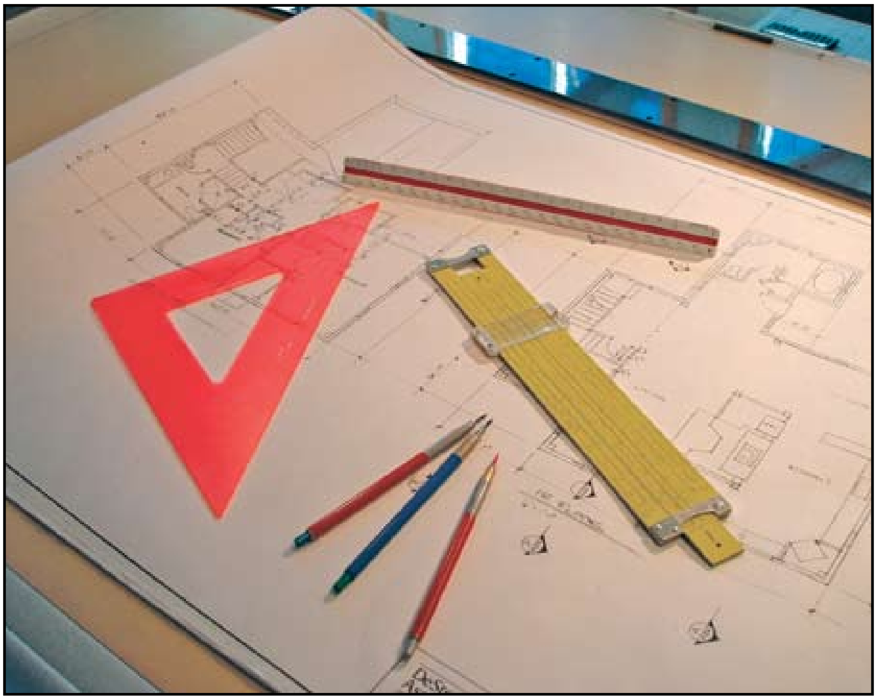
Computer Technology in the Practice of Structural Engineering

Past, Present and Future

By Jim DeStefano, P.E.



Acient tools of the trade.

In the beginning, there were slide-rules, pencils and drafting boards. There were Building Codes, but they were considerably smaller than telephone books. To the modern engineer, these time-honored tools of the trade may seem quaint and primitive, but in the hands of a skilled engineer they were all that was needed to design safe and sometimes magnificent structures.

It may seem as if these were simpler times, but there is no question that practicing structural engineering was hard work. Structural engineers made a good living at their trade, but seldom got rich at it. The engineer was respected by the contractor and held in high esteem by the other members of the project team.

Computers are a relatively recent addition to the engineer's toolbox. The development of the first digital computer began as a classified military project during World War II with the first working model, the ENIAC, making its debut at the University of Pennsylvania in 1946. This early computer was an experimental contraption with vacuum tube circuits that could only run for short periods of time before the vacuum tubes began to blow out and the system would shut down.

It was the development of silicon transistor circuits, and later micro chip circuits, that made digital computers a practical reality in the 1960s. Still, in those days computers were only seen in science fiction movies and in the back rooms of a few universities. When main-frame computers made their entrance on the scene, the engineering profession was quick to see the potential for this technology to relieve them of the drudgery and imprecision of tedious and repetitive hand calculations.

Early use of computers by engineers in the 1960s was achieved with teletype connections to a main-frame computer at a far-off (and sometimes far-out) university. The computer could be dialed up on a telephone and, when the connection was made, the handset of the phone would be inserted into the modem of the teletype. In those days "time-share" did not refer to a vacation condominium. The engineer would type in a simple FORTRAN program he had written himself for the computer to process. It was unthinkable at the time that an engineering office could own its own computer.

In 1972, the first hand-held calculator was introduced by Hewlett Packard. It did not take long for engineers to discard their slide-rules. They were no longer limited to calculations with a precision of three significant digits and a wild guess at the location of the decimal point.

Throughout the 1970s, the use of computers by engineers increased steadily. Main-frame computers left school and became common in large corporations. Teletypes were replaced by punch cards and card readers as computers and computer programs became larger and more powerful. But, an engineer owning his own computer was still just a dream.

In the early 1980s, Apple® Computers was born and introduced the Apple II computer to the consumer market. Hot on the heels of Apple, IBM® introduced the IBM-PC computer. At long last, every engineer could afford to own his very own personal computer. The practice of structural engineering has not been the same since. The rest is history, and where our story begins.

Structural Analysis and Design

Prior to the introduction of computer technology, structures were analyzed by hand calculations. Most structures were designed as statically determinant, and the majority of calculations involved some variation of $WL^2/8$. Indeterminant structures were solved with approximate methods such as moment distribution or the portal method. Graphical methods were used to calculate truss member forces. Structural engineers lived by their wits and developed a keen understanding of structural behavior.

Building architecture was responsive to structural efficiency and architects believed in "form follows function." Structural engineers were invited to the meetings where the conceptual design of a project was formulated. This was essential, since the engineer was the only one who knew how to use a slide-rule and somebody had to be able to calculate square footages and financial rates of return.

In the late 1960s, researchers at MIT developed the general purpose structural analysis program STRUDL™. Almost all subsequent structural analysis software has been modeled after the methodology and matrix methods used by this pioneer program. To engineers accustomed to tedious and laborious hand calculations, STRUDL seemed heaven sent. Although the original version of the program was not exactly "user friendly" and it guzzled up expensive computer time at an alarm-

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discussions and information on the impact of technology on structural engineering

ing rate, it changed structural engineering forever. Any structure that could be modeled as an assembly of two dimensional elements connected at nodes could be analyzed with precision, as long as you could afford the computer time.

Structural analysis and design software has since become much more powerful, user friendly and affordable. Universities no longer spend much time teaching students how to analyze structures by hand, since all they need to know is how to use popular computer programs. This has resulted in a generation of engineers who are dependent on computer technology. Some structural engineers have never had an opportunity to develop an intuitive feel for structural behavior and must rely solely on computer methods.

Architects have learned that structural engineers can now analyze anything, so they no longer feel an urge to consider structural efficiency in their building designs. Some architects have received acclaim for designing buildings that look as though they are collapsing. We have come a long way from the days of "form follows function."

Building Code committees have also learned how quickly engineers can do complex calculations with multiple load cases using computers, so there is no longer a need for simple and easy to understand code provisions.

Building owners have learned how much faster structural engineers can get their work done with computers. There is no need for long, dragged out project schedules anymore. We can fast track now and start building a project before the architect has designed it. Of course, there is also no longer any need to pay big fees to the engineers. After all, they can analyze a structure with the push of a button.

Structural analysis and design programs have become so powerful and so smart that you don't even need to be an engineer to use them any more. Pre-engineered metal buildings can now be designed by salesmen. Wood roof trusses and I-joist floors can be designed by lumber yard representatives. Even architects can design a structure all by themselves, with the right software.

Computer based structural analysis has become a powerful tool for structural engineers and it is unthinkable that any engineer would embark on a major project without this tool in his toolbox.

Computer Aided Drafting

Structural working drawings were once drawn by hand with pencils, ink pens, triangles and scales. The center of every engineer's work station was a drafting table. Each engineer developed his own distinctive artistic drawing style. Pride was taken in producing attractive and concise drawings. Since hand drawing was time consuming, skill was needed to convey critical building information in just a few drawings. Of course, revisions due to architectural design changes were not appreciated and nobody enjoyed erasing and redrawing their artwork.

In the 1980s, AutoCAD™ entered the scene as an affordable general purpose computer drafting program. At first, engineers were slow to embrace this new technology, but within a decade hand drafting had become a thing of the past. Using CAD technology, an engineering firm could quickly produce a lot of drawings. There was no longer a need for a large staff of poorly paid draftsmen, since one CAD technician could do the work of three draftsmen.

With CAD technology, making changes to drawings was easy. No more messy piles of eraser shavings and disgruntled draftsmen. Architects could now make design changes with very little effort and expect the engineer to revise his drawings accordingly. For the engineer, the trick has become figuring out what changes the architect had made since the last set of drawings he had sent. Without the shadow of an eraser on the drawings, there is no visible evidence of what has been changed.

There is no need to show information concisely with CAD drawings. Instead of showing several similar conditions with a single detail or section, it is easier to generate separate details for conditions that vary slightly. The number of drawings needed to convey building information has increased considerably with the transition from hand drafting to CAD drawings. Of course, with all of those extra drawing sheets there is less time for the engineer to think about what is being shown on the drawings and to coordinate his work with the rest of the design team. We can now convey less information with more drawings and do it much faster than we could in the past.

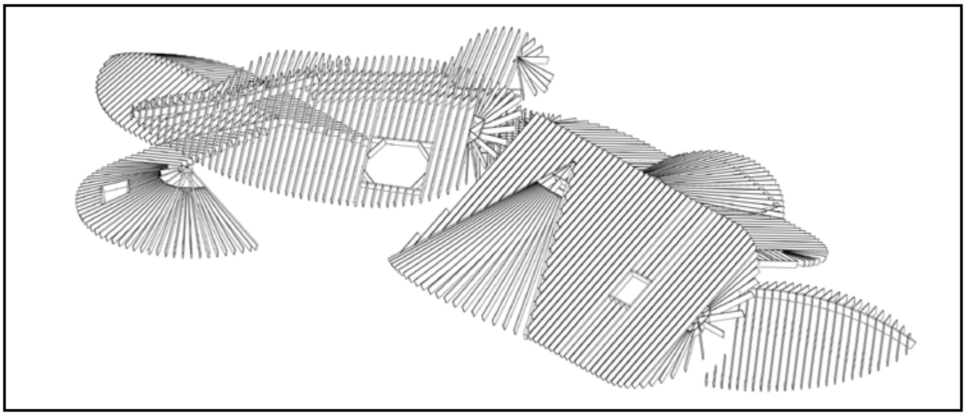
One would expect that with more drawings and details, the contractor's life would be easier and building construction would be less problematic. Unfortunately, that has not proven to be the case. Contractors and tradesmen have become so overwhelmed with the large number of drawings that they never have an opportunity to study the drawings and fully digest them. There never seems to be enough time during the bidding period for the estimators to fully understand what will be expected of them should they be awarded the project. Bids are based on square footage calculations and the expectation that they can make up for what they missed with change orders.

For the most part, engineers and architects have used CAD technology to produce drawings that convey information in the same manner as hand drafted drawings. Building information is conveyed by a series of disconnected 2 dimensional views. Pencil lines have been replaced with electronic vectors, but the lines are still dumb lines with no sense of identity. The first generation of CAD plotters used ink pens held in a robotically controlled arm that drew lines on paper much the way a human would, only faster.

Specifications

Project specifications used to be typed manually. This was a task that office secretaries dreaded. To save on typing, spec books from prior projects would often be cannibalized - sections were cut out with scissors and scotch taped together. This sometimes gave the specifications the appearance of a ransom note. Spec books were brief and concise and contained only essential information. In those days, contractors would actually read the specifications and study them prior to bidding a project.

When personal computers armed with word processing software entered the scene, producing specifications became easy. Cutting and pasting from prior specs became effortless and there was no longer the need for laborious manual typing. Suddenly, the size of spec books began to grow. With the aid of standard specifications such as Masterspec, the number of pages grew exponentially. It is now easier to leave information in a spec that does not really apply to the project than to edit it out.



3D model of roof framing

The problem with having a large, comprehensive project specification is that the contractor does not have time to read it. The only time the specs are actually read is when there is a problem or a conflict. Specifications have become irrelevant.

Building Information Models

The structural engineering profession is standing on the precipice of a new technology that will revolutionize the way buildings are designed and built. This change may prove to be more significant and more tumultuous than the transitions from hand calculations and drafting to computer assisted technology a generation ago.

Building Information Models (BIM) are 3 dimensional intelligent electronic models of a building. BIM technology is likely to make CAD technology obsolete within a decade. No longer will we need to draw building structures as a series of 2 dimensional views. The technology is now at hand, and affordable with BIM software such as Revit.

To the untrained eye, a BIM may look like a CAD drawing but it is actually something very different. With a BIM you are not drawing dumb lines. The computer understands what is being drawn and building elements can have attributes. The BIM knows that a line representing a beam is a beam of a certain size and material, and it may even contain information such as the internal forces and reactions of the beam.

Unlike a 2D CAD drawing, a BIM is a 3D parametric model of the structure. Parametric means that, when you make a revision to an element in the model, you only have to change it once and all views and details contained in the model are automatically updated. Not only does this feature make revising a design almost effortless, it virtually eliminates the possibility of errors associated with uncoordinated drawings.

With a BIM, every member of the design team adds information to the same model. The architect, structural engineer and MEP engineer are each adding layers of information to the model. One of the team members serves the role of the model manager. This changes the roles of the various design professionals. On a traditional project, the architect is the team leader. The model manager, who may be the structural engineer, tends to have more control on a BIM project.

Since all of the team members build on the same model, clash detection software can be used to identify conflicts. Based on the principal of classical physics that two objects cannot occupy the same space at the same time, clash detection will identify instances where ducts, sprinkler pipes or structural beams are in each other's way.

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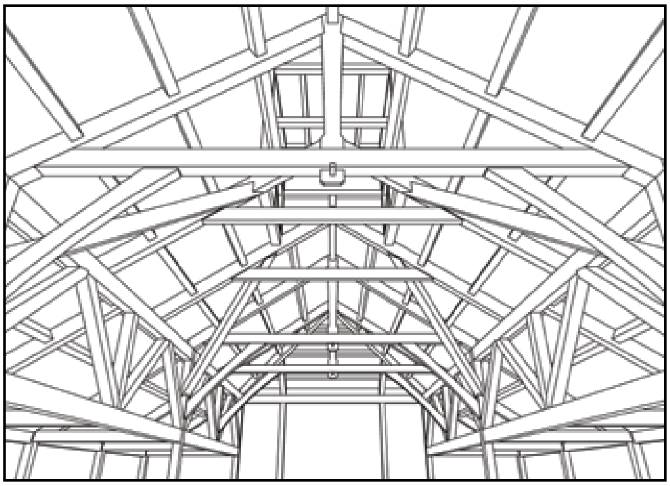

3D model of a timber frame structure

As BIM technology advances, there is an opportunity to link the model to the project specifications. When a particular product or building material is inserted into the model, it can trigger appropriate information insertions into the specifications and drawing schedules. This could make project specifications, once again, a useful addition to the contract documents.

I believe we will see the day when contractors no longer build from paper drawings, but work directly from the electronic BIM files.

Interoperability

Interoperability was once referred to as Electronic Data Interchange (EDI) but the name has been changed because EDI was too easy to pronounce. This is the principal of exchanging data between different software packages.

Many of the structural analysis programs, such as RISA™, can exchange information with BIM software. You can model a frame in Revit and export the file to RISA to be analyzed. This eliminates duplicate effort and reduces the chances for errors.

There is also the opportunity to import a BIM directly into a fabricator's shop drawing software. Structural steel shop drawing software such as Xsteel are actually a specialized BIM. This data can also be used to drive automated fabricating machinery. This has the potential of dramatically streamlining the shop drawing review process and eliminate the drudgery of processing paper shop drawings.

Challenges for the Future

If properly managed and applied, emerging computer technologies like BIM and Interoperability have the potential for being powerful tools for the structural engineer. Unfortunately, the industry has not had a good track record of applying computer technology smartly for the good of mankind.

If these tools are misused, it can have disastrous results. With a BIM there is the potential for the contractor to build an exact replica of the electronic model. So if there is an error in the model – what you see is what you get.

We should never forget that computer technology is a tool. As with any sharp and powerful tool in the hands of a skilled craftsman, it can produce a masterpiece. But in the hands of an unskilled tradesman, it can only produce garbage, and occasionally somebody can get hurt.▪

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This article is reprinted from I-STRUCTURE magazine, February 2007.