# THE IMPORTANCE OF ENGINEERING MATHEMATICS

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## ABSTRACT

Engineers are problem solvers whose decisions are constrained by cost and time. Their ideal would be the simultaneous prevalence of the cheapest, the quickest and the safest 'decisions'. However, since such an attainment is impossible, what is left is the endeavor for balance between accuracy, efficiency, sufficiency and safety. But, such a diversity, far from being liberating, astringes the engineers to the state of versatility - an engineer should be versatile enough to 'satisfy the various conditions' and this demands ingenuity. Mathematics on the other hand, is the language used in the understanding and deliverance of scientific notions describing the physics of the problems. As far as the appearance of the mathematical terms is concerned, one could not distinguish between physical problems until the specification of certain parameters. In other words, the 'same' mathematical expression would be representative of various equivalent physical problems and the understanding of the derivation and the solution of one typical mathematical statement would allow for the subsequent understanding of the other equivalent problems. Such generality and interconnection between subjects which can only be made possible by the marriage between mathematics and engineering knowledge is what is highly valued nowadays, especially in the advancement of computer technology and that is what this paper is about to venture.

## INTRODUCTION

Engineers are problem solvers whose decisions are constrained by cost and time. Their ideal would be the simultaneous prevalence of the cheapest, the quickest and the safest 'decisions'. However, since such an attainment is impossible, what is left is the endeavor for balance between accuracy, efficiency, sufficiency and safety. But, such a diversity, far from being liberating, astringes the engineers to the state of versatility - an engineer should be versatile enough to 'satisfy the various conditions' and this demands ingenuity. This is the quality of an engineer at the highest level, the quality at making decisions. Let's call it the 'engineering sense' and use this term interchangeably with the word quality itself.

## ENGINEERING SENSES

The best way to describe the engineering sense is to pose the Hambly's paradox. If one, who is weighing 600N, sits ideally at the centre of gravity of a stool and if the stool has three legs, the reaction force at each leg would be of course 200N (note that this is a paradox so all the ideal state of symmetricality and so on has been taken for granted). Now, if the stool has four legs, instead of three and by taking into account the reality that there could never be a smooth surface beneath the legs, at least one of the legs must be tilting (not in contact with the ground). This leaves three legs supporting the stool. However, since one of the legs must be diagonal to the tilted leg, satisfying the static moment equilibrium requires that the force at this leg to be zero. What this amounts to is that there are actually only two legs supporting the stool thus the reactions at each leg must be 300N instead of the intuitive 200N. A good engineering sense would have realized all these and assist the engineer to decide on the construction of three-legged stool instead of the four-legged stool. He or she should have realized that the construction of the four-legged stool is not only uneconomic but also lacking in safety.

The engineering sense revealed in the paradox is the decision for the construction of the three-legged stool instead of the four-legged stool through the realization that the former would not only be more economical but safer as well. But, the bigger picture to this is the appreciation of the fact that what seems trivial is not sufficiently necessary – 'intuition' is sufficient but 'technical intuition' is what is sufficient and necessary. This is the immediate example to the phrase given earlier in the text that "an engineer should be versatile enough to 'satisfy the various conditions' and this demands ingenuity". So what kind of ingenuity? In the paradox, this refers to the understanding of the concept of centre of gravity, equilibrium of forces (i.e. vertical reaction forces, moment), geometry, symmetricality and so on which are all under the realm of physics (or science in that matter) which understanding would be impossible without mathematics.

## THE ROLE OF MATHEMATICS

The role of mathematics in underlying the understanding of scientific notions (thus the engineering senses) can be best explained by analyzing the difficulty encountered by Robert Hooke (1635-1702) in explaining the concept of elasticity. Every engineer is very familiar, if not with the man himself, but with the law, the so called Hooke's Law, which in one dimension can be written as:

$$\sigma = E\varepsilon \tag{1}$$

where $\sigma, \varepsilon$ and $E$ are the stress, the strain and the Young's modulus of the material, respectively. The meaning and use of this law have been taken for granted by engineers. Every engineer understands it, they should at least. But what many do not realize is that, the simple nature of this notion of elasticity is possible because it has been taught and delivered in modern engineering schools in its mathematical form as given in Eq. (1). Many do not know that the original expression of the concept was explained by Hooke in words as (Gordon, 1983):

*The power of any spring is in the same proportion with the Tension thereof: That is, if one power stretch or bend it one space, two will bend it two, three will bend it three, and so forward. And this is the Rule or Law of Nature, upon which all manner of Restituent or springing motion doth proceed.* - Robert Hooke.

Imagine the difficulty to generalize (or to explain) this law for higher dimensions in words, both spatial and time. Fortunately, with the help of mathematical language (which was unknown to Hooke), the law can be easily understood and dealt with for higher dimensions as:

$$\sigma_{ij} = E_{ijkl}\varepsilon_{kl} \qquad \text{in tensor notation or} \tag{2a}$$

$$\boldsymbol{\sigma} = \mathbf{E}\boldsymbol{\varepsilon} \qquad \text{in matrix form} \tag{2b}$$

Eqns. (2) are excessively used in the contemporary engineering analysis, especially with the advancement of numerical analysis, for example, finite elements and finite difference methods. Referring back to the Hambly's paradox, mathematics is needed in the deliverance of the concept of, say the moment equilibrium as:

$$M = Fr \tag{3}$$

where $M$ is the moment, $F$ is the force and $r$ is the lever arm. Can there be any other efficient way to expand Eq. (3) for higher dimensions besides:

$M_i = \varepsilon_{ijk} r_j F_k$ in tensor notation or (4a)

(4b)

$\mathbf{M} = \mathbf{r} \times \mathbf{F}$ in vector form

All these emphasize the role of mathematics in the establishment of both the scientific notions and the engineering senses. But, let's not stop here. Let's look at the formal utterances on the matter. For example:

*Those who shy away from mathematics run the very real risk of becoming functionally illiterate........Indeed, it is this mastery of mathematics and science that distinguishes the engineer from the engineering technologist or technician* - (Duderstadt, et. al., 1982)

Applying this statement to the Humbly's paradox, we can address those who end up with the four-legged stool as mere technicians instead of real engineers. Repeating the earlier phrases, 'intuition' belongs to the technicians but 'technical intuition' belongs to the true engineers.

## COMPUTER AND IT REVOLUTIONS

Mathematics is the language used in the understanding and deliverance of scientific notions describing the problem at hand. As far as the appearance of the mathematical terms is concerned, one could not distinguish between physical problems until the specification of certain parameters. In other words, the 'same' mathematical expression would be representative of various equivalent physical problems and the understanding of the derivation and the solution of one typical mathematical statement would allow for the subsequent understanding of the other equivalent problems. Such generality and interconnection between subjects which can only be made possible by the marriage between mathematics and engineering knowledge are what is highly valued nowadays, especially with the advancement of computer technology. Quoting Trikha and Abang Abdullah (2004):

"*The IT revolution is in turn impacting on the construction industry in two major ways, the introduction of computer integrated construction and support for the construction of intelligent structures. The two developments making it imperative that countries, which have missed opportunities during the industrial revolution, take advantage of the IT revolution now. For the construction industry, computer integrated construction and intelligent buildings are the two current challenges which must be accepted with alacrity and enthusiasm*'.

Based on the above, it is enlightening to know that we, especially the engineers of developing countries, still have the chance to be at the frontier and becoming one of the world major players. This is because, whilst the last century was about fragmentation of scientists, engineers and sociologist etc., in their own specialized areas, IT revolution evoked the cross-bordering of specializations solely due to the availability of high-tech computers. For example, solving a set of non-linear of partial differential equations are no longer under the realms of the mathematicians; any engineering 'dons' could solve it with the help of commercial software such as Maple, MATLAB and MATHEMATICA. Such a privilege has caused the explosion of daring experimentations and unorthodox ideas all around the world which could not even have been imagined fifty years ago. Such a privilege promotes the frequency and the efficiency of communications between various learned parties. Today's world headlines of bioengineering, for example, are simply possible because mathematicians, physicist, engineers and biologist talk in the same language, understanding each other. Therefore, any countries or societies failing to exploit such an opportunity would definitely fail in their endeavor to be the pioneer or frontier of anything.

Discussing on a more contemporary engineering topic, Industrialized Building System (IBS) is the best example to illustrate the need for an integrated, multi-displinary and cross-bordering type of engineering knowledge. IBS can be defined as those incorporating a total integration of all subsystems and structural components into an overall process; one fully utilizing industrialized production, transportation, and assembly techniques (Dietz and Cutler, 1971). Based on this definition, it should be understood that IBS is not only about the pre-cast or pre-fabricated structural components i.e. beam, slab, column, etc. (like many have thought) but more than that, it is the whole system that matters. It involves detailed knowledge and management of the whole construction lifecycle thus requires the establishment of a systematic interaction between various parties and procedures which is best handled by information and computer technology or ICT. Bergsten (2005) stated that failure in appreciating IBS as a system would prevent the prevalence of the whole concept.

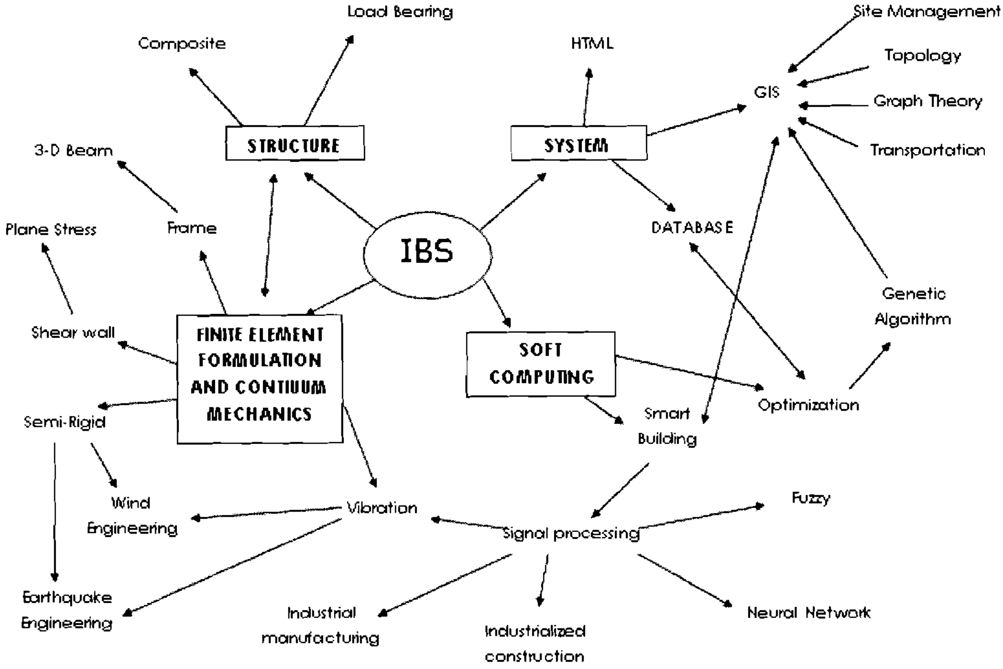


FIGURE 2 IBS Body of Knowledge

Analyzing Figure 2, one should have realized the importance of communication between various parties which can only be made possible through the language of mathematics. Such a network of knowledge is also the manifestation of the need for the versatility from an engineer as someone who is able to satisfy the 'various conditions'. In another context, one can also observed that, take vibration for example, how one physical problem can be mathematically representative of other related problems, in this case, wind engineering, earthquake engineering and signal processing as these problems have in general identical mathematical representations. All these only manifest the importance of the marriage between mathematics and engineering knowledge. In the commentary on ABET Engineering Criteria for Civil and Similar Named Programs, American Society of Civil Engineers (ASCE) documented the concern and the need for the future engineers to be versatile as stated in the following statement:

*As the boundaries of technological knowledge expand, as new disciplines emerge, and as the boundaries between existing disciplines blur, professional civil engineers must increasingly draw upon a broad understanding of math and science fundamentals. Breadth in math and science provides a strong foundation for engineering problem-solving (Outcome 5) and lifelong learning (Outcome 9)—not* *only in the traditional civil engineering discipline areas, but in emerging fields and interdisciplinary endeavors as well* – (ASCE, 2006)

## CONCLUSIONS

On the question of how demanding is the 'engineering sense' hence the Engineering Mathematics, the answer is the single most important fact as it governs the whole discussion of *to be* or *not to be*. The answer is all spatial, time and personality dependent and initially, it would seem like a dilemma. Spatial wise, it depends on where the engineer is working, i.e. company, country. If he or she works in a company with less challenging projects (both in the practical and research aspects), we can suppose that this sense would be less demanding. The same argument applies to the country where the company is operating. Although the generality of the argument degrades (since one may argue that many of the contemporary engineering 'state of the art' works are being carried out in the developing countries, although the question of whether they are being carried out by the local engineering talents remains) but at least we can still say that less-developed countries would demand less of the quality than the developed countries, again due to the nature of the projects (i.e. not very challenging) as well as other factors such as internalization and globalization (difficulties of local talents to penetrate the global scene). In other words, since the job is not challenging and the company (and country in that matter) is not internationalized, why then bother? Time wise, based on the law of entropy, order degrades over time so we can expect a more chaotic world in the future which demands, of course, versatility. Increase in oil prices, terrorism, neo-capitalism, environmental issues, political instability etc. are the factors contributing to such a chaos. Finally, personality wise, it depends on how ambitious the engineer, the company and the country are. The greater the ambition the higher is the demand for the quality (or the engineering sense).

Indeed, there is no dilemma. For both spatial wise and personality wise, if we insert time into the equations, things would become obvious (time wise, it is already obvious). Spatial wise, a company (and a country in that matter) will either be losing or gaining over time as staying stagnant would be almost impossible. Such changes will create competition and as far as competition is concerned, only those with the quality will survive. Personality wise, it is very hard to imagine of any society or any country that is not being ambitious, at least in the long run. We are witnessing the rise of new world powers such as China and India, to name only a few. Therefore, based on these, it can be concluded that, the engineering sense of the engineers is ever demanding with its magnitude increasing 'exponentially' over time. The same goes with Engineering Mathematics for that matter.

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