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Teaching and Learning Engineering Design
An Introduction for Strength of Materials

What You're About

This note is **not** to tell you how to teach or learn; rather it is to tell you what to teach and learn to do good engineering design and why you should learn it. We draw upon your intuition, experience, first year design course and engineering statics and focus on strength of materials learned just in time in this course, theory interleaved with design process, to enable you to meet intermediate milestones and complete an engineering design project. (By the way, who are "you"? *You* are instructors and students or anyone involved with teaching and learning design.)

Why teach/learn engineering design anyway? Because to engineer is to plan the construction or fabrication or development of something useful. In short, engineers do the planning! Engineering design process enables you to draw up a plan to whatever level of precision your present knowledge affords. Strength of Materials within an analytical framework raises that knowledge to a level sufficient to do **engineering design** within a tolerance required by the application. Engineering Design shows you why you are learning the theory and what it enables you to achieve.

Be aware that design in general is more than engineering: it encompasses styling and art—the esthetics of design. When applied to products or buildings, it is called industrial design or architectural design. For an example, on the surface, automotive design is styling; underneath, it's engineering design. And the adage, 'function before form', always applies.

How does creativity come in? In two ways: how you apply both the science and the art. On the one hand, is your application of science novel? Revolutionary? Is the design object's **function** new? This is the function-side, the engineering/technical part of the design. It emphasizes usefulness, material strength/stiffness/weight, geometry for fit, stability and load path, and the like. On the other hand, is your design object artistic? Attractive? Exciting? Evocative? **Form** involves styling, material sheen and color, geometric shape, and the like. In no way does engineering preclude esthetics. So if you have any art in you, good. Be artistically creative. Indeed, if interested, elect an art course. Learn styling. Learn art. From an engineering and artistic point of view, creativity requires affirmative support: the learner must learn enough to be confident; the teacher must be a positive, encouraging coach.

Engineering Design Today

While teaching and learning the application of Strength of Materials to engineering design, today the more astute among us realize that the earth is worth saving. This raises two issues to bear in mind when doing engineering design: **Life Cycle Engineering** and **Design For the Environment**. LCE involves cradle-to-grave design: from the energy to refine materials to the energy to manufacture a product to the energy to run it and to the energy to dispose of it. And this coupled with DFE, concern for a sustainable earth throughout all aspects of LCE, is paramount to total cost of the product. We bear responsibility to design not only for product life, but for afterlife: recycling some of it for further use, recycle the rest harmlessly back to the earth! Obviously in this introductory engineering design experience, we cannot cover these issues in depth, nonetheless, teach and learn engineering design with LCE and DFE in mind.

Analysis of structural designs today employ sophisticated computer programs (e.g., solid modeling for shape, volume, weight, esthetics; finite element methods for analysis; statistical reliability for quality and safety), but these are beyond the scope of an introductory strength of materials course. The design project must be compatible with analysis techniques covered in class for bars, trusses, beams and columns. But we must emphasize that we do design with the theory at hand and its success is not restricted, only the degree of precision of the design; how close to a functioning limit can we make it. To wit, Roman roads and 14th century cathedrals still stand and function and their design did not employ finite elements or electronic computers. Of course their tolerances were not tight and their objects over designed. But then your more powerful, modern methods must address a new set of problems. What is new is only the precision available to overcome them. You can not only design with this course, you can use it to check future, more sophisticated work.

What is Engineering Design in Strength of Materials

In a nutshell, engineering design employs the theory in Strength of Materials to size members in your design object (a structure or product) in an efficient manner. To determine sizes, we treat two aspects of structural behavior: **strength** and **flexibility**. Strength provides the size required for the structure to not fail elastically, that is, to not permanently deform under load. Flexibility provides the size required for the structure to not deform elastically beyond a specified limit. Then it is your decision to choose which of these sizes permits an acceptable design.

For example, using design process for a bar, decide its length *L*, applied load *P*, the limit of stretch δ_{Max} and select materials with property sets (E_1, σ_1^{ALL}), (E_2, σ_2^{ALL}) where *ALL* denotes ALLowable. Here "decide" and "select" are not lightly chosen words: they are the careful result of other influences on the design known as design specifications. Then using design formulas (for details, see the course design website and your textbook on the theory for uniaxially loaded bars):

1. Design for strength: $A_1 \geq P/\sigma_1^{ALL}$, $A_2 \geq P/\sigma_2^{ALL}$ where *A* is cross section area of a bar.
2. Design for flexibility: $A_3 \geq PL/(\delta_{Max}E_1)$, $A_4 \geq PL/(\delta_{Max}E_2)$
3. Decision: from these results, choose *A* based upon design criteria and explain your choice.

This process is a technically sophisticated engineering design of a bar. It is oh so simply elegant!

It is important to realize that this process is not analysis in the traditional sense. As you will discover, analysis is used to find internal force or stress or stretch from a given load applied to a given size member. Design is an inverse problem; it solves for the size; little is given.

NOTE: In grading design problems or reports, a solution that employs analysis rather than design cannot receive an A grade. Why? Because analysis does not display knowledge of the design process, so important in engineering practice, and it is neither efficient (because it adds trials to an already trial and error process) nor precise (because only results from design formulas yield the limits of feasible design spaces without iteration).

Other Steps in Engineering Design

Textbooks present problems that have in effect already been designed. They supply location and magnitude of loads and a model of reality in the form of idealized supports and member geometry and then ask you to do analysis to find a result like stress or deformation in order for you to learn the theory. Yes we must teach and learn analysis. But this is not prevalent in the real world of engineering. Yes, engineers do analysis of model problems like those found in textbooks, but only to check designs. A majority of engineers do design. So then what else is required to do design?

- Modeling and why do it? Modeling reduces complicated real problems to an idealization, a model of reality. You model to remove complications superficial to your purpose, yet include those features that dominate behavior pertinent to your work. In particular you seek a model simple enough so analytical theory you know can address it. Teaching and learning this requires insight and intuition; some experience won't hurt. Modeling is an absolute necessity and a common engineering practice. Most problems in your textbook are models, even those rendered realistically. Learn to replicate them. Furthermore, the modeling you learn now is used in sophisticated computer analysis and in testing that you may learn and do in the future.
- Importance of loads. From where do loads come? Primary loads are live loads, that is, loads applied to the structure. Secondary loads are dead loads, those inherent in the structure itself, e.g., self-weight of structural members. Determining load types and their magnitude is not trivial. Research is almost always required to find them. For examples, rocket ship payloads and their distribution, loads of people (How much do people weigh? Where to locate them?), snow loads on roofs. Teaching and learning how to determine loads is important to success of the design.
- Why loading scenarios? In design you must predict where and how various loads will be applied. You must consider all possible situations and rank order them either through analysis or experience. For example, where on a beam should a load be applied for maximum deflection? For maximum bending stress? For maximum shear stress?…Indeed there are two types of shear stress to consider. Importantly the load location will most likely differ for each case; consider a vehicle moving across a bridge. You must find and prove the worst case and design for it.
- Why free-body diagrams? Because Statics is fundamental to analysis and design of global behavior (the whole thing can tip over!), to local behavior (it can yield), and to the correct application of Strength of Materials. Free-body diagrams are key to getting the structure and its components correctly loaded. Draw them! They too appear in computer modeling and analysis.
- Why work in teams? Well bluntly, that's the way industry works today. More subtly, teaching, learning and working on multifaceted systems involves more than technical theory, analysis and, yes, even design. Since most work is complicated, it is an interactive process: you must teach and learn project management skills that enable you to contribute to, even manage, the whole design. You must learn to understand, motivate, influence people: this should be part of your design-team teaching and learning objectives. Although instructors may provide some guidance here, learning this in this course is primarily experiential—pick it up as you go. Nonetheless, treat it seriously. Most of all, learn to understand colleagues—be congenial.
- Why report? If you don't communicate your work, who else will? That's the road to success in life. Report your work clearly to win acceptance of your project. Follow course guidelines.
- Why review your work and that of others? Reviewing work is a fact of life. Consider review of your own work as an "alpha-test", review of your work by others and your review of the work of others as a "beta-test". You learn, they learn.

What Infrastructure is Available To Do Design

- The Course Design Website and other websites. The course website has been created specifically for you. It is your guide. Indeed, people worldwide use it. Treat it as an important supplement to your textbook. It contains all the ‘formulas’ to do design with strength of materials and to report your work. Since it is an ongoing project, please keep instructors informed of shortcomings; your suggestions are appreciated. Other websites are out there: find and use them. When you find a good one, tell the entire class.
- Libraries. Traditional libraries still rule the information world: the Internet is secondary, despite its convenience. Why? Because libraries provide verification/validation of their contents through the recognition and critical judgement of experts; the internet does not. The Engineering Library is the primary source for technical information and catalogs and interacts with the developers of this course regularly; it provides materials specific for this course. The Earth and Mineral Science and the Architecture Libraries are also useful. If you need help using any library, just ask for it: indeed, the Engineering Library offers a short course on its use.
- Standards. Engineering standards and codes are a key ingredient to engineering design. The primary difference between standards and codes is that codes are codified into law. Codes may adopt standards. Your website, ANSI’s website and the library are primary sources. Use them. As an example, most buildings are constructed to satisfy codes; playground equipment and helmets are made to engineering standards (in some locations and applications, codes as well).

Closure

Here the why and what of doing engineering design is covered. Though it is focused on the application of strength of materials, it applies in general; it’s not restrictive to this course. It lays the groundwork for future teaching and learning. The details on how you teach and learn this stuff is your task. Need help? Just ask.