Quality Assurance for Structural Engineering Firms

By Clifford W. Schwinger, P.E.

Fast schedules, complex codes, the plague of incomplete and uncoordinated contract documents and the ever increasing reliance on computers to perform engineering analysis and design are but a few of the reasons why Quality Assurance programs are becoming ever more important for structural engineering firms.

Implementation of Quality Assurance programs by structural engineering firms will lead to:

- Better design
- Better contract documents
- More efficient design process
- Fewer mistakes
- Fewer Request For Information (RFIs) and change orders
- Increased profits

A model structural engineering QA program should include certain key components, as described in this article.

Training for Young Engineers

Young engineers today are faced with the challenge of taking on more responsibility earlier in their careers. The days of spending several years "on the board" are over. Further challenging the young engineer's transition into the profession are complex building codes, the details of which are seldom taught in school, and the lack of any practical training in the art of structural detailing. The ability to convey one's ideas to paper is an essential skill. Establishment of a formal in-house training program is one solution to the challenge of moving young engineers to be productive contributors to the project team.

Programs for young engineers commonly consists of in-house lunchtime training seminars covering the full spectrum of topics pertinent to the type of work performed by the firm. Seminars should focus on the practical aspects of structural design, including topics such as lessons-learned from previous projects, review of common mistakes and how to avoid them, and discussion of procedures, tips and techniques for verifying the accuracy of computer analysis and design. Emphasis should be on the practical application of engineering fundamentals, with focus on the "Four S's" – statics, strength, stability and serviceability.

Design Standards

Design Standards are comprised of Engineering Standards, Design Guides and Checklists. Engineering standards must be formally established so that there is no confusion regarding design procedures and methodologies. For example, is the office policy for structural steel design to use ASD or LRFD? Are the beam reactions shown on the framing plans service level loads or factored loads?

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

Checklists are useful tools for engineers new to the profession, as well as for experienced engineers trying to remember the hundreds of things that go into the design and documentation of a building structure.

Documentation Standards

Structural drafting is a lost art. Whereas mechanical drawing used to be taught to students in high school and college, most engineers now arrive in the profession with no training in a skill that is essential for communication of design intent to others. Likewise, the transition to project delivery via BIM modeling presents both challenges and opportunities. Documentation standards refer to CAD graphic standards and BIM modeling standards.

Documentation standards include:

- Drafting/detailing procedures
- BIM modeling procedures
- CAD/BIM checklists
- Typical detail library
- "Go-by" drawings/BIM models

Drafting procedures define rules for laying out framing plans, drawing sections and details, setting up column schedules, etc. High quality contract documents require uniformity and consistency from project to project, with lessons learned from previous projects being used to improve future projects.

BIM modeling procedures establish the process by which BIM models are started, updated, maintained and coordinated within the office and with other consultants. Included also is the protocol for what information is to be included in the BIM model. Is reinforcing steel shown for floor slabs, walls and columns? Are brick shelf relieving angles shown in the model?

Checklists include the myriad of things needed to produce a complete and coordinated set of contract documents.

A comprehensive structural engineering detail library is the repository for typical details. Individual design teams within a company should not have their own personal libraries of favorite typical details.

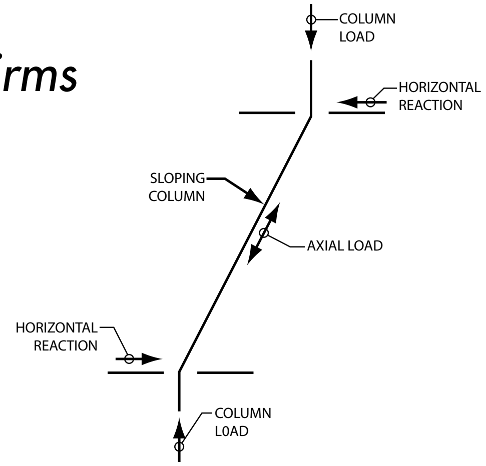

Figure 1: Forces must resolve.

"Go-by" drawings and "go-by" BIM Models provide examples of how to indicate information on the contract documents or model.

Project Delivery System

A Project Delivery System (PDS) is a library of forms, checklists, procedures and correspondence templates used to administratively navigate a project from inception through construction. Key to the success of all projects is effective communication with clients and other consultants. The PDS contains the tools required to improve both the communication and managerial skills of engineers.

Knowledge Base

A Knowledge Base (KB) is a searchable electronic database of all in-house 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 for which engineers may need quick access. The primary benefit of the KB is that it serves as a single source for practical answers to specific topics related to structural engineering. When a question or topic comes up for which there is no information 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 a senior level engineer responsible for establishing and maintaining engineering standards and for verifying that all design performed by the firm is performed in accordance with those standards. The QA manager has the following responsibilities:

- Monitoring development of engineering standards
- Answering technical questions

- Staff training
- Maintaining familiarity with projects during design and providing input as required
- Performing QA reviews on all projects

Quality Assurance Reviews

While the size and scope of a QA program will vary depending on firm size, the core of any structural engineering Quality Assurance program is the Quality Assurance review process.

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 provide redundancy via a second set of experienced eyes to catch mistakes, errors and omissions on the contract documents. QA reviews should be performed either by the QA Manager or by other senior level engineers, and should be used to monitor the effectiveness of the QA program.

Multiple QA reviews should be conducted at predetermined intervals during project design, preferable to a single review at the end of design, in order to catch mistakes early when they can be more easily corrected.

There are two primary goals of a QA review. The 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. This second goal is not just founded on a desire to reduce RFIs 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 – one that can lead to change orders and potentially to structural failures. If the drawings are complete and well detailed before construction, the design and accompanying 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 RFIs during construction will be greatly reduced.

Engineers performing QA reviews should be senior level experienced staff. When performing a QA review, it is useful to employ a variety of tactics in order to effectively scrutinize the 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. Common mistakes in this category include:

- Wrong design loads used
- Inefficient framing configurations
- Problems with computer model
- Load path problems
- Missing or improperly located expansion joints
- Constructability issues

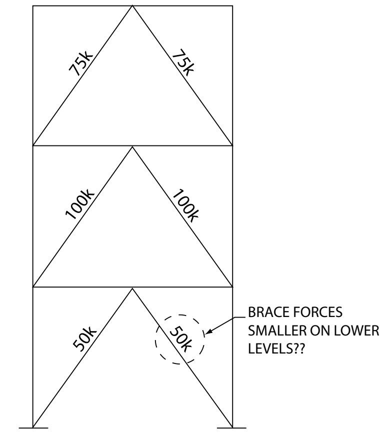

Figure 2: Load path problem resulting from infinitely rigid floor diaphragm in computer model diverting load out of braced frame.

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, flaws with load paths are frighteningly common. *Figure 1* illustrates a common condition where failure to follow the load path with sloping columns can result in a serious structural deficiency. Sloping columns impose horizontal forces into the floor framing where they transition from vertical to sloped. Proper attention to these horizontal forces, including the connection details between the floor framing members and the sloping columns is essential. *Figure 2* illustrates a load path problem created both by a computer program that assumed floor diaphragms to be infinitely rigid and by an engineer who did not recognize the potential pitfall of this often unrealistic assumption. In this situation, the "infinitely rigid" floor diaphragm pulled load out of a braced frame and sent that load to an adjacent braced frame.

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 the computer input is correct. This is accomplished by reviewing and manually designing several typical beams, girders and columns. If the beam size, number of studs, camber and reactions for a typical beam and girder are verified to be correct, a review of those two members alone provides a high level of confidence that the other framing members on the floor are 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 of steel framed structures is an invaluable aid when performing a QA review. Seeing reactions allows the reviewer to quickly compute the total load used for the design of a member, and verify whether or not that design load is correct. Showing reactions enhances the safety of the structure by illustrating the load path and flow of forces through the structure. Improperly sized members and load path problems are easier to find when reactions are shown.

Analysis of lateral load resisting systems requires the reviewer to verify that the correct wind and seismic loads were used by the design team. Quick manual computation of the lateral wind and seismic forces can usually be performed in minutes. While the level of accuracy of rudimentary manual computations may not be as exact as those performed by computer software, the goal of the QA review is to spot big mistakes. Such mistakes are usually quicker and easier to spot by independently computing the lateral forces and distributing those forces to the lateral load resisting elements manually, as compared to delving into the computer models to check the input.

When reviewing member sizes, the reviewer must pay attention to framing and details required to support elements or components that may not have been considered in the computer model. Examples include framing for support of window washing davits, folding partitions in ballrooms, catwalks, roof screens and heavy rooftop mechanical units. Framing required to support these elements are often not included in the computer model because the locations and details of these items are often not known early in the project when design is performed for early steel mill order issues.

Review Connection Details

Review of connection details is a critical aspect of a QA review. Many RFIs and change orders are related to connections and, more important, many structural failures are connection failures.

Look for Mistakes

The list of mistakes that might be found on drawings is endless. Spelling mistakes do not provide a good reflection on the engineer. Typos on beam sizes (W16x22) will result in RFIs. Mistakes on reactions (11k versus 111k) can be catastrophic. *Figure 3* illustrates a drafting error that potentially could have resulted in a

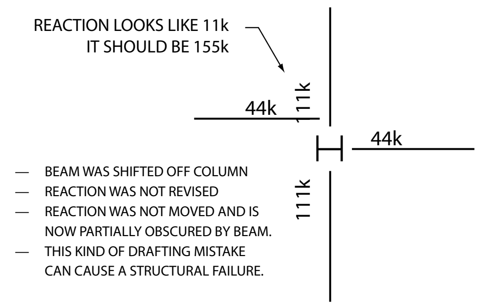

Figure 3: Example of a seemingly small drafting error that can cause structural failure.

structural collapse were it not caught. In this situation a beam that previously framed to a column was shifted off of the column to accommodate a floor opening. Not only was the girder reaction not increased to accommodate the additional load from the shifted beam, the reaction was partially obscured by the shifted beam.

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. Problems with load paths fall into this category.

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

It can be easy to lose sight of the fact that everyone using the drawings is not a structural engineer, and to rationalize not spending the extra time needed to show something clearly by justifying to oneself, "…they'll know what I mean." Unfortunately, this attitude can lead to RFIs and change orders. Engineers performing QA reviews must continually look at the drawings through the eyes of the contractor, detailer, inspector, architect, engineer performing a peer review, engineer performing a value engineering review, a building official, a young engineer reviewing the shop drawings, and even a lawyer.

Review for Clarity

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

Look for Omissions

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

Look for the Little Things

"Little" things can result in "not so little" problems. Examples include:

- Low beams causing headroom 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

Verify that the Structural Drawings Match the Architectural & MEP Drawings

Fast-track construction often requires issuance of 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.

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Conclusion

All structural engineering firms will benefit from having a Quality Assurance program. QA programs in larger firms will by necessity be more elaborate than those required for smaller firms. At a minimum, all firms must have an internal QA review process.

One of the fundamental benefits of QA programs is to provide a mechanism by which lessons learned from past mistakes can be used to avoid repeating them in the future.

The structural engineering profession is a challenging and continually changing one. Engineering firms who implement QA programs will see improvement in productivity, improvement in design and documentation of that design, fewer mistakes and increased profitability.▪

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