# *Structural Analysis: Are We Relying Too Much on Computers?*

Part 1: The Problem

*By Graham H. Powell, Ph.D., P.E.*

I have noted with interest some recent editorials in STRUCTURE magazine on the subject *Are We Relying Too Much on Computers* (February 2007 and August 2007), and also the article *Basic Education for a Structural Engineer* (April 2007). I disagree mildly with the editorials. I disagree strongly with the Course Content in the *Basic Education* article.

I do agree that problems can arise when computers are used for structural analysis. However, the computer is not at fault. The computer is merely a tool, and like all tools it must be used in a craftsman-like fashion. In my opinion, the problem lies not with the computer but with the craftsmanship. In this article I explain why I believe this is the case. In a follow-up article I propose a solution.

In this article, I argue two main points, as follows:

1) Older engineers often complain that young engineers lack a "feel" for structural behavior. For example, a young engineer may get an analysis result that is obviously wrong, yet may not realize that there is an error, and may even believe that the result is accurate to 6 or more significant figures. A viewpoint that is often expressed is that hand calculation methods, such a Moment Distribution, help an engineer to develop a better "feel", and that computer analysis does not. I emphatically disagree with this viewpoint. In my opinion the opposite is the case – computer analysis can give a young engineer a much better feel for structural behavior than hand calculation.
2) In structural analysis there are three phases, which I will identify as the *Modeling, Number Crunching* and *Interpretation* phases. In my opinion, the modeling and interpretation phases are by far the most important, and should be given by far the most attention. As far as I can discern, the structural analysis courses at most universities devote almost all of their attention to the number crunching phase, and very little to modeling and interpretation. This does not provide students with the skills that they really need.

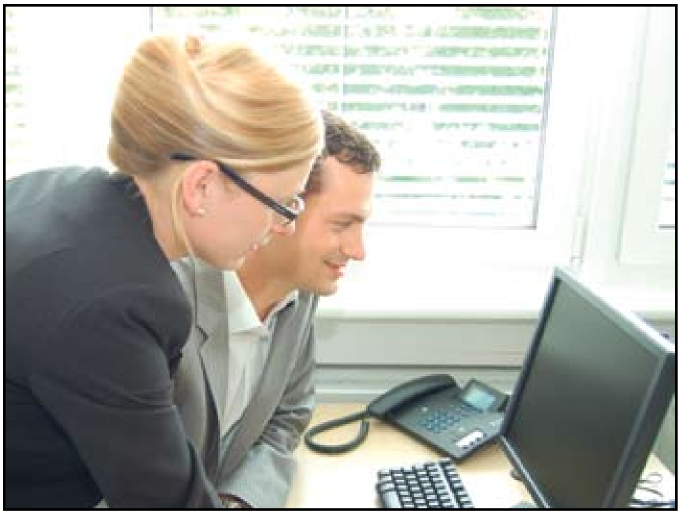
I also consider a number of secondary points, in particular (a) the role of structural analysis and (b) the coordination of courses in structural analysis with courses in structural design.

## Developing a "Feel" for Structural Behavior

Once upon time it was necessary to analyze structures "by hand" (I graduated in 1958, so I was trained in that era). A number of useful, and occasionally elegant, analysis methods were developed, the most important of which was Moment Distribution. It is often argued that when engineers used Moment Distribution they developed a "feel" for structural behavior, but that when they use a computer this "feel" is lost. I strongly disagree with this argument. I firmly believe that if you give a computer program to a student, and if you teach him or her to use that program properly (a big "if", which I address later), then that student can develop a better "feel" for structural behavior in a couple of semesters than he or she could develop in a lifetime of using Moment Distribution.

The following is a list of some structural analysis exercises. I believe that by examining and explaining the analysis results for exercises of this type, a student can quickly develop a "feel" for structural behavior.

1) Analyze a truss structure as a simple truss (assuming pinned connections) and as a frame (accounting for continuous members and estimating connection stiffnesses). Do this for trusses with slender and not-so-slender members, and compare the results. Discuss whether the bending moments can be ignored for design.
2) For a simple cantilever shear wall, calculate the moments, shears and deflections both including and ignoring shear deformation. Vary the wall aspect ratio. Compare the deflected shapes for a slender wall (mainly bending deformation) with that for a squat wall (mainly shear deformation). Do the same for a coupled shear wall. Vary the coupling beam span to see how it affects the results. Both include and ignore shear deformations in the walls and coupling beams. For a cantilever wall and a coupled wall, estimate the rotational stiffness of the foundation, and see whether foundation deformation has much effect on the behavior.
3) Apply support settlements on a statically determinate structure and a similar, but statically indeterminate, structure. Examine the moments, shears, reactions and deflections. Explain the results. Do the same with thermal expansion loads. Use this example to consider the advantages and disadvantages of redundancy, not in terms of the number of unknowns for analysis by the force method, but as a physical concept.
4) For a reinforced concrete frame, consider different methods to estimate the bending stiffnesses of the beams and columns. See how different stiffness estimates affect the calculated moments and deflections. Use this example to explain how cracking affects stiffness. Emphasize that there is a lot of uncertainty in modeling for analysis, and that analysis results are at best approximate.
5) Analyze a multi-story frame and a shear wall separately for lateral load, and note that they have different deflected shapes. Then couple them together and explain what is happening (one way is to connect them with stiff bars, and look at the forces in the bars).



6) Analyze a steel frame with semi-rigid connections. Vary the rotational stiffness of the connections and see the effects. Estimate the stiffness for an actual bolted connection.
7) Analyze a frame with stiff end zones (or rigid offsets) in the connection regions. Examine the effect on the frame deflections. Compare the beam bending moments and shear forces at the column faces (which would be used to design the beams) and at the joint center-lines.
8) Analyze a steel frame with and without deformable connection panel zones at the beam-to-column connections. Calculate how much of the frame deflection originates in the panel zones. Explain how loads are transmitted through the connection and why the shear stress in a panel zone is much larger than in the webs of the adjacent beams and columns.

For these exercises, the analyses are all easy to do with a computer but would require an impossible amount of time by hand (not to mention a high level of expertise in hand calculation methods). Using a computer, a student can quickly build the model and run the analyses, see the structure in 3D, vary the dimensions, loads and other properties, and display the results graphically. Most importantly, a student can focus on the modeling and interpretation, and not get bogged down in number crunching. I believe that a student can learn much more about structural behavior by completing exercises of this type than by learning how to analyze structures by hand, and can also have more fun doing it.

It is important to note that to gain benefit from such exercises it is not enough just to run the analyses – it is essential to understand and explain the behavior. The computational details of the analysis are relatively unimportant. The important things are what procedures and assumptions are used to set up the analysis model, and what the analysis results mean in terms of structural behavior and performance.

## What is "Modeling"?

It may seem obvious, but it is worth keeping in mind that we analyze a model of a structure, not the structure itself, and that the behavior of the model may or may not be close to the behavior of the actual structure. The challenge is to create a model that is accurate enough for practical purposes.

To create a meaningful model an engineer must (1) understand the behavior of the components that make up the structure, and (2) know how to capture the important aspects of this behavior in an analysis model. This is not a simple task. It requires an understanding of such things as axial and shear forces, bending and torsional moments, beam and column behavior, load transfer through connections, connection deformations, composite action, cracking, yield, bolt and bond slip, buckling, and many other aspects, including the difference between actual and design loads. It then requires decisions on how (or whether) to model different aspects of behavior, given the capabilities of the available analysis methods (or computer programs). Modeling is especially difficult for nonlinear analysis, because of the many types and causes of nonlinear behavior. It is also more difficult for dynamic loads.

An important skill for an analyst is the ability to create useful models of real structures (not just simple two-dimensional frames of the type that are often considered in analysis courses). A useful model must capture the behavior of the structure with sufficient accuracy for design purposes, it must produce results that are accurate enough for making design decisions, and it must not be so large or complex that it takes too long to analyze. A model does not have to be, and never can be, "exact".

## What is "Interpretation"?

There are two parts to interpretation, namely (1) checking the analysis results to make sure that they are reasonable, and (2) organizing the results in a form that supports decision making for design.

Checking analysis results requires a number of skills. There are several tools that can be used, including free bodies and equilibrium equations, and methods for checking displacement compatibility. Common sense and a feel for structural behavior are indispensable. Experience is always valuable.

Organizing the results requires an understanding of how analysis results are used for assessing performance and making design decisions. Almost always, design decisions are made using strength and/or deformation demands, corresponding capacities, and hence Demand/Capacity ratios. In the analysis of a frame structure, the deflected shape and the bending moment diagram are useful for checking the analysis results. They are not particularly useful for assessing performance or making design decisions.

## What is "Number Crunching"?

The number crunching phase is everything that is not included in the modeling and interpretation phases. It includes the numerical computations and the underlying theory.

## Do We Have a Problem?

I believe that we do have a problem, and that it is a serious one.

For an engineer who uses structural analysis, the most important phases are modeling and analysis. These are tasks that require engineering skills and judgment, and can not (yet) be done by computer. The number crunching phase is not unimportant. However, with modern computer programs, this phase can be handled entirely by the computer. An engineer needs a basic understanding of the theory (i.e., the Direct Stiffness Method) and the computational procedure, but for the most part the analysis details are not important.

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The problem, I believe, is that young engineers are not being taught the skills required for modeling and analysis. In most structural analysis courses, the emphasis is overwhelmingly on the "number crunching" phase, even to the extent that students are being taught Moment Distribution (which I find horrifying). As a consequence, young engineers have to learn the really important skills on the job. At the very least, this is an inefficient use of resources.

In my opinion, we spend far too much time teaching unimportant (and relatively uninteresting) skills, and far too little time teaching the skills that are important (and more interesting).

This is the main problem. There are also some secondary ones.

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## The Purpose of Structural Analysis

In structural analysis courses, students can easily get the impression that analysis is an end in itself. This is rarely, if ever, the case. The end result for the analysis of a building frame is not the deflected shape and the bending moment diagram. Usually, the required result consists of the strength and deformation demands on the structure and its components, so that a designer can assess the performance of the structure by calculating Demand/Capacity ratios. When students present the results of a structural analysis, they should consider how to organize those results in a way that supports decision making for design. This is rarely done in structural analysis courses.

## Coordination with Design Courses

Design courses frequently make use of structural analysis, but often the analysis methods are different from those that are taught in analysis classes. Students can get the impression that analysis and design are unrelated disciplines. It is important, if only in the interests of efficiency, that the course material in analysis be coordinated with that in design.

## Accuracy

Students can easily get the impression that structural analysis results are somehow "exact". This relates to the common complaint is that inexperienced engineers often present analysis results to six-figure accuracy or more. Even worse, students may be led to believe that structural analysis can predict the behavior of a structure exactly. Researchers who should know better often suggest that "advanced" structural analysis can accurately simulate and predict structural behavior, accounting for all types of nonlinearity and all types of load. The truth is that structural analysis is almost always very approximate, and for real structures accurate simulation is impossible. Even if this were not the case, over-reliance on analysis can lead to "design by analysis", which is a very bad idea.

Students should be taught that for real structures there is a great deal of uncertainty, in the properties of the structural components, the support conditions, the loads, and the contributions of nonstructural components. Students should not be under the illusion that analysis results are "exact".

## Conclusion

I have seen it argued that back in the days when engineers did structural analysis by hand, they developed a better "feel" for structural behavior than engineers who use computers. In my opinion this is, or should be, incorrect. With proper instruction, an engineer can get a much better feeling for structural behavior by running computer analyses and examining the results rather than by doing repetitive and boring hand calculations. Using a computer, an engineer can analyze complex 3D structures, quickly explore the effects of different modeling assumptions, and consider dynamic loads and nonlinear effects. None of this is possible when hand calculation is used.

The key point is that engineers are not being educated to use computers effectively (I deliberately use "educated" here, not "trained", because this is an academically demanding process). Engineers are also not being educated to think critically about computer results. If an engineer believes that a computer analysis model is "exact", or that it is the only possible model, or that the results are accurate to 6 significant figures, that engineer has received a poor education. An engineer has also been poorly educated if he or she thinks that structural analysis is an end in itself, rather than just a way to get useful information for design.

The problem, in my opinion, is that structural analysis, as it is presently taught in most of our universities, incorrectly emphasizes the number crunching aspect of analysis, and greatly underestimates the importance of modeling and interpretation. Modeling and interpretation are not simple tasks. They can be complex even for structures that have static loads and linear behavior, and they can be very complex when dynamic loads and nonlinear behavior are considered. Modeling and interpretation are academically demanding processes that require an understanding of structural behavior, the modeling capabilities of computer programs, and the needs of designers. Typical university courses in structural analysis provide very little instruction in these important areas. The problem is not with the computer, it is with the professor.

In the second part of this article, in an upcoming issue, I propose a solution.▪

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