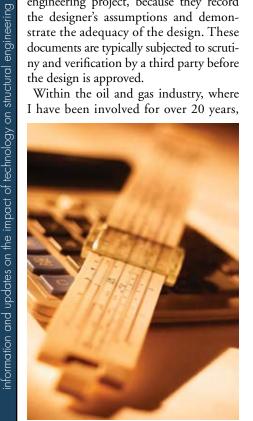# The Engineer's Calculations

By Robert Mote, P.Eng

When it comes to doing calculations and attracting new blood into the structural engineering profession, I believe that we are a profession in crisis.

Let me relate a common story. I was asked to check a calculation, long overdue, for a wide operating platform supported on three buried vessels. In essence, it is a continuous beam over multiple supports with lots of point loads for grating dead and live loads. I had a picture in my mind of what to expect – perhaps two pages describing the platform, a general arrangement plan, loading and vendor information, a sketch layout for the designer, and an additional two pages of simple numbers to confirm beam sizes. This would equate to a calculation in the range of seven to ten pages and a morning's worth of work. What I actually received was closer to 250 pages analyzing 242 possible load combinations that took three months to prepare, with overtime. While the design was not ultimately flawed, I accepted the calculation without any changes, and the engineer thought that his work was a progressive piece of art. I know that this is the tip of the iceberg; it produces the sense of engineering walking backwards.

Engineering calculations are a legal and practical requirement for any structural engineering project, because they record the designer's assumptions and demonstrate the adequacy of the design. These documents are typically subjected to scrutiny and verification by a third party before the design is approved.

Within the oil and gas industry, where I have been involved for over 20 years, there has been a sea of change in the way we work, where we work and how we work – from the smoky, noisy halls of stand-up drawing boards and manpower to the silent office spaces of cubicles and screen power. I have experienced the generational changes and seen how we are losing our craft. I learned from past masters and then got lost in the same 'computer age' maze as everybody else, but I think that I have found a way back to the traditional roots. They have been designing structures for over 100 years, successfully for the most part, using design tables derived from experience and common sense. Traditional does not mean nostalgic, it means smart.

This article looks at the structural engineer and the calculations that become the go-by examples, the default-setters for the future. I find that engineers usually do not challenge these examples or seek to improve upon them. On large projects, change is frowned upon and engineers are not encouraged to go against the grain. It takes a special engineer, with confidence, to challenge this mode of operation.

The last fifteen years have seen a straitjacket mentality evolve in how structural engineers work in the design office. The emergence of desktop computers ironically killed their ability to interact with technology. What happened? It used to be that mainframe computers were designed, programmed and managed by engineers; this is how we put men on the moon, built and operated nuclear power stations and modelled complex seismic behaviors. It was not "pretty" but it worked. Desktop computer technology smashed that.

The structural engineering profession also saw the loss of many engineering graduates and professionals to computer industries during the 1990s, which left large generation gaps within our discipline. In many locations around the world, we are a senior and aging profession lacking the continuity of maturing engineers to maintain and nurture our numbers into the future. While no profession has been immune to the impact of the new technology, some have maximized the benefits more than others. For example, architects and electrical engineers have embraced the opportunities more positively, using Web-based applications.

Thirty years ago, we lost slide rules to digital calculators. Programming Hewlett Packard, Texas Instruments and Casio calculators became the next personal project for many engineers. Results from this activity were integrated into hand calculations. As the programming was step-by-step in machine code, many engineers produced flowcharts and documentation to explain their logic and assumptions. This activity was accepted and supported by senior engineers and department managers. Structural engineering calculations produced by hand were concise and simplified; they identified and addressed the key elements of the design.

The desktop computer rendered them obsolete. It brought different programming concepts into play, which were without engineering precedence and non-intuitive to most engineers. Applications were designed for secretarial work and did not engender natural support among technical professionals. Remember how word processors and spreadsheets were continuously revised to our continual disappointment? Electronic calculations and spreadsheet development still has a bad name among senior engineers and department managers, who see it as a time-wasting activity. Crucially, in a world of high expectations, we lost time to learn, think and talk to each other about our common tools.

Nowadays, the chances are high that calculations are not concise or simplified; they are voluminous and detailed, attempting to address every component of the design without identifying the critical behaviour. A crucial part of the engineer's job is to check another's calculations, but this is requiring more and more time and resources. When I look back on twenty years of checking calculations myself, I
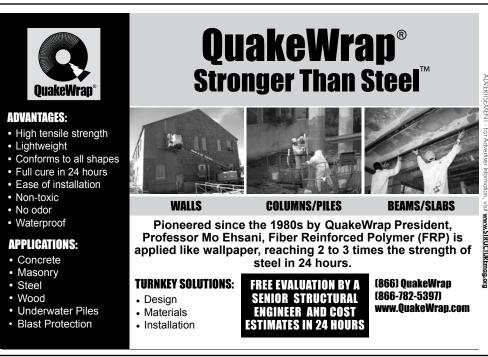
can see that fundamental questions are often overlooked, such as:

- Critical load path
- Controlling load combination
- Assumptions such as support conditions, joint behavior, etc.

Explaining these things in simple terms, as positive declarative statements, would benefit the reader. These are not intuitive, but they form the core of the calculations. It would be helpful to know that a tension bracing member and its connections are the most critical parts of the pipe rack design at 146 kips (650 kN); or to read that a total of 67 kips (300 kN) of wind load is applied to the structure. I have used simple numbers, but you will see 67.098 kips (298.465 kN) or 6.7967E+04 lbs (3.02332E+05 N). Try to remember them in twenty minutes' time! I receive calculations lacking these summaries and simple numbers, and am expected to approve them quickly.

The calculations are the face of the engineer. Unfortunately, the activity of checking is commonly getting pushed all the way out to five minutes before the deadline. For checking, assume that it takes a minute a page; what would your confidence factor be in the reviewer receiving ten pages of top-quality visuals and specific statements, as opposed to 250 pages without explanations or graphics?

Most companies now provide a standard suite of software – word processor, spreadsheet, database, etc. – to all employees regardless of discipline or needs. Training is not offered, as it is deemed to be intuitive and of low value to the business balance sheet. Such software is not geared for engineers but for businesses concerned with payroll, marketing and sales; one need only look at the endless examples and references. In addition, the constant revisions and upgrades also frustrate engineers. The lack of consistency and uniformity has kept us away from learning how to maximize the opportunities collectively.

So what happened to the calculations? Structural analysis programmers saw the opportunity

to bind the structural engineers to their products by taking care of the reporting features. Many of the big-name software applications were developed so long ago that they still employ courier text, fixed lines, poor graphics and ASCII formats. Engineers embraced the new technology to perform complex and over-detailed 3D analysis, where 2D would suffice. The result of every structural member is now printed out and presented as the calculation and the proof. We have been drawn into focusing on the quality of the analysis, not the quality of the calculation. Calculations have become quantitative tomes of work, failing to meet their primary and fundamental requirements.

To break the mold, engineers need to re-examine the way we work:

- Brainstorm the details together
- Talk to each other
- Work together, not in isolation
- Break the work into smaller calculation components
- Perform more frequent and regular checks
- Be visual in your work
- Identify, agree and focus on the key component of the design
- Avoid automatically performing 3D analysis
- Use and provide simple numbers
- Use analysis to verify the thinking

- Leave the analysis towards the end of the design cycle
- Summarise the major loads and material take-offs
- Think about the reader
- Do not keep a history of superseded pages in the calculations
- Ensure that the calculations are an active component of the design office cycle
- Treat the calculations as a minimum basis for design, not the final
- Go forward in time; do not recycle work for small changes
- Recognize that the sequence of work is not the same as the sequence of the calculations
- Go electronic, and use templates

An engineer's career goes through a life-cycle of changes, but I believe that we often do a disservice to future generations of engineers

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when we prepare our calculations. I learned how to be a structural engineer through writing and checking such calculations. It is where I started and where I come back, on every project. I know that just about every

engineer has a horror story to relate, but we are a melting pot of experiences and generational knowledge, so we should be able to relay the baton into safe hands with our best efforts.

We must assume responsibility for the quality, not only of the analysis but also of the calculations. The presentation is key to demonstrating excellence and professional pride. Graduates beginning a career in the design office face a culture shock on many levels. To future engineers, calculations are the face of the engineering profession, far removed from applied physics or pure analysis. It is a world of teamwork, building confidence, demonstrating that confidence, leading, interacting and communicating. Good calculations inspire good engineering.

Graduates coming into the structural engineering profession need to know that they have discovered an exciting world of challenges and opportunity. We, as practicing and professional individuals, need to recognize how we can do better in our calculations, set a benchmark for expectations and engender critical thinking in a world of too much information. We are back to square one, the calculations. Let's start talking.▪

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