

QUALITY ASSURANCE FOR STRUCTURAL ENGINEERING FIRMS

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ABSTRACT

Changes have occurred in the structural engineering profession over the past twenty years which have created a need for engineering firms to implement formal in-house quality assurance programs. This paper discusses the components of a model QA program and reviews procedures, tips, techniques and strategies for conducting in-house quality assurance reviews on structural drawings with a focus specific to structural steel building structures.

INTRODUCTION

The structural engineering profession has undergone dramatic changes over the past twenty years. With fast-track construction, computerized design, complex building codes and younger engineers taking on more responsibility earlier in their careers, the need for structural engineering firms to have a comprehensive in-house Quality Assurance program has never been greater. Adoption of a comprehensive Quality Assurance program will result in better design, high quality contract documents, fewer RFI's and change orders during construction, a better product for clients and increased profitability for engineering firms.

THE QUALITY ASSURANCE PROGRAM

A Quality Assurance program is a defined set of procedures and standards used to facilitate design and to facilitate documentation of that design. Implementation of a QA program results in:

- Better design
- Better drawings
- More efficient design process
- Fewer mistakes
- Fewer RFI's and Change Orders
- Increase client satisfaction
- Enhanced reputation
- Increased profit

Prior to 1990 the concept of formal QA programs was virtually unheard of within the profession. Quality was assured by relying on the experience, skill, continual oversight and expertise of trained engineers, structural designers and drafters. Structural design was a linear process and contract documents were usually not issued for bid until the design and the drawings were 100% complete. Formal QA programs, where they existed, consisted primarily of a senior engineer being assigned as the "go to" person for answering technical questions. That engineer would also review the drawings before the project went out for bid – providing a second set of eyes on the contract documents in order to catch mistakes. Such a QA program, consisting of a "technical guru" and a single QA review does not work today.

Today a comprehensive QA program requires the following components:

- Training for young engineers
- Design standards
- Drafting and CAD standards
- Project delivery system
- Knowledge base
- Involvement of the QA Manager and QA reviews

Training for Young Engineers

Prior to the use of computers, young engineers working in design offices typically spent the first several years of their careers doing repetitive manual calculations. Most new engineers also spent “time on the board” learning the art of structural drafting under the guidance of experienced engineers and senior drafters. The training of a young engineer was a gradual process. As experience was gained, more responsibility was delegated - reviewing shop drawings, developing details and eventually coordinating projects with architects and answering questions from contractors. Computers have eliminated most laborious manual calculations and while they have greatly increased productivity, computers have also altered the informal training phase that all new engineers go through. Young engineers today are faced with the challenge of taking on much more responsibility early in their careers. Further challenging a young engineer’s transition into the profession are complex building codes, the details of which are usually not learned in school and the lack of any knowledge of structural drafting, a skill which is just as valuable today as it was years ago. The ability to convey one’s ideas to paper for interpretation by others will always be an essential skill. For moderate to large-sized engineering firms, the solution to this problem is establishment of a formal in-house training program.

Training for young engineers should consist of in-house lunchtime training seminars covering the full spectrum structural engineering topics that are pertinent to the type of work performed by the firm. Because the goal of the training program is to pass on the combined knowledge of the senior staff, the list of topics for these seminars is long. Passing knowledge includes not just interpretation of codes, standards and design procedures, but also a discussion of practical applications and lessons learned. A short listing of typical seminars includes:

AISC 360-05	Braced frames
IBC 2006	Moment frames
Dead, Live & Snow load	Trusses
Wind loads	Joists
Wind Tunnel Studies	Metal deck
Seismic loads	Slabs on metal deck
Site Specific Seismic Analysis	Floor and roof diaphragms
Load Paths 101	Window washing davits
Reviewing shop drawings	Elevators and escalators
Connection design	Facade systems
Member design	Post-installed anchors
Stability	Expansion joints
Braced frames	Slide bearing connections
Vibration	Concrete mix design
Coordination issues with MEP	Slabs-on-grade
Stairs and monumental stairs	Masonry design
Structural drafting	Wood design
Framing plans	How to perform a self-QA review
How to draw details	Lessons Learned
Foundation design	Communication skills
Concrete design	Legal and liability issues

These seminars are best conducted once or twice per week. While some topics can be covered in a single session, others, such as structural steel connection design, can take several sessions to fully cover.

Seminars focus on actual application of the principles discussed and are interspersed with lessons learned, discussion of common mistakes, examples of manual calculations and tips and techniques for verifying the accuracy

of computer analysis and design. Software limitations and assumptions are reviewed with continual emphasis that computers are tools to be properly used by engineers; the creativity and solutions to structural engineering challenges come from the mind and imagination of the engineer, not the computer.

Design Standards

Design standards are comprised of:

- Design Guides
- Formal design procedures
- Checklists

Medium and large-sized engineering firms must have written formal design procedures, standards and methodologies in order to produce consistently high quality design and to minimize the risk of errors due to miscommunication.

Office standards must be formally established so that there is no confusion regarding design procedures and methodologies. Is office policy to use ASD design or to use LRFD design? Is the policy to show beam reactions on framing plans or to require that shear connections be designed for a percentage of the member uniform load capacity? Are connections designed by the EOR or is connection design delegated to the steel fabricator's engineer? Is there a minimum percentage of code wind load below which the wind tunnel wind pressures will not be used? Serious consequences could result if two engineers are working on a project with one showing service level member reactions on the framing plans and the other showing factored reactions. The purpose of office design standards is to keep everyone on the same page and to provide a roadmap to insure uniformity of design.

Design guides are one of the ways that design procedures are set forth. Design guides delineate office policy regarding design procedures and bring together building code and design standards, textbook theory, local construction practices, practical applications and lessons learned.

Checklists are useful tools both for engineers new to the profession as well as for experienced engineers trying to remember the hundreds of things that go into design and documentation of a building structure. While major items like reviewing diaphragm strength and stiffness are well ingrained in a seasoned engineer's mind, little things like remembering to coordinate locations of fall protection tiebacks on the roof might occasionally slip by but for reminders provided on checklists.

Drafting and CAD Standards

Structural drafting is fast becoming a lost art. Whereas mechanical drawing used to be taught to students in high school and college, many engineers now arrive in the profession with no training in a skill that is essential for communication of their design intent to others. Likewise, most structural drafters have now been replaced by CAD operators who, while proficient in use CAD software, may be lacking in the knowledge and understanding of how to lay out framing plans, draw weld symbols or dimension details. The solution to this problem is to establish drafting and CAD standards, the components of which include:

- Standardized drafting procedures
- CAD checklists
- Typical detail library

- “go-by” drawings
- Standard block library

Drafting procedures include information related to rules for laying out framing plans, drawing sections and details, setting up column schedules, etc. Uniformity and consistency within the office requires that everyone draw objects consistently on the correct layers and use the same linetypes and linetype scales. While these may seem like trivial issues having no bearing on structural design, they will improve the quality and legibility of a set of structural drawings.

Checklists include the myriad of things needed to produce complete and legible drawings. They cover things as seemingly minor as making sure north arrows are shown on the framing plans to more important items such as making sure that beam reactions are indicated.

A comprehensive structural engineering typical detail library will contain over hundreds of typical details.

“Go-by” drawings are reference drawings that show examples of how to indicate information on framing plans, schedules, etc. While “go-by” framing plans may have originated from actual projects, they will usually be modified over time to include everything that can possibly occur on a framing plan. “Go-by” framing plans for various structural systems provide engineers and drafters a single point of reference to see how to properly draw anything they will encounter on the plans. The use of “go-by” drawings prevents younger engineers from using previous projects for learning how to show things on the drawings. While using other projects as a frame of reference is not necessarily a bad idea, doing so can lead to a gradual divergence of drafting standards in larger firms.

A standard block library is essential for increasing productivity and maintaining drawing uniformity. “Blocks” are pre-drawn objects such as bolts, angles, W-shapes, weld symbols, headed studs, section cuts, etc.

Project Delivery System

The Project Delivery System is a library of forms, checklists, procedures and correspondence templates used for administratively carrying a project from inception through construction. The PDS is divided into five sections:

- Project startup
- Schematic design
- Design development
- Contract documents
- Construction administration

The Project Startup section contains things required at the beginning of a project such as a design criteria form listing design information such as the applicable building code, design standards, loads, wind, snow and seismic design criteria, summary of the structural systems being used and fire ratings required. Correspondence templates for letters to the client regarding information needed from the geotechnical consultant and wind tunnel consultant as well as correspondence templates that summarize presumed design criteria and required “due by” dates to meet schedules, etc. are provided.

The Schematic Design, Design Development and Contract Document sections contain checklists and procedures related to the deliverables in each phase of design.

The Construction Administration section contains meeting agenda templates for the pre-steel detailing meeting, the pre-concrete meeting, meetings with the inspector as well as checklists to be used when reviewing shop drawings.

Knowledge Base

The Knowledge Base (KB) is a searchable electronic database of all knowledge related to structural engineering. The KB contains the notes from training seminars, design guides, design standards, drafting and CAD standards, and information on all other topics that engineers may need to access. The primary feature of the KB is that it's a single source for answers to all questions related to structural engineering. When a question or topic comes up for which there's no answer on the KB, that information is added. When problems occur or lessons are learned, the solutions to those problems and lessons learned are added to the KB.

Involvement of the QA Manager and QA Reviews

The QA manager is senior level engineer who is responsible for establishing and maintaining engineering standards and for verifying that all design is done in accordance with those standards. The QA manager has the following responsibilities:

- Establishing and maintaining design and drawing standards
- Answering technical questions and getting the answers to those questions onto the KB as appropriate.
- Staff training
- Maintaining familiarity with all projects during design and providing input and suggestions as required.
- Signing off on sections and details prior to them going to the CAD department. (A cursory review and signoff of sections and details by the QA manager is required to catch mistakes before sending sections and detail to the CAD department. Such a review saves time, is informative for the engineer whose details are being critiqued.)
- Performing quality assurance reviews on all projects.

THE QUALITY ASSURANCE REVIEW

Quality Assurance reviews are in-house reviews conducted to verify that all design is performed and documented in conformance with the procedures and standards mandated by the QA program.

QA reviews serve two purposes. The primary purpose of QA reviews is to provide redundancy via a second set of experienced eyes on the drawings to catch mistakes, errors or omissions. The second purpose is to monitor the effectiveness of the QA program. If the QA program is working properly and engineers are following the procedures and utilizing the resources provided therein then problems, mistakes, errors and omissions caught during the review should be minor. While the QA manager is usually the one who performs the reviews, other experienced engineers can likewise perform the task.

Changes in the way contract documents are now issued have altered the way QA reviews are performed. Until ten years ago a single QA review was performed prior to the contract documents being issued for bid. Fast-track construction scheduling now requires multiple reviews at stages during design. It's not uncommon to have eight or more reviews on large projects. While the number varies from project to project, a typical QA review schedule for a steel framed structure on pile foundations might be as follows:

- Pile bid
- Steel mill order
- Foundation concrete bid
- Steel Addendum / detailing issue
- 100% concrete
- 100% structural steel
- “Issued for Construction” final review

Multiple reviews are also a good idea for those projects still delivered via the traditional design-bid-build process. Interim reviews will catch mistakes early when corrections can be easily made.

There are two primary goals of QA reviews. The first and most important goal is to review the contract documents to verify that the structure was properly designed, is efficiently framed and is constructible. The second goal is to verify that the contract documents are complete, well detailed, correct and coordinated. The goal of issuing complete and well detailed contract documents is not just one founded on a desire to reduce RFI's and change orders – it is one that is essential to insuring structural integrity. Finishing the drawings during construction via the RFI process is a bad idea. Not only do RFI's frequently lead to change orders, unless senior level experienced engineers are the ones answering RFI's, mistakes can slip through. If the drawings are complete and well detailed before construction, those details will have gone through the scrutiny of the QA review process and the probability of engineering mistakes being made during the process of answering RFI's during construction will be greatly reduced.

A variety of tactics are employed when performing QA reviews. Those tactics are as follows:

- Look at the big picture
- Verify load paths
- Review framing sizes
- Look at connection details (constructability)
- Look for mistakes
- Look for subtleties
- Look at the drawings for constructability
- Review for clarity
- Look for omissions
- Look for “little” little things
- Look for the “big” little things
- Verify that the structural drawings match the architectural & MEP drawings

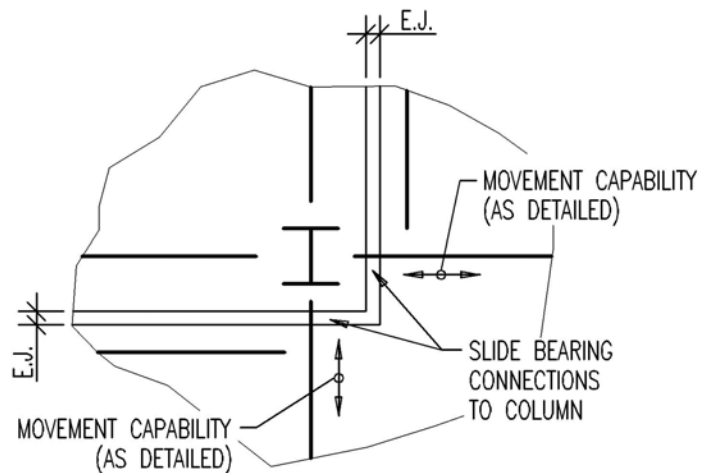
Looking at the Big Picture

Engineers immersed in large projects can lose sight of the big picture and miss things that are often immediately obvious to someone who was not working on the project. Some common mistakes in this category include:

- a. Missing or improperly located expansion joints
- b. Improperly detailed connections at expansion joints (*example: uni-directional slide bearing connections locking up the expansion joint at corners. See figure 1.*)
- c. Load path problems (*example: braced frames cut off from floor diaphragms; failure to design diaphragms at vertical irregularities in the lateral load force resisting system.*)

- d. Equilibrium of forces not investigated (*example: horizontal kick at base and top of sloping columns not considered and connections not detailed. See figure 2.*)
- e. Constructability issues (*example: moment connections in both directions at a column where beams are different depths and stiffener plates are specified in both directions*)
- f. Inefficient connections (*example: severely skewed joists framing to W shape girders.*)
- g. Connection problems (*example: column base plate anchor rods that don't fit in the piers or are too deep for the footings.*)
- h. Inefficient framing configurations (*example: too many pieces; beams framed in wrong direction*)
- i. Inefficient spandrel details (*example: too much "gingerbread" framing.*)
- j. Wrong design loads used
- k. Problems with computer model (*examples: problems related to "infinitely rigid" diaphragms; double counting structure self-weight or ignoring self-weight; pushing "reduce live loads" button on computer where live load reductions are not permitted.*)
- l. Using wrong "R" factor (Use R=3 for steel buildings in areas of low seismicity.)
- m. Failure to consider snow drift
- n. Failure to consider loads such as folding partition storage pockets, heavy runs of piping, window washing davits, etc.
- o. Excessive deflections on spandrels or ends of cantilevered beams

Figure 1: Example of improperly detailed slide bearing connections locking up the expansion joint because they are detailed to permit movement in one direction only.



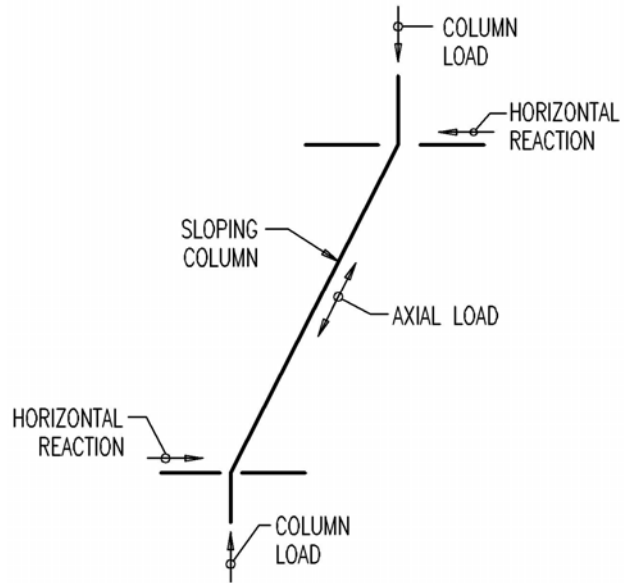


Figure 2: Forces must resolve.

Verify Load Paths

There must be continuous and realistic load paths from the point at which loads are applied to the structure down to the foundation. While this may seem so basic as to not warrant discussion, it is a common problem.

The most common load path problems are with floor diaphragms - usually because when engineers define floor diaphragms as rigid, computer programs give those diaphragms infinite strength and stiffness, both assumptions often being unrealistic.

Some examples of problems associated with assumptions of rigid diaphragm:

- Lateral loads in braced frames increase from the top to the bottom of the braced frame. When braced frame member forces get smaller on the lower levels (*see Figure 3*), that's usually a sign that an "infinitely rigid" floor diaphragm diverted lateral load out of the braced frame and sent the load elsewhere. Relying on a slab-on-metal-deck diaphragm to drag loads out of one braced frame and into another is usually not a good idea.
- **Figure 4** shows a rectangular building with a shear wall at one end and a moment frame at the other. The computer results indicated that 95% of the north-south lateral load was resisted by the shear wall and only 5% was resisted by the moment frame. This result was due to the combined effects of the floor diaphragms having infinite rigidity and the two east-west shear walls preventing the floor from twisting. The problem with this analysis was that while the floor was probably closer to the building code definition of a rigid diaphragm than it was to a flexible one, it did not have sufficient strength to work as a rigid diaphragm. The lateral loads were manually adjusted and conservatively enveloped to account for a more reasonable lateral load distribution between the shear wall and moment frame.
- **Figure 5** shows a portion of a floor where the slab-on-metal-deck was input as a rigid diaphragm and the computer then modeled the exterior columns as braced at each floor. In reality, the floor slab did not have sufficient strength to provide P- δ buckling restraint to the columns in the strong axis direction at each floor.

Compounding the problem, the computer did not consider bending and shear in the diaphragm from wind loads on the exterior wall because the diaphragm was infinitely stiff and infinitely strong. This framing was repeated for several floors. The computer sized the columns as W14x90's. Manual calculations showed that the columns had to be W14x211's.

- **Figure 6** shows a brace frame adjacent to an exterior stair that's substantially cut off from the floor diaphragm. While the computer model sees a connection to the floor diaphragm, the slab engagement to the diaphragm is not sufficient to get the diaphragm load into the braced frame. A drag strut is required.
- **Figure 7** shows an in-plane vertical discontinuity in a braced frame. A drag strut is needed to transfer the horizontal load from the base of one braced frame to the top of the adjacent braced frame. The computer will not design the connecting drag strut member for the horizontal load because the rigid diaphragm is assumed by the computer to transfer the load from one braced frame to the other.
- **Figure 8** shows an out-of-plane offset irregularity in a braced frame. The floor diaphragm must be manually designed to transfer the lateral loads from the braced frame BF2 to the two adjacent braced frames, BF1 and BF3. Diaphragms, even if they are rigid, must be manually designed and detailed to resist the applied shears and moments.

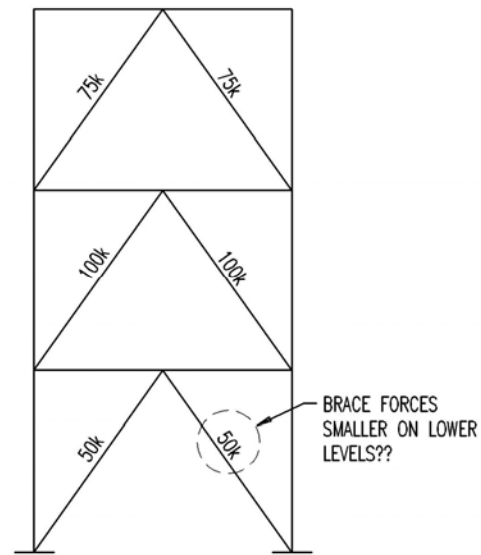


Figure 3: Load path problem resulting from infinitely rigid floor diaphragm in computer model diverting load out of brace frame

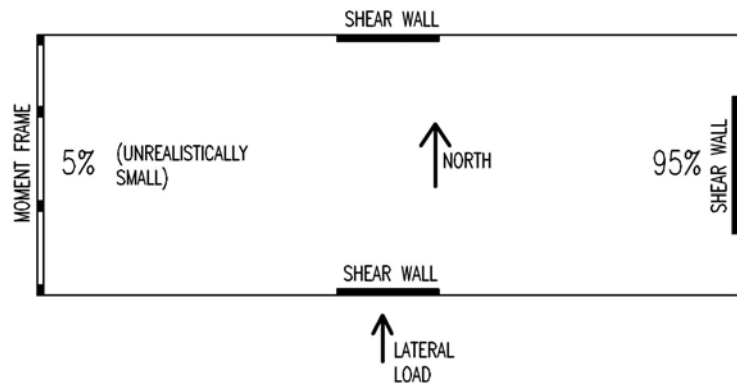


Figure 4: Problem related to infinitely rigid floor diaphragm directing too much load to shear wall and not enough to the braced frame.

Figure 5: Example of floor problem related to floor diaphragm not being strong or stiff enough to brace the columns. Computer model sized columns as W14x90's. Actual required size = W14x211.

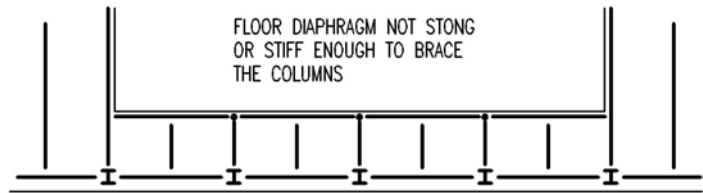


Figure 6: Illustration of floor diaphragm cut off from braced frame. Solution: Provide drag strut with appropriate connections to brace frame.

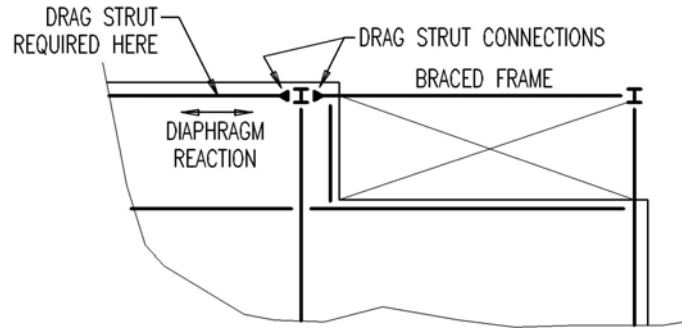


Figure 7: Example of shortcoming of computer model in computing drag strut axial load.

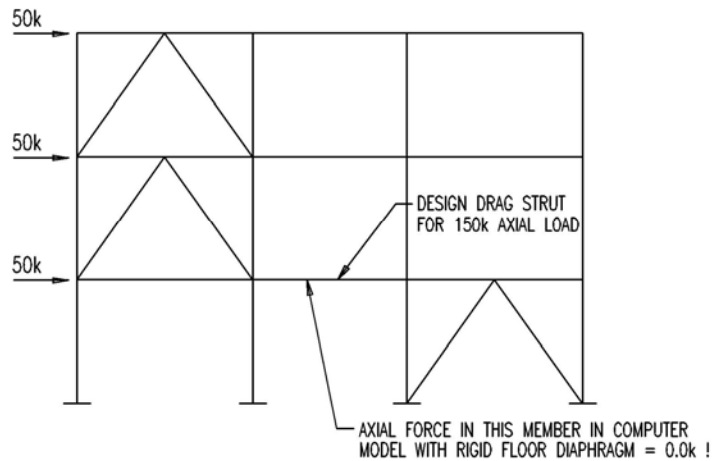
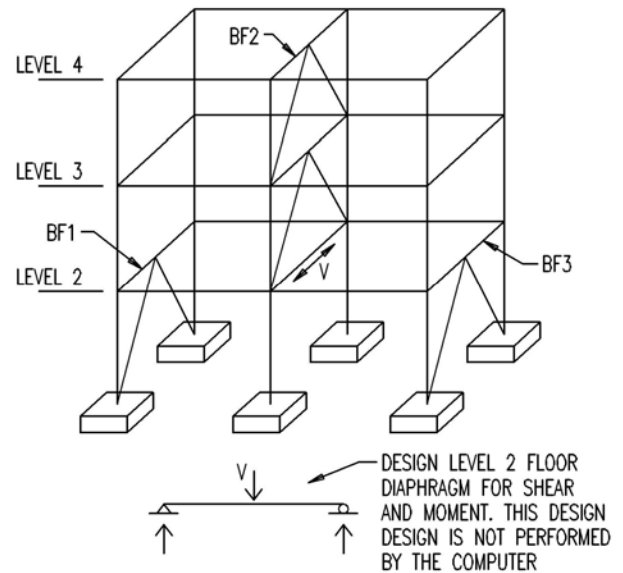


Figure 8: :Level 1 floor diaphragm must be designed to transfer BF2 lateral loads to BF1 and BF3.



Review Framing Sizes

Review of member framing sizes is the most basic aspect of a QA review. This task can be daunting on large projects with thousands of framing members. Fortunately, there are several tricks that can make review of framing sizes easier.

Since most framing is designed by computer, member sizes will usually (but not always) be correct as long as the input is correct. A global review of floor framing can therefore be performed by verifying that all of the computer inputs (loads, slab thickness, concrete strength, headed stud sizes, etc.) are correct. This is accomplished by reviewing several typical beams, girders and columns. If the beam size, number of studs, camber and reactions on the typical beam and girder are checked and verified to be correct, a review of those two members alone provides a high level of confidence that the other framing on the floor is correct. If several different design loads are used on different areas of the floor, then checks of typical beams and girders in each area should be performed.

Showing beam reactions on the framing plans is an invaluable aid when performing a QA review. Seeing reactions allows the reviewer to quickly compute the total load used for design of the member and verify whether or not that design load is correct. The effort required to show reactions on framing plans is minor. A push of a button in the analysis/design program will transfer the reactions to the CAD drawings. Showing beam reactions also reduces the cost of the structural framing by allowing steel fabricators to detail connections for the actual reactions versus having to detail connections based on arbitrary and usually overly conservative percentages of non-composite uniform load capacity.

The combined use of strength design and 50 ksi steel can result in beams that sometimes have excessively high span to depth (L/d) ratios. Beams with high L/d ratios are susceptible to problems related to deflection and vibration. A rule of thumb for the maximum recommended span of composite beams is to limit beam span (in feet) to 2 x depth of the next larger nominal beam depth (in inches). (Example: Maximum span of a W12 beam = 2 x 14" = 28 feet.) For non-composite beams the maximum span (in feet) should not exceed 2 x beam depth (in inches). (Example: Maximum recommended span of a W12 beam = 2 x 12" = 24 feet). This is a general rule and these maximum recommended spans can be exceeded if justified by analysis.

Composite beams are usually constructed with $\frac{3}{4}$ " diameter headed studs field welded through the metal deck onto the top flange of the W shape. AISC 560-05 Section I3.2d(6) requires the flanges of composite beams with $\frac{3}{4}$ " diameter studs to be at least 0.30" thick unless the studs are located directly over the web of the beam. Assuming such precise alignment is not realistic to expect. Accordingly it's a good idea to design beams lighter than 17 pounds per foot as non-composite beams.

As with the beams and girders, several typical interior, corner and edge columns should be designed manually to verify that the member sizes are correct. As with beam reactions, showing column loads on the schedule will assist in the QA review process. Columns that are part of the lateral load resisting system should be identified as such on the column schedule.

Review of member sizes in braced frames and moment frames requires the reviewer to compute wind and seismic lateral loads, distribute those loads to the various lateral load resisting elements and then calculate member forces, wind moments, etc.

When calculating wind loads during a QA review, it's usually sufficient to compute the wind pressures only at the ground level and roof and then linearly interpolate between the two points. Calculation of seismic base shear is a simple task with the exact building period being the only value needed from the computer. For steel structures designed with $R=3$, located on good soil (Site Class "C" or better) and in areas of low seismicity, it usually doesn't make a difference whether seismic base shear is computed using the exact fundamental building period "T" or the more conservative approximate building period "Ta" since both values will often result in a seismic base shear, "E" smaller than that from wind.

QA review analysis of lateral loads on structures located in areas of low seismicity usually requires only looking at the lateral loads in each of the two orthogonal directions with due consideration of diaphragm stiffness and building irregularities to verify that the lateral load resisting system is adequate. Rational manual distribution of manually computed lateral loads based on orthogonally applied loads to the braced frames and moment frames will often yield results that are more realistic than computer generated results generated from investigation of many different load combinations applied to a structure with infinitely rigid floor diaphragms. Structures of unusual geometry may require closer investigation. The key when designing building structures as well as when performing QA reviews is to temper computer analysis based on idealized (and occasionally unrealistic) assumptions with engineering judgment.

When reviewing member sizes, the reviewer must pay attention to framing and details required to support elements or components (see **Table 1**) that may not have been considered in the computer model.

Elevators	Escalators	Facades
Window washing davits	Fall protection tiebacks	Stairs
Monumental stairs	Catwalks	Theater rigging
Horizontal loads from rigging	Folding partitions	Hang points in ballrooms
Rooftop MEP equipment	Screen walls roof	Special around skylights
Heavy piping	Special around skylights	Theater rigging loads

Table 1. Partial list of elements and components supported by the primary structural system.

Framing required to support these things are often not included in the computer model because the locations and details of items such as window washing davits, catwalks and theater rigging often not known early in the project when the bulk framing models are developed for the structural steel mill order issue.

Check Connections and Constructability

Review of connection details is a critical aspect of a QA review. Many RFI's and change orders are related to connections, and more important, most structural failures are connection failures. The term "constructability" as it pertains to structural engineering refers to the efficiency, ease of construction, and cost effectiveness of a structural design. Constructability of steel structures is enhanced when connections are configured such that they simplify detailing, fabrication and erection.

Some things to look for:

- Severely skewed beams framing to girders can have long copes. Skewed beams should be *at least* W12's in order to have sufficient flexural strength in the cope. In some cases deeper beams should be used even if the loads are small. The cost of deeper and heavier beams is usually less than that of reinforcing the webs of lighter shallower beams.
- Beams framing to low girders should have sufficient depth to permit use of standard shear connections to the web of the girder. The most frequent example of high beam to low girder connection problems occurs where shallow beams frame to girders supporting LH series joists with 5" joist seats (*see Figure 9*). These beams should be at least 16" deep to allow for at least two rows of bolts. For reactions requiring more bolts it is most economical to make the beam deeper rather than rely on unusual connection details.
- Beams with flange plated moment connections should have flanges at least 5 ½" wide in order to install the bolts through the flanges (*see Figure 10*). Many fabricators today are trending to the use of 7/8" diameter A325 bolts as the standard connection bolt. It's difficult to install these bolts in beams with flanges narrower than 5 ½" and if the bolts can be installed, the strength of narrow width beams at the holes may be substantially reduced unless flanges are 5 ½" wide.
- Use bolted connections where possible. Bolted connections are generally less expensive than welded connections. Welding requires more labor which generally increases connection cost.
- Square connections are less expensive than skewed connections. Where possible make connections square. Square connections can usually be detailed with economical all-bolted connections. Aside from bent plate bolted-bolted connections, skewed connections usually require welding.
- Framing should preferably be configured so that no more than one beam frames to each of the four sides of a column. Where two or more beams connect to one side of a column, connections can be difficult to detail.
- Where possible, gravity columns should be oriented with girders framing to the flanges and beams framing to the webs (*see Figure 11*). Doing so allows fabricators to utilize cost efficient double angle connections between the girders and column flanges and single angle connections between the beams and column webs. Engineers sometimes mistakenly think that framing girders to column webs is more efficient configuration because smaller moments are induced on the columns by framing the larger reactions to the web. This assumption often backfires when the fabricator details extended shear plate connections off the web to insure safer steel erection of the heavy girders. The most erectable and cost-efficient gravity column

connection configuration is usually one where the girders are bolted to the column flanges with standard double angle connections and beams are bolted to the column web with single angle connections (*see* Figure 12).

- Use OVS holes in plates on moment connections, braced frames and trusses. Oversized holes facilitate the erection of steel by providing some adjustability.
- Truss members should be sufficiently large so that there is sufficient strength at the net section. Connection problems arise when engineers size truss members (primarily tension members) based on the limit state of yielding on the gross section and neglect to check rupture through the net section at the bolt holes.
- Don't specify "X" bolts unless the connected elements are thick enough to get an "X" bolt connection regardless of the direction that the bolt is installed.
- Make sure there is enough clearance for installing and tightening bolts. When developing connection details engineers should envision themselves trying to physically install the bolts in the field. If you can't visualize how you will install the bolts, then the detail is most likely not a constructible one. Electric wrenches are usually used to tighten bolts. Wrench dimensions are available from the manufacturers. Having wrench dimensions available is useful when reviewing the constructability of connection details.
- Special column splice details are frequently required in columns on braced frames where substantial net tension forces can occur.
- Check all heavily loaded connections. Critical heavily loaded connections should be designed and detailed on the contract documents. While some steel fabricators are very connection savvy, others may not have the expertise to design unique and critical connections. Accordingly it is best to document special connections on the structural drawings so that all bidders have a full understanding as to what the design intent is. Connections falling in this category include:
 - a. Transfer girder connections
 - b. Truss connections
 - c. Braced frame connections
 - d. Connections at ends of sloping columns
 - e. Heavily loaded hanger connection
 - f. Moment connections
 - g. Plate girder connections
 - h. Special column splices (where net tension is occurring)
 - i. Braced frame connections to foundations
- Other connections for which details must be provided include:
 - a. Connections with unusual geometry
 - b. Girt connections
 - c. HSS connections
 - d. Facade connection details
 - e. Connection details for support of items listed in *Table 1*.

As mentioned earlier, beam reactions, moments, braced frame member forces and truss member forces should be shown on the drawings. This information requires little more than the push of a button to transfer the information

between the design software and the CAD drawings. Showing this information not only reduces cost (by permitting the fabricator to detail for the actual shears, moments and forces) but it also enhances the safety of the structure by showing engineers working on the project, including the QA reviewer and the steel fabricator's connection designers, where the loads are, the load path and the flow of forces through the structure. Showing this information on the drawings also allows the bidders to suggest alternative connection details that can further reduce cost.

The more connection information provided, the more competitive the bids will be and the fewer the number of RFI's during construction.

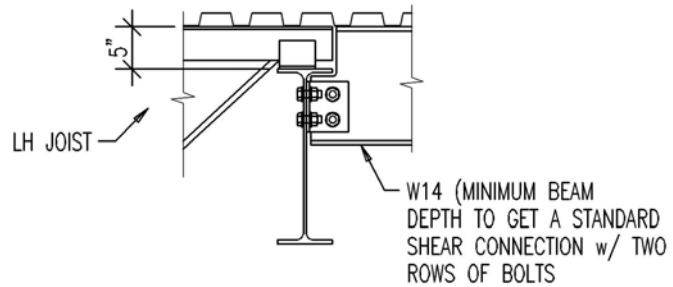


Figure 9: High beams framing to low girders should be deep enough to permit use of standard shear connections.

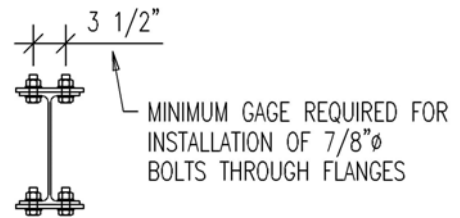


Figure 10: Beams with flange plate bolted moment connections should have flanges at least 5 1/2" wide to accommodate bolts.

MIN. RECOMMENDED FLANGE WIDTH TO INSTALL BOLTS THROUGH FLANGE = 5 1/2"

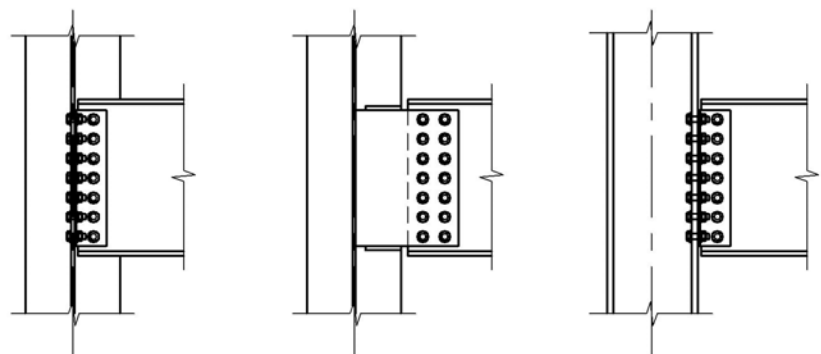


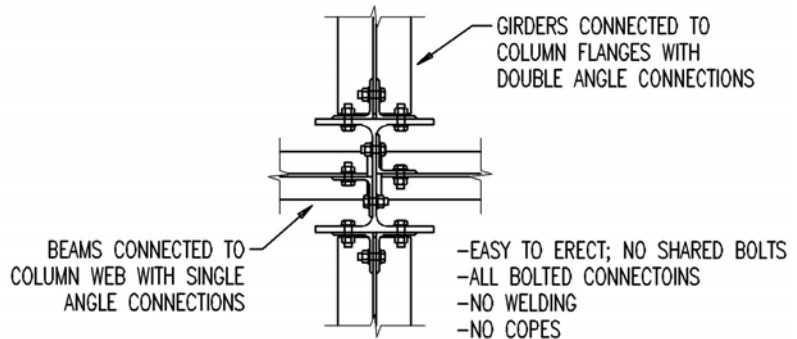
Figure 11: Frame girders to column flanges where possible on gravity columns.

CONNECTION THAT ENGINEER ANTICIPATED (ECONOMICAL BUT NOT EASILY ERECTABLE)

CONNECTION THAT ENGINEER GOT (ERECTABLE BUT EXPENSIVE)

BEST CONNECTION (ECONOMICAL AND ERECTABLE)

Figure 12: The easiest to erect and most cost-efficient gravity column connection configuration.



Look for Mistakes

The list of mistakes that might be found on drawings is endless. Spelling mistakes are not a good reflection the engineer. Typos on beam sizes (W16x22) will result in RFI's. Mistakes on reactions (11k versus 111k) can be fatal.

Some examples of common mistakes:

- **Figure 13** shows what can happen when framing is carelessly moved to accommodate an opening that was added near a column. In this illustration a girder was shifted off a column and onto a beam. This revision increased the beam reaction from 36k to 101k but the reaction wasn't revised. Note that is a mistake that most likely would have resulted in a connection overstress even if the engineer did not show the reactions and instead specified more conservative reaction capacities based upon an arbitrary percentages of non-composite uniform load capacities.
- **Figure 14** shows a spandrel beam adjacent to a corner stair. The spandrel was designed for gravity loads by the computer but the computer did not consider horizontal wind loads on the beam and the resulting weak axis bending on the beam..
- Maximum permitted spans of slabs on metal deck must be reviewed. Maximum spans are often dictated by the span limit of the metal deck for support of the wet weight of concrete. A three-span condition is usually used for this check, but more stringent single span conditions occasionally occur, such as in elevator lobbies with opposing elevators. The solution is usually to add an additional beam which both reduces the deck span and creates a two-span condition.

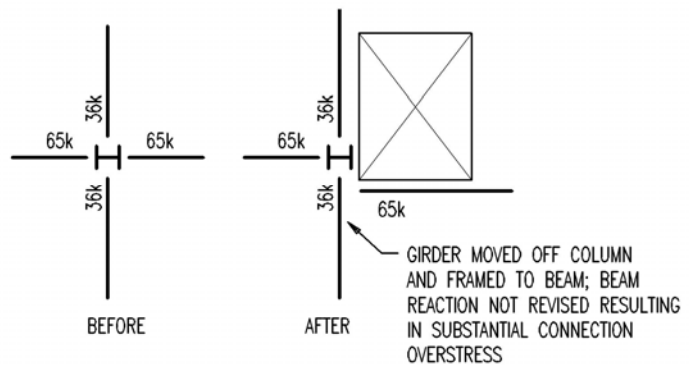
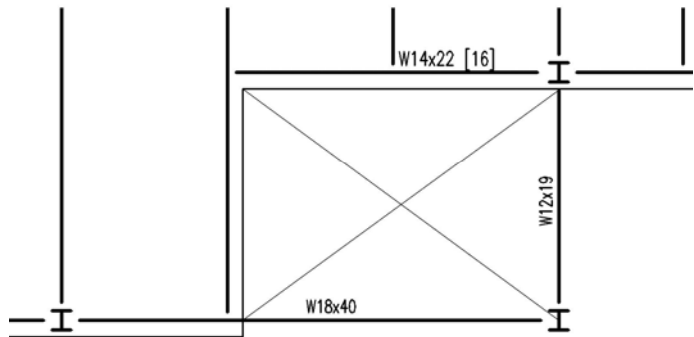


Figure 13: Connection overstress when girder was moved off column but reaction was not revised.

Figure 14: Spandrel beams not strong enough to resist horizontal wind loads.

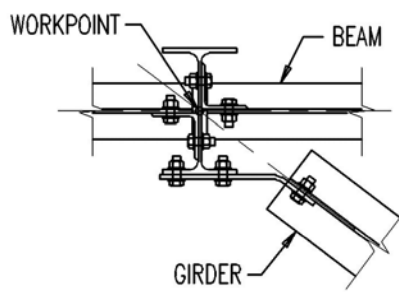


Look for Subtleties

Subtle mistakes are often the hardest to find and generally will only be spotted by experienced engineers who have made their share of mistakes over the years and have learned from them.

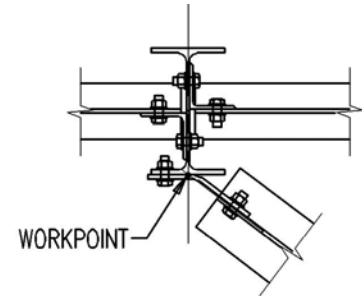
Some examples:

- Column splices should only be made at locations where a floor slab is bracing a column in both directions, unless those splices are designed to have sufficient flexural capacity. Standard gravity column splices most likely will not work near the mid-height of tall unbraced columns resisting wind loads on the exterior wall of building structure. Splices in all tall unbraced columns should be designed and detailed regardless of whether or not they resisting wind loads.
- Horizontal reactions on columns from wind girts are generally not considered when computers design columns.
- Unacceptably large weak axis moments can occur in columns with skewed connections – especially skewed connections of the type shown in *Figure 15a*. This problem can occur when both square and skewed members frame to the same side of the column and both are modeled framing into the same workpoint. Most of the structural engineering software used for designing floor framing requires beams and girders to frame to the geometric centers of columns and problems such as this are not noticed until the shop drawings are reviewed. A better detail is shown in *Figure 15b*. The weak axis eccentricity is eliminated and the strong axis eccentricity on the column will usually be ok.



NO GOOD - LARGE WEAK
AXIS ECCENTRICITY RESISTED
BY ONLY ONE COLUMN FLANGE!

FIG. 15a



PREFERRED DETAIL - BUT REQUIRES
FORETHOUGHT DURING DESIGN TO
SHIFT GIRDER WORKPOINT AS SHOWN

FIG. 15b

Figure 15: Problems can occur with skewed connections to columns if not considered during design

Look at the Drawings Through the Eyes of Everyone Else Using Them

It can be easy lose sight of the fact that everyone using the drawings is a not structural engineer and to rationalize not spending the extra time needed to show something clearly by justifying to yourself "...they'll know what I mean." Unfortunately this attitude can lead to RFI's and change orders. Engineers performing a QA reviews must continually look at the drawings through the eyes of a:

- Contractor
- Detailer
- Inspector
- Architect
- Engineer performing a peer review
- Engineer performing a value engineering review
- Building official
- Young engineer reviewing the shop drawings
- Lawyer

Engineers should always ask to themselves, "Is everything shown on the drawings that will allow a contractor to build the structure without having to guess or issue RFI's"? Can the steel detailer interpret the details and detail the connections without having to compute stiffener plate thicknesses, weld sizes, etc.? Are all of the dimensions provided that will allow the detailer to detail the steel? Is every linear foot of the building perimeter covered by a section or detail? If reactions are indicated, is it clear as to whether they are service level or factored reactions?

Review for Clarity

Look for conflicts between the framing plans and the sections and details. Look for inconsistencies in framing. Consistency and repetition usually contribute to an economic design.

Look for Omissions

Things that are missing are sometimes the hardest to find. Common omissions include missing reactions, sections, details, dimensions and elevations.

Look for “Little” Little Things

Spelling mistakes are embarrassing, especially if they are words like “momint”, “sheer” and “engeneer”!

Look for the Big Little Things

“Big little things” are mistakes that may seem minor but can result in costly change orders or worse – structural failures.

Examples include:

- Low beams causing headroom clearance problems
- Diagonal braces intruding into corridors or interfering with doors
- Truss members interfering with mechanical systems
- Diagonal braces in braced frames interfering with girts on the exterior of building

Figure 16 shows an example of a “small” drafting error that could result in a structural collapse. The steel beam was moved off the column but the girder reaction was not moved. The 111k reaction looks like 11k – and it should have been revised to 155k.

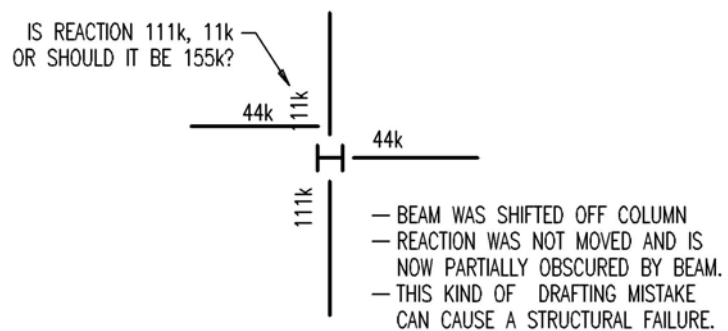


Figure 16: Example of a seemingly small drafting error that can cause structural failure.

Verify that the Structural Drawings Match the Architectural and Mechanical Drawings

Fast track construction often requires issuing structural drawings months before the architectural and MEP designs are completed. Frequently when QA reviews are performed on fast track projects, the only architectural and MEP drawings available are progress prints or schematic level drawings. That said, it is still important to review the architectural and MEP drawings and compare them to the structural drawings.

Things to review on the architectural drawings include:

- Slab edge locations
- Wall sections
- Column locations
- Slab openings
- Headroom clearances
- Facade details
- Floor plans (verify design loads)

Things to review on the MEP drawings include locations of:

- Heavy runs of piping
- Large ducts
- Rooftop mechanical equipment
- Mechanical unit weights
- Layout of equipment in mechanical rooms

Some things to check:

- Verify that there is sufficient room for mechanical ductwork and piping below the floor framing, especially if the building has low floor-to-floor heights.
- Verify that braced frames along the exterior of the building are not architecturally objectionable with respect to seeing the diagonal braces behind the windows.
- Verify that diagonal braces on braced frames don't interfere with doors, large mechanical ducts or corridors.
- Determine if rooftop screen walls are required around mechanical equipment
- Look at rooftop parapet heights and verify that snow drift loads were considered.
- Locations and dimensions of openings in floors
- Stair details (Can the stairs as shown on the architectural drawings be supported by the structural framing shown on the framing plans? Are there any "head knocker" conditions with steel beams?)
- Monumental stair details
- Facade details (Are the facade details shown on the architectural drawings consistent with the way the structural drawings show the facade being supported by the structural framing?)

SUMMARY AND NEW CHALLENGES

QA programs must be adaptable to new challenges that continually occur. One challenge is that of recognizing the limitations and constraints of computer software and keeping up with software changes and improvements, all the while keeping in mind that while computers are indispensable tools, they will never replace the judgment of experienced engineers who have mastered the art of structural engineering. Another challenge is that of training highly motivated young engineers so that they are best equipped to be the skilled and productive professionals they enthusiastically strive to be. A comprehensive QA program can help them succeed - and everyone benefits.