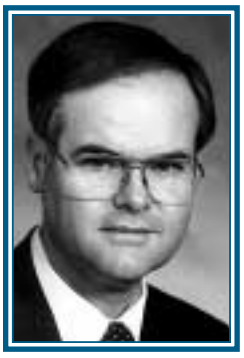
EFFECTIVE CONTRACT AND SHOP DRAWINGS



Emile W. J. Troup, is a structural engineer and consultant based in New England. He also currently serves as president of the National Council of Structural Engineers Associations.

DURING THE PAST TWO DECADES, OUTSIDE INTERESTS HAVE INCREASINGLY INFLUENCED CONSTRUCTION CONTRACT DOCUMENTS and the assignment of tasks associated with design, detailing and quality assurance of fabricated structural steel framing for buildings. Insurers and attorneys have been advising structural design professionals to limit their scope of service and issue contract documents that make working relationships with contractors more confrontational and defensive. This is hardly the stuff of "partnering" or "team building". The term "approve" has been displaced on shop drawings by "reviewed for conformance to the design concept", whatever that might be.

For their part, since the "fast-track" construction process became popular, owners and developers have come to believe that Rome really was built in a day. Projects that sit on the shelf for two years suddenly must be designed and bid in two or three weeks.

Occasionally, this "schedule driven" mentality allows design professionals insufficient time for preparation of complete contract documents. The contractor bidding process deteriorates into one of speculation rather than a meticulous estimate of the work to be done. Speculative bidding breeds uncertainty and uncertainty increases bid prices. Incomplete design drawings also increase the chance that they will be misinterpreted. Not only is the public perhaps at higher risk, but the fast track project can quickly become plagued with bloated cost and schedule — and greater potential for disputes, claims and litigation. Healthy profits may be realized, but not by those involved at the level of structural design or steel fabrication. Ultimately, one way or another, the owner must understand that there is a premium to be paid for short-circuiting the design process..

The purpose of this paper is to encourage more consistency in the way contract drawings and shop drawings for structural steel are prepared. The author's recommendations are based primarily upon a series of "round table" discussions, which were held during the past several years among members of steel fabricator, steel detailer and structural engineers associations throughout New England.

Should pre-qualification of structural fabricators be specified?

Background. On most building projects, the Structural Engineer of Record is not involved in the selection of structural fabricators or suppliers. The "low bid" mentality employed by many general contractors and construction managers sometimes results in selection of a structural steel fabricator who may be unable to produce a product of the required quality, on schedule, and in accordance with contract documents. Under this scenario, while valiantly shifting into a rectification mode on behalf of the owner, the SER can witness its profit being eroded while the owner observes the routing of its project goals.

Since the mid-1970s, the American Institute of Steel Construction (AISC) has administered a Quality Certification Program for structural steel fabricators. (A similar program was recently launched by AISC for steel erectors.) 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 several model code agencies (e.g., BOCA International) as fulfilling the requirement for evaluating a steel fabricator's procedures as stipulated under provisions for "Special Inspections", Section 1705 of the National Building Code.

Attempts by the SER to pre-qualify steel fabricators for complex building work are often rebuked by general contractors who convince owners that selection of structural fabricators should be solely by price. Even with nearly 400 domestic AISC certified plants, owners may perceive that pre-qualification will limit competition. Although this may be true in certain regions, owners should be advised that pre-qualification of structural fabricators may reduce certain construction costs, including those for structural tests and inspections.

Recommendation: For buildings requiring "Special Inspections", contract documents should specify that fabricators of any structural material (whether custom or "prefabricated") be pre-qualified. Owners should

be informed of the potential risks to its budget and schedule when accepting bids from structural suppliers or subcontractors who have not been pre-qualified or evaluated by the design professionals.

What loads does the fabricator need to know to prepare responsive bids?

Background. In general, the realities of the marketplace, i.e., the pressure by the client to reduce design time, have had a negative impact on the thoroughness and accuracy of construction 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 upon insufficient information, disputes are likely to arise if those assumptions are later challenged by the design professional.

Recommendation. If the steel fabricator is assigned the task of selecting and/or designing connections, certain information about loads 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 noncomposite), unacceptable connection types, and axial or torsional loads, if any;

Bracing Connections:
Axial loads (+ or -) and whether or not 1/3 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 reinforcement requirements), and whether or not the 1/3 increase in stresses is permissible.

Truss Connections:
Shears, moments and axial loads, depending on function of trusses;

All Connections:
Whether loads are based on Allowable Stress Design (ASD) or LRFD and if either procedure can be used to design the connections. (Many fabricators and detailers, like some design firms, are not yet experienced with LRFD.) Design procedures to be used (especially if not included in the AISC Manual) should be stated and referenced.

Should there be direct communication between the SER and the fabricator/detailer?

Background. Unfortunately, due to a lack of a contract between the SER and structural fabricator, their respective clients occasionally prohibit direct communication even though it is the most effective means by which cost- and schedule-sensitive issues can be resolved in an efficient manner. During the construction documents phase, the SER should seek advice about selection of connections from steel fabricators and erectors. Perhaps more important is a post-award (pre-construction) conference with the successful bidder of structural steel work to reach a consensus about typical connections and details. Agreement among members of the "structural system team" prior to placement of mill orders and preparation of shop drawings can avoid subsequent backcharges, "extras" and delays.

Direct and timely contact between these parties serves the purposes of quality assurance, expediency and clarification; it is not a substitute for the normal chain of communication with clients or other parties as required by contract.

Recommendation: Prior to preparation of shop drawings the SER, steel fabricator and erector should agree as to what typical connections will be used. Subsequently, the structural steel fabricator and detailer should have an open line of communication with the SER during preparation of shop drawings.

Should simple shear connections be selected by the SER?

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

There is a significant difference between connection selection and design. There are currently seven common simple shear connections, but there are many more possible combinations of bolted or welded details and shop or field assembly. Of the seven basic types, perhaps three or 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, two or three are probably better and of these, each fabricator would have a preference. The SER may know the three or four suitable connections but probably not the fabricators' preferences from among the many possible combinations of shop and field details.

In addition to requiring knowledge of basic design concepts, selection of connections requires knowledge of fabrication and erection practices and preferences, constructibility, erection safety and local erection capabilities (experienced field welders are not always available in the local market). Simple shear connection design (assuming loads and criteria are given) can be accomplished by the detailer by correctly applying the 1990 AISC Simple Shear Connection handbooks. In many cases, simple shear 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 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 documents 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 RAMSTEEL automatically show design reactions (which can be modified at the SER's discretion) on the drawing printouts.

Recommendation: Fabricators and detailers involved in structural steel work prefer the opportunity to select and design the common simple shear connections that are presented in the AISC connection design aids. Contract documents should provide selection and design criteria, including all end reactions, and specify in the general notes any connection types that are not acceptable.

How can the fabricator demonstrate competence of simple shear connection design?

Background. Connections are critical elements of the primary structural system. Without adequate connections the structure's load paths and integrity of the building are in doubt, regardless of how well the primary members have been designed. If the fabricator is permitted to select simple connection types and is assigned the task of designing these connections, the fabricator should substantiate the competency of this work. A requirement for substantiation should render:

- A more level playing field for bidders;
- A faster "turn-around" time for review of shop drawings by the SER; and
- Another element of quality assurance for adequacy of connection design.

Recommendation. The following are examples of documentation that the SER might require when the fabricator is assigned the selection and/or design of simple shear connections.

- Pre-qualify the steel fabricator, recognizing that pre-qualification is no guarantee of acceptable fabrication on a specific project and attests only to the capability of the fabricator to perform work of the required quality.
- Require a pre-construction meeting and review the typical connection types and design procedures the fabricator proposes to use on the project.
- Require the fabricator to verify the selection and design methods used by submitting sample calculations, tabulating results, or listing technical references (e.g., AISC design aids). Require that all procedures and calculations be maintained in a form that can be readily reviewed.
- Require the detailer to show both connection design loads (they should agree with those shown on contract documents) and connection capacities on shop drawings.

Should connections in lateral load resisting frames be designed by the SER?

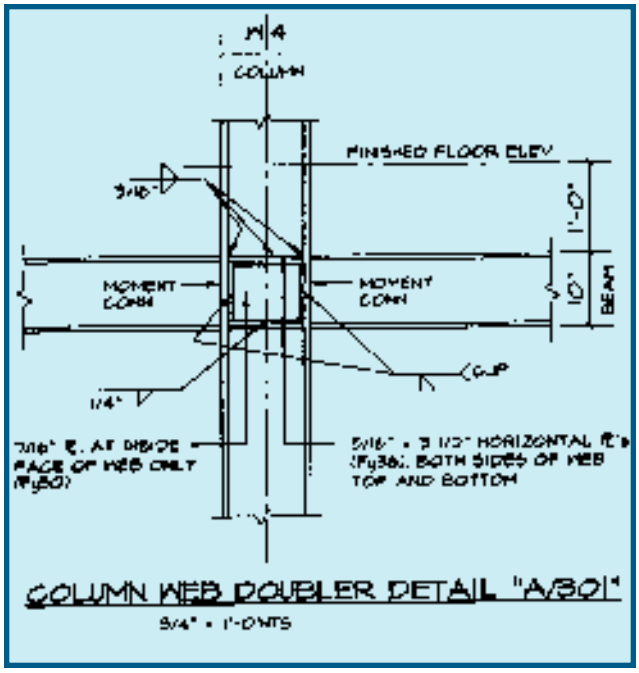
Background. Under today's "fast track", budget-sensitive, schedule-driven project environment, the Structural Engineer of Record is often hard-pressed to complete the design of lateral load resisting systems prior to bidding. Since fabricators and detailers are usually under similar constraints and pressures from general contractors, insufficient information in contract documents about moment and bracing connections, including column strengthening (web doublers and stiffeners), often results in unrealistic or nonresponsive bids. In the highly competitive subcontracting marketplace, owners, design professionals and general contractors must anticipate that omission or ambiguity of information at the bid stage may produce justifiable change orders, claims for "extras", disputes, cost escalations and delays. Thus, this message for owners and architects: Limiting the SER's scope of services, through financial and/or time constraints, is false economy.

With the adoption of the International Building Code in 2000, and perhaps performance-based seismic design sometime thereafter, many more states will be enforcing seismic design and detailing provisions. For this reason alone, the SER should, with input from prospective fabricators, be selecting and designing connections in lateral load resisting frames.

Especially in the Northeast, perhaps no other single steel detail has caused fabricators and detailers more frustration, time and expense than that of reinforcement (strengthening) of under-designed columns in moment frames. In areas of high seismicity, such as parts of the Western United States, the practice historically has been for the SER to fully design steel moment connections. In areas of the East, however, as seismic provisions have begun to work their way into state and local codes, this task has occasionally been left to the steel fabricator and detailer. In the worst case, information provided to bidders about the costly detailing and fabrication required for column strengthening has been totally lacking. Fabricators cringe when cost estimates must be figured from drawings containing notes at moment connections, such as, "Design connections for the full capacity of the beams" or "Provide doublers and stiffeners where required".

The need for web doubler plates to strengthen a column web in moment frames is symptomatic of an undersized column. The SER could, of course, benefit all parties by increasing column sizes, where practical, to eliminate doublers and reduce both the cost and time of shop drawing preparation, shop drawing review, fabrication and inspection. It is well-recognized that a "clean" column, heavier by 50 to 100 lbs/ft or more, can be more economical than a lighter column that requires web doublers2,3,4. And, a heavier column promotes the "strong column - weak beam" design concept, generally preferred for seismic design. As doublers are eliminated in seismic resisting frames, so is the associated cost of field weld inspection.

As a less desirable alternative, bidders could be given the option of substituting stronger columns to eliminate doublers. However, unless



the larger column sizes are specified as alternatives on the plans, this option puts a substantial burden on bidders during a normally tight bid schedule. This exercise is more properly executed - once - during final design by the SER. This is much more efficient than having five or ten bidders all figuring the need and cost for doublers. The best alternative of all is for the SER to check with several fabricators and have the most economical solution determined prior to final design of the columns.

If there is no way to avoid doublers, they should be shown designed on the contract drawings. Location of doublers could easily be shown on the column schedule. Some design firms have developed simple software programs to figure web doubler requirements. A new AISC Design Guide for column reinforcement in moment connections4, due for publication in mid-1999, should greatly facilitate the assessment and design process. At the least, bidders should be informed as to the number of connections needing doublers, the design procedures to be used, and the welding requirements.

Some design firms require transverse or continuity stiffeners in columns at all moment connections. Although this is not an economical approach for detailing and fabrication (especially if full penetration welds are required), it levels the playing field for all bidders and is probably preferable to most fabricators than the note, "Provide stiffeners as required". In the future, the need for stiffeners may turn out to be a non-issue as the trend is for all beam-to-column moment connections in earthquake-prone regions to have stiffeners.

To summarize the crucial issue of connections in seismic resisting frames, the owner and code enforcement agency must be made aware of the risks associated with short-circuiting the structural design process, i.e., by not allowing sufficient time for the SER to furnish the design of the complete lateral load resisting system. Some of the documented risks are:

- A final design that may not meet the intent of the governing building code;
- Nonresponsive bids from poorly qualified or naive suppliers;
- Bids inflated by factors applied in response to incomplete construction documents;
- Delays in development of structural shop drawings;
- Delays in review and approval of structural shop drawings;
- Insufficient time to perform a required, meaningful structural peer review;
- Cost escalating backcharges due to incomplete or ambiguous construction documents;
- Delays in construction while disputes between designers and contractors are resolved;
- Delays in obtaining the occupancy permit if issues of noncompliance are belatedly raised.

The implications for the owner's bottom line should be clear: an extra dollar spent during structural design can reduce total construction costs while meeting, or beating, the target occupancy date. Presented properly, this is a deal any astute owner can hardly refuse.

Recommendation: Most fabricators prefer that contract documents show connections for lateral load resisting frames, especially those designed and detailed by seismic provisions for extraordinary strength and enhanced ductility. As an alternative, all criteria and procedures for selecting, designing and detailing such connections, including column strengthening, should be clearly specified with sufficient information provided to allow timely preparation of responsive bids and the subsequent preparation of shop drawings. Specifically:

- If web doubler plates and/or continuity stiffeners for columns are not designed, located, or otherwise clearly indicated on the contract documents, bidders may assume that none are to be provided.
- If column strengthening is necessary, i.e., if increasing column size is not cost-effective, the SER should design web doubler plates and stiffeners or, as a minimum, identify joints where they are required and indicate the criteria and procedures by which all reinforcement is to be sized and detailed.
- Welding of stiffeners and doublers to the column should be by fillet welds, where possible and where permitted.
- Columns and beams should be specified as A992.

When should the fabricator be required to furnish a P.E. stamp on shop drawings

Background. Since the Kansas City Hyatt Regency walkway collapse and subsequent litigation during the 1980's, it has become standard practice in some design firms to require stamped structural steel shop drawing submittals. However, the kind of documentation noted in Section 5 may be a better way to assure conformance to contract documents rather than the stamp of another licensed design professional who may not be familiar with the SER's design concept or connection performance requirements.

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. Shop drawings generally do not show explicit design calculations by which connections are sized and detailed for structural adequacy. Furthermore, the shop drawing shows information that is normally not reviewed for accuracy by the SER (e.g., detail dimensions for fabrication and erection that are the responsibility of the fabricator).

If all connections are selected and shown designed in the contract documents, it should not be necessary to require 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 available), usually it should not be necessary to require involvement of another design professional.

For other connections not selected and/or designed by the SER, the SER must determine the necessity of requiring the involvement of another design professional. This decision may depend on the existence of a pre-qualification provision in the contract documents. (Pre-qualified fabricators should know their limitations and those of their detailers and should voluntarily retain professional design services when necessary.) The owner must be told that such a requirement will impact bid prices and will likely extend the time needed for bidding and for preparation and review of shop drawings. The owner can ill-afford these schedule-extenders on a fast-track project.

Upon review of shop drawings, if connections designed by a fabricator's design professional meet the criteria and intent of the contract documents (and are in accordance with agreements reached during pre-construction discussions), the connections should be accepted as presented. Therefore, the SER should clearly indicate, in advance, any restrictions or preferences imposed on connection selection or design. In the past, disputes have arisen when the SER rejects competent work, without technical justification, of another design professional who has been retained by the fabricator or detailer.

The national debate among all the affected disciplines over insurability, liability and ethics concerning the design of steel building connections has been ongoing since the 1981 Kansas City Hyatt Regency event. In spite of all the rhetoric, no one has proposed an allocation of tasks or a national Standard of Care that might be acceptable to both the structural engineering profession and fabricating industry and would be in the best interest of quality assurance and safety of the completed building. In the meantime, the courts — and not the design professionals or the fabricating industry — will continue to decide these issues on a case-by-case basis.

Recommendation: It is certainly within the SER's purview, in the bid documents for any project, to require the fabricator to furnish the stamp of a licensed design professional on shop drawings or other connection submittals. In general, however, it should not be necessary if only simple connections are to be selected and designed by the fabricator. In any event, the "playing field will be level" if the bidders know exactly what is required, i.e., if the contract documents are explicit and unambiguous.

When should the SER consider a fabricator's request for changing a connection?

Background. One comment heard from SER's is that fabricators often request a change to a connection that has been designed on the structural plans. This reflects the preference of most fabricators to use the best talents of their shop personnel and equipment. And, it may help explain why there has been a tendency for connection criteria in contract documents to be incomplete. (Why should the SER design a connection if the fabricator will want to change it?)

The SER should consider a request for 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 structural plans, it should be bid and detailed as such, unless an alternate is perceived to benefit other members of the construction team. On any project, the fabricator can, at its own risk, submit a bid based on alternate connections, but, the SER is under no obligation to accept any that the fabricator proposes. If such a change is accepted during a pre-construction discussion, the fabricator should be prepared to supply supporting calculations (and perhaps compensation) for review by the SER.

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

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

What should be the extent of shop drawing review by the SER?

Background. Regardless of who ultimately performs the tasks of selecting and designing steel building connections, SER's should note the Council of American Structural Engineers (CASE) July 30, 1994 Position Statement, excerpted here:

> "The SER (Structural Engineer of Record), 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 [sic] should review such designs and details, accept or reject them and be responsible for their effects on the primary structural system."

Also noteworthy is an addendum published by the Associated Subcontractors of America, as a commentary to new AGC 650/655 model subcontracts:

> "Any design services provided by the Subcontractor or its designer will be reviewed by the architect/ Engineer responsible for the overall project to assure that the design will be acceptable when integrated with the entire work. Contractor, Owner and Architect [and Engineer?} are entitled to rely on the accuracy

and completeness of the designer hired by the Subcontractor only if all design criteria are furnished to the Subcontractor by the Contractor, Owner and Architect [and Engineer?]"

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 and facilitates review of shop drawings. The SER's review of shop drawings should be as thorough as necessary to verify structural adequacy of the complete primary structural system including, by definition, its connections.

Is there a better way?

Reviewing hundreds of shop drawings on even a medium-sized project is an onerous and time-consuming task for the SER. One major structural firm in New York City reviews only certain details (piece drawings) and requires the detailer to provide all connection information on the erection drawing. This SER approves the fabricator's job standards in advance and the detailer keys each connection to one of those standards. Without passing judgement on this approach, it raises the question: are there more efficient ways to review connection design performed by the fabricator/detailer?

Summary of recommendations

With regard to contract documents, the Structural Engineer of Record should:

- Select and design connections in lateral load resistance frames.
- Permit steel fabricators to select and design simple shear connections in compliance with the SER's specified criteria.
  OR
- Select connection types for lateral load resistance frames. Provide steel bidders with sufficient information upon which to base cost estimates, including all criteria, loads and acceptable methodologies for design of these connections. Permit steel fabricators to select and design simple shear connections in conformance with the SER's specified criteria.
- Establish project specification language for pre-qualification of structural suppliers and subcontractors.
- Not require stamped shop drawings or calculations if the fabricator has been assigned only the selection and design of simple connections.
- Check preliminary column sizes for web doubler plate requirements. If possible, increase column sizes to eliminate doubler plates. If doublers must be provided, indicate the locations (i.e., quantity) and provide criteria and design methodologies on the contract drawings. Specify Grade 50 columns and beams and, where possible, fillet welds for necessary column reinforcement.
- Conduct a pre-construction conference with the structural steel fabricator/detailer and erector to agree on typical connections and other connection issues prior to preparation of shop drawings.
- Require the steel fabricator/detailer to substantiate competency (not necessarily from a licensed design professional) in selection and design of connections that they have been assigned.
- Regardless of who is assigned the selection and design of connections, review shop drawings to the extent necessary to confirm structural adequacy of the total structural framing system.
- Work with the local fabricating and detailing industry to develop factual data for the owner that supports the concept and advantages of re-allocating resources for connection design between the Structural Engineer of Record and the steel fabricator/detailer.

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