Documents. Such documentation will provide:

- A more level playing field for bidders;
- A faster "turn-around" time for review of the shop drawings by the SER; and,
- Another element of quality assurance for adequacy of a vital part of the structural system – the connections.

Recommendation. The following examples detail some situations (or conditions) and how to fulfill documentation needs:

- Pre-qualification of the steel fabricator – recognizing that AISC Certification, as an example, is no guarantee of acceptable fabrication and attests only to the *capability* of the fabricator to perform work of the required quality.
- Require a post-bid award meeting to review the typical connection types and design procedures the fabricator proposes to use on the project. (It is a sad commentary to the current process that the need for this meeting even has to be stated.)
- With the shop drawing submittal, require that the fabricator verify the selection and design methods used by submitting sample calculations, tabulating results or listing technical references. In addition, require that all calculations be maintained in a form that can be readily reviewed.
- Require that the detailer show both connection *design loads* (they should agree with those shown on the Contract Drawings) and the *connection capacities* on shop drawings.
- If the Contract Documents require the involvement of another structural design professional for connection design, specify that bidders list the structural design professionals who would be considered for performing this service. (The intent here is not for the SER to "approve" the selection but to assure that bidders understand that another qualified design professional must be involved.)

When Should Another Professional Engineer Be Involved in the Selection & Design of Structural Steel Connections?

Background. If all the connections are selected and designed based on the Contract Drawings, it should not be necessary to require the involvement of another design professional. Likewise, if only simple shear connections are to be selected and designed by the fabricator and detailer (given the excellent AISC design aids now available), it should not be necessary for another design professional to be involved.

For other connections not selected and/or designed by the SER (including those in lateral load resisting frames), the SER must decide if it is necessary to require the involvement of another design professional. (Pre-qualified fabricators should know their limitations and those of their detailers, and should voluntarily retain professional design services when necessary.) The project schedule and cost estimates should reflect the fact that such a requirement may extend the time needed for bidding and for the preparation of shop drawings, and may inflate bid prices.

Upon review of the shop drawings, if the connections meet the criteria and intent of the Contract Documents (as well as meet criteria set forth in agreements reached during post-award discussions), the connections should be accepted as presented. Therefore, the Contract Documents should clearly indicate any restrictions or preferences imposed by the SER on connection selection or design. In the past, disputes have arisen when the SER rejects the competent work of another design professional retained by the fabricator or detailer without technical justification.

Since the Hyatt Regency walkway collapse in Kansas City in 1981 there has been an increase in the requirement for stamped or sealed structural steel shop drawing submittals. However, it is suggested that documentation by the fabricator of design procedures or calcu-

lations is a better assurance of conformance to Contract Documents than the shop drawing stamp or seal of another design professional not familiar with the SER's design concept. (There have been instances when the other design professional is either not qualified to design or review connections, or else simply stamps the fabricators's work without a thorough review.)

The fabricator's shop drawing is a detailed pictorial description of how primary structural elements (beams, columns, truss members, etc.) are to be fabricated and assembled to produce, ultimately, the building frame. Shop drawings generally do not show design calculations or specific procedures by which connections are sized and detailed for structural adequacy. Furthermore, the shop drawing shows information that is normally not reviewed for accuracy by any design professional, including the SER (for example, the detail dimensions for fabrication).

Although acknowledging the need to sometimes involve another professional engineer to oversee the design activity assigned by the Contract Documents to the fabricator, the appearance of that professional's stamp or seal on shop drawings raises very serious questions concerning the *insurability* of the steel fabricator, as well as the *allocation of risk* between the SER, fabricator, detailer and the other design professional. The debate among all the affected disciplines over insurability and liability issues concerning steel building connections has been ongoing by national organizations, blue ribbon committees and symposiums since the Kansas City Hyatt Regency walkway collapse. In spite of all the legal rhetoric, no one has proposed a solution that might be acceptable to all parties and, most important, would be in the best interest of quality assurance and public safety of the completed building. Barring such an acceptable resolution by the affected parties, the courts will eventually decide the issue (probably to the detriment of one or more of the parties).

Recommendation. It is certainly within the SER's purview (in the bid documents for any project) to require the fabricator to obtain the assistance of a design professional in the selection and design of connections. In general, however, it should not be necessary if only simple shear connections are to be selected and designed by the fabricator. Otherwise, it is a judgment call and it may depend on the size, complexity and occupancy of the project, among other factors. In any event, the playing field will be level if the bidders know exactly what is required — *i.e.*, if the Contract Documents are clear.

What Loads Does the Fabricator Need to Prepare Responsive & Competitive Bids?

Background. The realities of the marketplace — *i.e.*, downward pressure on design time and fees — have, in some instances, had a negative impact on the quality (completeness) of Contract Documents. Lack of key information reduces the confidence with which fabricators prepare their bids and often delays the preparation of shop drawings. If the fabricator makes certain justifiable assumptions during bid preparation based on the insufficient information provided, disputes are likely to arise if those assumptions are later challenged by the SER.

Recommendation. If the steel fabricator is contractually assigned the task of selecting or designing connections, certain information (as follows) must be supplied in the Contract Documents to permit responsive and timely bidding and preparation of shop drawings:

- *Simple Shear Connections:* End reactions (composite or non-composite), unacceptable connection types, and axial or torsional loads, if any;
- *Bracing Connections:* Axial loads (+ or -) and whether or not one-third increases in stresses are permissible;
- *Moment Connections:* Shears and moments (ft-kips), axial loads, all reinforcement of main members (or, at the least, clear and complete connection and joint design requirements), and whether or not a one-third increase in stresses is permissible.
- *Truss Connections:* Shears, moments and axial loads, depending on the function of the trusses;
- *All Connections:* Whether loads are Allowable Stress Design (ASD) or LRFD and if either procedure can be used to design the connections. Some fabricators and detailers, like some design firms, are not yet

experienced with LRFD. Also, any design procedure to be used that is not included in the AISC Manual.

When Should the SER Consider a Request for Changing a Connection Specified in the Contract Documents?

Background. One frequent complaint from SERs is that fabricators request a change to a connection that has already been shown on the Contract Drawings. This request reflects the preference of most fabricators to use the best talents of their shop personnel and equipment, and it may also help explain why there has been a tendency for connection criteria on Contract Drawings to be incomplete.

The SER should consider a request for the review of a specified connection that the fabricator believes to be structurally deficient, unsafe for ironworkers or impractical to erect. Otherwise, when a connection is shown designed on the Contract Drawings, it should be bid exactly that way unless an alternate is perceived to benefit other members of the construction team. On any project, the fabricator can, at his/her risk, submit a bid based on alternate connections, but the SER is under no obligation to accept any change that the fabricator proposes. If such a change is accepted during post-award discussions, the fabricator should be prepared to supply supporting documentation (and perhaps compensation) for review by the SER.

Under no circumstances should a steel fabricator or erector modify — without approval from the SER — shop or erection drawings that have been reviewed and released for construction.

Recommendation. The SER should consider changes proposed by a fabricator if they are necessary or beneficial to the project.

What Should Be the Extent of the SER Shop Drawing Review?

Background. Regardless of who ultimately performs the task of the original selection and design of steel building connections, SERs should note the Council of American Structural Engineers (CASE) July 30, 1994, Position Statement:

"The SER should be responsible for the design of the primary structural system. There may be times when some element of the primary structural system is to be designed and sealed by someone other than the SER.

"Nevertheless, such elements, including connections designed by others, should be reviewed by the SER. He[/she] should review such designs and details, accept or reject them and be responsible for their effects on the primary structural system."

Recommendation. Fabricators who are provided the opportunity (by virtue of the Contract Documents) to select connections that suit shop efficiency and economy should submit documentation that substantiates conformance of the work to the Contract Documents and facilitates the review of the shop drawings. The SER's review of the shop drawings (and any other structural submittals) should be as thorough as necessary to verify the structural adequacy of the complete primary structural system including, by definition, its connections and joints.

NOTES — *The recommendations made here represent the author's opinion. Even though key engineers and steel fabricators have reviewed the recommendations, no attempt has been made to solicit a formal consensus from any of the associations mentioned here.*

ACKNOWLEDGMENTS — *The author gratefully acknowledges the helpful input from David T. Ricker, P.E., and Robert O. Disque, P.E. Appreciation is also due the Structural Steel Fabricators of New England, whose geographic location makes it imperative that some resolution to these issues be achieved. The four state structural engineer associations in New England were also instrumental in organizing the discussions that made this article possible.*

EMILE W.J. TROUP *is a past president of BSCES and has been a technical and marketing consultant in steel design and construction since 1986. He was the Regional Engineer in New England for the American Institute of Steel Construction from 1974 to 1986. He is currently a Trustee on The Engineering Center Education Trust in Boston and is Chair of the Membership and Marketing Committee of the National Council of Structural Engineers Association.*