Ethically Understanding The Role of Computer Software In Engineering Calculation

By Ken Maschke, M.ASCE

ASCE's Daniel W. Mead Prizes for Younger Members and Students—established and endowed in 1939 by Daniel W. Mead, a former president and honorary member of ASCE—are awarded annually to the authors of papers that explore the topic of professional ethics in civil engineering. The question posed this year was, is it ethical to use an engineering software program to solve a problem if you cannot complete the calculations manually? The essay presented here, by Ken Maschke, M.ASCE, who works in Chicago with the LZA Technology Division of the Thornton-Tomasetti Group, won in the younger member category.

The newest generation of engineers has matured within the information age. Computer familiarity, introduced by console gaming and Web searching, has overcome the typical human resistance to nontactile information sources. This exuberance for technology provides the potential for considerable growth within the engineering profession as well as a new set of ethical questions. As computers redefine the engineer's moral compass, the following question is paramount: is it ethical to use an engineering software program to solve a problem if you cannot complete the calculations manually?

This ethical quandary encompasses two distinct questions. Is it ethical to use computers to solve problems that could not otherwise be solved accurately or in timely fashion by hand? Yes, responsibilities to employers, clients, and the standard of care create a reality that precludes the regular use of complex hand calculations. Conversely, is it ethical to use computer software to solve problems in which the user is not otherwise competent? No, engineers must use their technical knowledge and intuition to create designs in which they are fully confident.

These conclusions require the responsible engineer to take inventory of his or her professional relationship with computer methods. Engineers need to consider why computers are used, how closely computer programs capture the complex nature of the real world, and what kind of

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environment promotes responsible use of computer software. In addition, an examination of the accepted professional norms regarding the relationship between the engineer and his or her calculations is important.

The professional engineer must seriously consider the effect of his or her work and submit finished designs with a sober confidence because an engineer's ultimate responsibility is to hold paramount the safety, health, and welfare of the public. When seeking an ethical baseline from which to begin this debate, the ASCE Code of Ethics dictates only that "engineers shall perform services only in areas of their competence." Omission of text related specifically to calculations serves to emphasize the individual's responsibility to participate in work only when fully competent.

In the legal context, competency is often related to the professionally accepted "standard of care"—what, simply put, a reasonable engineer in the industry would do. Consider the case of a high-rise building located in a region of high seismic activity. A reasonable structural engineer is likely to perform a computer analysis of the entire lateral-force-resisting system. Relying on simplified hand calculations for only a few elements of the structure would not meet the industry standard of care.

The most common gauge for the standard of care in structural design is the building code. Recent iterations of code development have highly recommended and sometimes required the use of computer analysis. For example, the American Institute of Steel Construction has required computation of P-Delta effects in its most recent design guide. This effect considers the addition of internal forces as a member begins to bend and is extremely difficult to calculate without computer assistance for all but the most basic systems.

In many cases, it can be extremely difficult to capture the complex nature of the real world in an engineering model. Engineers must not allow themselves to assign lesser importance to design considerations that cannot be quantified easily.

To understand why modern building codes now require the use of computer analysis in some situations, one must consider why engineers use computers. When working within a corporate environment, profitability places nontechnical pressures on engineers' practice. In addition to actual design work, engineers write reports, manage projects, market their company, and promote the profession. However, the engineer's obligation to public safety and liability for completed work are never diminished. "Canned" software and "homemade" spreadsheets are used to meet these obligations by removing the burden of tedious calculations from the engineer.

Like the personal calculator, the computer can be a reliable mathematical tool. When the proper equations are input, it provides nearly mistake-free computation. In comparison, "it has been estimated that a person, on average, makes about one error in every 10 calculations performed" (Altabba 2002). Though this issue is tempting to debate, this paper reasonably assumes that man makes far more mistakes than the "well-oiled" machine.

The responsibility to properly use software falls on the shoulders of the engineer. When using commercially produced, or canned, programs, many assume that their only obligation is to accurately build the system on-screen. In fact, their responsibility and liability extend to the procedures through which results are computed. Delving into such software or creating one's own spreadsheets provides a valuable learning opportunity. Oftentimes, well-conceived software will automatically consider conditions that the busy engineer may forget. Some programs may even consider systems in a way that is not possible by hand calculation.

Finite-element analysis (FEA) is one such computational tool used to predict the behavior of real systems. Materials are divided into hundreds or even thousands of elements, each connected to its neighbor by a complex series of mathematical relationships. To synthesize the same information without computers would require expensive physical models or a lifetime of calculation. Thus, both the design phase and the final product can be more efficient. For example, the development of the Boeing 7E7 Dreamliner would be impossible without computer modeling. Its high-strength, high cost composite body would have been impossibly expensive to develop using hand calculations and iterative modeling.

In many cases, it can be extremely difficult to capture the complex nature of the real world in an engineering model. Engineers must not allow themselves to assign lesser importance to design considerations that cannot be quantified easily. In such context, computer models may provide an alternative procedure to facilitate a complete analysis. The ethical baseline is clear in assigning equal emphasis to all design problems that pose a danger to health or safety.

In 1978 engineer William J. LeMessurier encountered one such "lesser" design consideration in his already constructed project: Citicorp Tower, in the New York City borough of Manhattan. Though his design team had carefully considered the effects of perpendicular winds, *(continued on page 87)* *(continued from page 61)* winds blowing at a 45 degree angle (quartering winds) caused an overstress in the lateral system. A change in the construction methods from welded to bolted connections further increased the potential for disaster (Morgenstern 1995). These problems were not caused by computer models and could not have been avoided by using such models. Rather, the design engineers' own intuitions were called into question.

Despite the best efforts of engineers to predict the natural forces that control design, seemingly random and exogenous actions can have disastrous effects. Consider a situation in which an airline pilot spills coffee on the cockpit controls, sending the plane spiraling out of control. Should the engineer have foreseen this potential? Would the responsible engineer have provided a secondary control system for any contingency? As the engineering community faces the challenge of protecting structures from terrorist activity, similar random acts are entering the design engineer's thoughts. For such considerations, the computer has no answer.

These examples serve to illustrate the role that engineering intuition plays in the design process. All engineering software is limited in scope. Competent engineers must understand where the limitations occur and apply judgment to fill in the blanks. While inherent in the mind-set of a responsible engineer, competent engineering may be reinforced by an environment that promotes responsible use of computer software.

Fostering this responsible environment begins with a learning process. Mathematics educators have begun to realize the effectiveness of semantic learning methods (Dancis). These understanding-based lessons require students to learn the justifications for their calculations and emphasize concepts and general principles that are useful in many situations. To most engineers, this approach to algebra would seem obvious. However, the same mind-set is essential to the ethical use of computer programs. The ethical engineer must understand the concepts behind engineering calculations, seek to look beyond "cookbooklike" instructions, and compare computer results against similar data.

Software often utilizes algorithms too complex to recreate by hand. Such computer methods as FEA utilize the numerical power of the computer and are, therefore, too complex and time consuming to verify by hand. Graphical output from these programs should always be sought to verify that the results "make sense." Whenever possible, competent engineers should review documented procedures carefully and critically compare results with similar work.

Many software packages and spreadsheets are just simply meant to save time. Hand calculation provides the engineer with a longer time frame in which to consider the applicability of the chosen procedure and the accuracy of the work being done. Also, some manual calculations must be completely redone when design iterations are performed. The opportunity to check for error is inherent in the process, and the ability to perform hand calculations demonstrates a thorough understanding and true competence in the field. Engineers should consider the loss of this review time and make special effort to build confidence in the procedures performed by the software.

While software tools are making the workplace more efficient, the potential has been created for the nonengineer to attempt the same work as a professional. As noted in the cases above, the ability to recognize conditions not allowed for by the software is essential to the art of engineering. Therefore, it is unethical to operate design software without a competent understanding of the engineering process.

The application of computer software to engineering problems is highly diverse. Despite the differences in uses, the means by which engineers ethically interact with computers can be summarized as follows:

1) A review of ethical norms emphasizes the necessity for engineers to work only in their areas of competence. When the professional standard of care dictates the use of computer methods to better protect the safety of the pubic, using such software is ethically obligated.
2) Computer software is employed because of the efficiency demanded by the corporate world, the accuracy of the tool, the ability to check scenarios that the engineer may have forgotten, and the potential to provide designs that are safer and more efficient. Use of this tool is ethically obligated when time, efficiency, and safety requirements preclude the use of hand calculations.
3) Capturing the complex nature of the real world is a priority of the engineer though sometimes is beyond the scope of computer programming. It is not ethical to use computer software when the engineer cannot demonstrate competency by understanding the limits of the machine.
4) The competent engineer creates a working environment in which semantic methods are used to approach verification of simple and complex computer programs. Following this responsible approach, it is ethical for an engineer to use an engineering program to solve a problem even if he or she cannot complete the calculations manually.

The use of computer software is redefining the role of the engineer in the technical society. Emphasis is placed on problem-solving skills and the proper use of engineering judgment to recognize potential threats to health and safety. Armed with a talent for operating the computer as a tool, the next generation of engineers will be highly efficient. Empowered with a well-defined ethical approach to using computer software, they will mature into fully competent industry leaders. ■

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