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Who invented Young's Modulus?

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Introduction

In science and engineering, we owe much of the knowledge we take for granted to a few original thinkers. Some of them are quite famous: Archimedes and his bath; Galileo; Newton, who gave us gravity and the laws of force and motion; Euler who solved the problem of classic strut buckling; Rankine who gave us earth pressure theory and also thermodynamics; and Coulomb who gave us another earth pressure theory and also the unit of electric charge. But who was the 'Young' of 'Young's Modulus'? Was he a noted engineer in days gone by, or was he an obscure loner who made the study of elasticity his life's work? Who was he and what else did he do with his life?

Before answering these questions, a little quiz is in order. Look at the pictures on this page: what do they have in common?

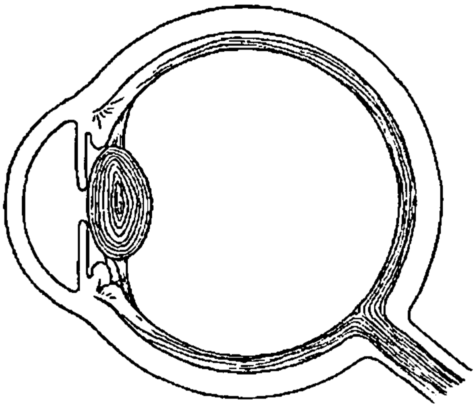

Fig. 1

Fig 2

Fig. 3

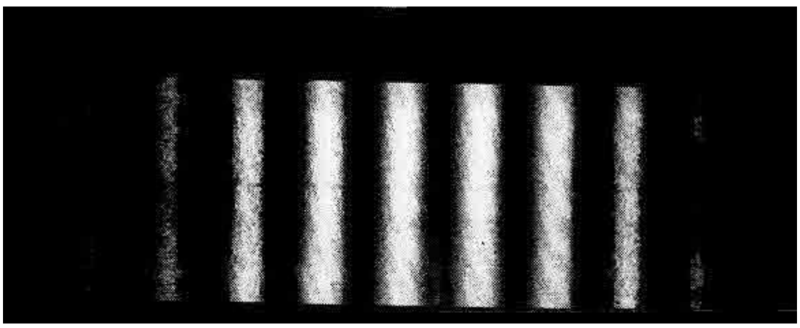

Fig. 4

The first (Fig. 1) is that wonderfully complex organ, the human eye. The fundamental principles of how it focuses light and perceives colours were first worked out by a man called Young.

The second (Fig. 2) is the Rosetta Stone: an engraved stone from Egypt, dated to 196 BC. It caused a sensation when it was discovered in 1799, because it appeared to have a message inscribed on it in three languages: the bottom section in Greek, the middle in an old Egyptian script and the top part in ancient Egyptian hieroglyphs. The Rosetta Stone was seen as the key which would allow scholars to crack the code of the hieroglyphs and read the hieroglyphic inscriptions that had been found on monuments around the country. The code was eventually broken and the first hieroglyphics were translated by a man named Young.

The third (Fig. 3) is a drop of water, which is held together by surface tension. The equation for this was worked out and its value first calculated by a man called Young.

The fourth (Fig. 4) is the interference pattern created when light passes through two closely-spaced slits. This classic experiment proved that light is a form of wave energy, not a stream of particles. Physicists call the pattern 'Young's Fringes' and refer to it as 'Young's Experiment', after the man who devised it.

So all these things are associated with people by the name of 'Young'.

What is not so well known is that all these 'Youngs' were actually the same man and he is also the 'Young' of 'Young's Modulus'. Amazingly, although he is almost forgotten today, the above examples represent only a fraction of his total contribution to human knowledge.

In addition to the aspects of his work on vision, light, Egypt and engineering which will be discussed later, he did many things that can be mentioned only in passing: he investigated sound waves and harmonics; he made the first calculated estimate of the size of a molecule, 50 years before anyone else; he invented the mechanism used in recording barometers (Fig. 5) and made a major contribution to the theory of tides; he was responsible for an Admiralty report which transformed the design of wooden warships; linguists remember him as the man who introduced the term 'Indo-European' to show that the languages from India to Ireland share a common root. In his day, he was known as 'The English Leonardo'.

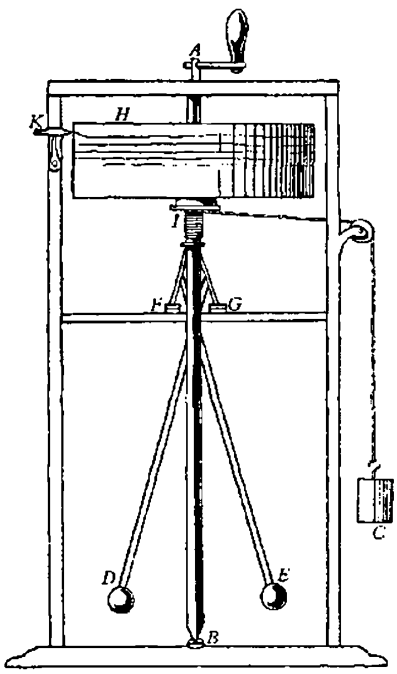

Fig. 10. Forerunner of Recording Barometer

Fig 5. Forerunner of recording barometer

I was actually introduced to Young not through engineering but by Daniel Kline, Professor of Physiology at Cincinnati University, who came across his work when studying Egyptology. Kline went on to write a short biography [1]. Kline recommends the detailed biography by Wood & Oldham [2] and this is the source for most of the material presented here. Young cropped up again in a paper by Chapman & Buliagiar [3] about the buckling of cold formed steel beams in the August 1993 issue of the ICE *Proceedings,* which included an interesting summary of Young's contribution to structural engineering. This paper recommends the account of Young's contributions to structural engineering given by Timoshenko [4] and I have also referred to this.

So who was 'Young'?

Fig 6.

The name of this remarkable man was Thomas Young (Fig. 6) and his career was actually in medicine, as a doctor in general practice. Of his medical work, it was said that:

'He is ... not celebrated as a medical practitioner; nor did he ever enjoy an extensive practice; but in information upon the subjects of his profession, in depth of research into the history of diseases and the opinions of all who have preceded him it would be difficult to find his equal' [5].

Thomas Young was a Quaker, who was born in Somerset in 1773 and died in London in 1829. He had an extraordinary intelligence, which was noted at a very early age: he could read 'with considerable fluency' [6] at the age of 2 (yes, 2!) and had read the Bible twice through before he was 4 years old. He began learning Latin when he was five. By the time he was 13 he had also learnt Greek, Hebrew, Italian, and French and was learning Chaldee, Syriac, and Samaritan and he had also developed an interest in optics and telescope making. In the years that followed, he studied more languages, read French, Italian and English classics, mathematics, astronomy, natural philosophy, botany, chemistry, and medicine.

At the age of 20, Young presented a paper to the Royal Society on how the eye focuses, and he was elected a Fellow of the Society the following year. He was Professor of Physics at the Royal Institution from 1800 to 1803 and in 1802 he gave a series of 31 lectures there, expanded to 60 the following year. These were published in 1807. The lectures were remarkable not only for their breadth but also for their depth of coverage: in many of the subjects (including engineering) Young introduced major advances in knowledge. The first 20 lectures dealt with 'mechanics' and covered what would be expected plus also lectures on drawing, writing, and measuring, as well as architecture and carpentry. The second set of 20 dealt with 'hydrodynamics' and covered the physical properties of liquids and gases, discussion of reservoirs, canals, piers and harbours, the theory of the sailing boat, water pump and air pump, in addition to acoustics and optics. The third set of 20 covered astronomy, gravitation, tides, cohesion, heat, electricity, climate and wind, vegetation, and animal life.

According to a 1934 article in *Nature*, 'The greatest and most original of all general lecture courses was Young's *Lectures of Natural Philosophy and the Mechanical Arts*' [7].

Between 1817 and 1825, a number of supplements to the fourth edition of *Encyclopaedia Britannica* were published and Young was a major contributor to these. He covered annuities, bathing, bridge, carpentry, chromatics, cohesion, double refraction, Egypt, fluents (integrals), Herculaneum, hydraulics and tides, languages, life preservers, roadmaking, steam engine, weights and measures, as well as 45 biographies of leading scholars, with bibliographies of their work. He was asked to do articles on 'blasting and boring' and 'mining and stone cutting' but turned these down as he felt that he did not know enough about them.

As well as his work as a doctor and all this theoretical work and writing, he worked on the theory of mortality tables for life assurance and was employed by what is now Eagle Star insurance company as inspector of Calculations. He also found time to serve as Editor of *Nautical* Almanac, Secretary of the Board of Longitude, and Secretary of the Parliamentary Commission which defined British standards of measurement.

To cover all Thomas Young's attainments properly would take far more than this short paper, so I have selected some of the more interesting examples, which give insights into his approach and methods. (It should be mentioned that, although referred to only occasionally in biographies, Young's wife Eliza was clearly a highly intelligent person in her own right and took a close interest in his work.)

Wave theory of light

Young's work on light is one of the few achievements for which he received proper recognition. He worked out the basic theory and devised the key experiment that proved that Newton's corpuscular theory of light was wrong and that light is, in fact, a form of wave energy. The 'Young's Slits' experiment requires precision and care to carry out, but it is wonderfully simple and decisive (see Fig 7). If light is a stream of particles, there should be just two bright lines, one in line with each slit. However, instead of two bright bands, when light passes through 'Young's Slits', a pattern of light and dark bands is seen: proof that waves are spreading out from the two slits and interfering with each other as they cross. Not only did this experiment prove Young's wave theory of light but he also noticed that the spacing of the fringes varied with the colour of the light: he therefore used this to calculate (correctly) the actual wavelengths of light of different colours and correctly inferred that the radiation continued to higher and lower wavelengths in the infrared and ultraviolet ranges.

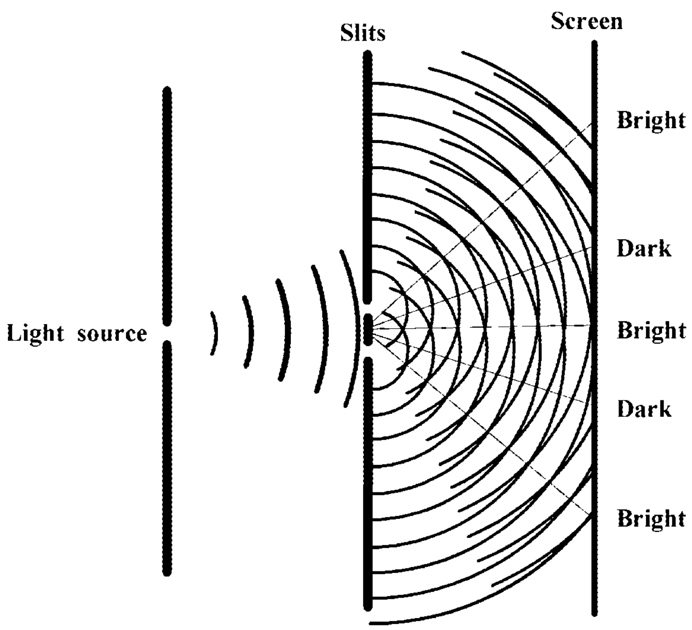

Fig 7. interference: Young's double-slit method

His interest in wave behaviour led him also to invent the ripple tank, still used today to analyse and illustrate wave behaviour. Fig 8 shows his design:

'An apparatus for observing the motions of waves excited, in a fluid poured into the trough AB, by the vibrations of the elastic wire C, loaded with the movable weight D; the shadow of the waves being thrown on a screen E and by the lamp F, through the bottom of the trough, which is of glass'.

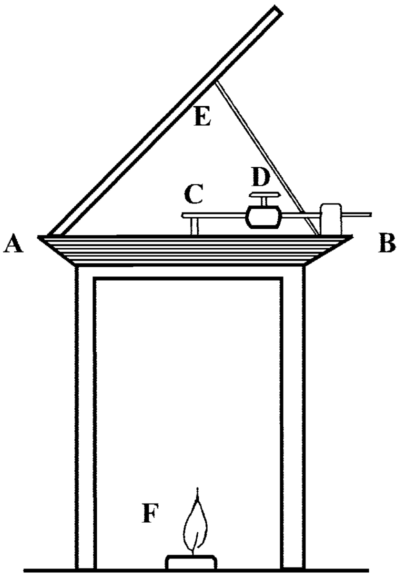

Fig. 8 Ripple Tank

It is a simple, classic piece of engineering which seems as right for its purpose today as when it was invented.

The eye

Young's paper 'The mechanism of the eye', presented to the Royal Society in 1800, is one of his most notable achievements, laying the foundations for most of what we know about the operation of the eye (Fig. 9). In his researches for it, he devised a new form of optometer, which measures the focusing of the eye; he carried out direct measurements on the dimensions of his own eyeballs (which must have been very difficult and uncomfortable); and, along the way, he discovered astigmatism, which gives different focus to horizontal and vertical lines.

Young also established conclusively for the first time how the eye focuses. His experiment on its focusing gives an interesting insight into his methods. At the time, there was dispute about whether the eye focused by changing the curvature of the cornea or by changing the shape of the crystalline lens. How could these two effects be distinguished, as both are lenses and both refract the light? Young reasoned that, if the eye was immersed in water, its cornea would then have water on both sides of it, which would neutralise its contribution. He found that, if he immersed his eye in water, he could not focus sharply, which is why we do not see very well underwater. However, he then tried holding a lens equal in power to the cornea in the water in front of his eye and found that he could once again focus accurately on objects, even though the water was stopping his cornea having any effect on the light. In this way he proved that it must be the crystalline lens that does the focusing.

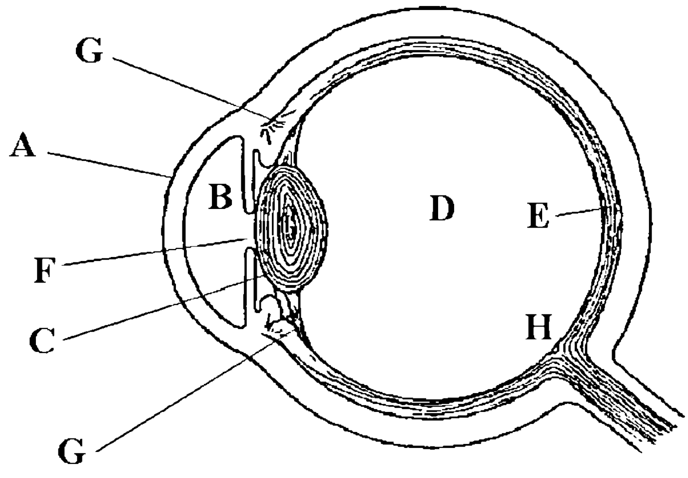

Fig. 9 The eye

A is the outer transparent cover, the *cornea*
B is a space filled with a fluid called the *aqueous humour*
C is the *crystalline lens,* an elastic, jelly-like body
D is a space filled with another fluid, the *vitreous humour*
E is the sensitive coating of the inside of the eye, the *retina*
F is the *pupil,* an adjustable diaphragm which regulates the amount of light entering the system
G are the *ciliary muscles* which adjust the power of the lens, but whose function was unknown to Young
H is the blindspot where the optic nerve enters the retina

In 1801, he presented 'On the Theory of Light and Colours'. This established the basis of the modern understanding of colours and colour vision, where all colours are based on the three primary colours of red, green, and blue:

'Now, as it is almost impossible to conceive each sensitive point of the retina to contain an infinite number of particles, each capable of vibrating in perfect unison with every possible undulation, it becomes necessary to suppose the number limited, for instance, to the three principal colours ... and each sensitive filament of the nerve may consist of three portions, one for each principal colour.' [8]

Young's proposal is based essentially on considerations of engineering simplicity. His theory not only explains colour and its perception, it also provided an obvious explanation for the mystery of colour blindness: if one set of nerves is paralysed or absent, only two of the three primary colours can be recognised. Many years later, the great James Clerk Maxwell wrote:

'It seems almost a truism to say that colour is a sensation; and yet Young, by honestly recognising this elementary truth, established the first consistent theory of colour. So far as I know, Thomas Young was the first who, starting from the well-known fact that there are three primary colours, sought for the explanation of this fact, not in the nature of light, but in the constitution of man.' [9]

In fact, Newton thought there were seven primary colours and it was Young who proposed reducing this to three.

Young's theory of colours was not widely noticed at the time and it was only when Helmholtz rediscovered it, nearly 50 years later, that it gained general currency.

Eriometer/size of blood corpuscle

When a point source of light is viewed through a cloud of small drops or particles, coloured rings are seen around it and the radius of these varies inversely with the average size of the particles. Young took advantage of this effect to make an ingenious instrument called the eriometer, which he used to measure the size of very small particles.

The eriometer effectively measures the angle to these rings formed by light shone through a sample. The measured angle can then be compared with the angle generated by a sample of known size. This allows the size of the particles to be calculated. Its operation is illustrated in Fig 10. Using it, Young measured the size of blood corpuscles as 0.000278in, or 7.1μm. This was the first time this had ever been measured and his figure compares with the modern textbook value of 7.8μm.

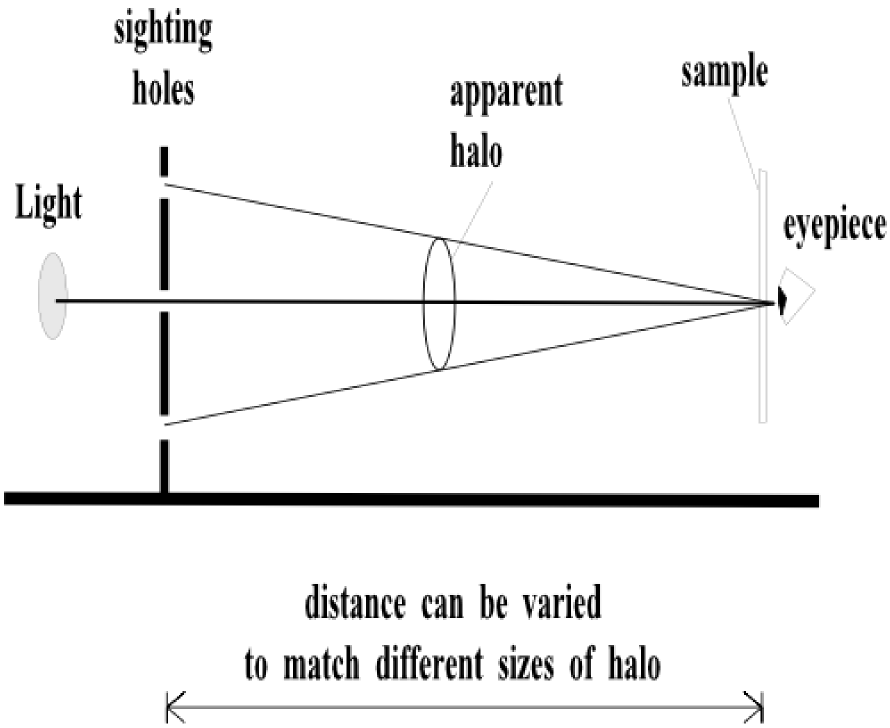

Fig. 10 Eriometer

Hydraulics

In 1808, Young presented a paper entitled 'Hydraulic investigations' to the Royal Society, which included a new formula for the flow of fluids in pipes, the resistance to flow caused by bends and the propagation of an impulse through an elastic tube. He had investigated these things in preparation for his paper 'On the functions of hearts and arteries' later that year. The prevailing view of the time was that contraction of the walls of arteries was an important cause of the circulation of blood in the human body but Young's paper conclusively disproved this idea, opening the way for the correct solution.

Egypt

The Rosetta Stone was discovered in 1799 and its Greek section translated by 1802. However, after that, progress was slow: by 1814, scholars had made out only a few words of the ancient Egyptian demotic script and they had made no progress at all on the hieroglyphs. Young became interested and set to work on it in the summer of 1814.

He decided to attack the demotic script first and his account of his method is interesting. He noticed that the Greek section had two references to Alexander and Alexandria, so he first looked in the demotic script for two well-marked groups of characters resembling each other. Then he looked for a small group of characters that occurred in almost every line, which he thought would probably signify 'and'. He then noticed a group of characters in the demotic script which appeared about 30 times and reasoned that this must correspond to the only equally common word in the Greek, which was 'king'. By a similar process, he identified 'Ptolemy'. He then wrote out the lines of the two texts side by side, used the words he had identified as markers to divide up the text and compared the words in between.

Young's approach was simple, practical, and effective. By October 1814 he had translated more of the demotic script than anybody else and he was starting to look at the hieroglyphic section. He noticed strong resemblances between some of the hieroglyphs and some of the demotic characters and deduced that the demotic script must have been derived originally from the hieroglyphic. He worked out that some of the hieroglyphic signs represented objects but that others might be used alphabetically to represent sounds, and proceeded to identify and decode the name 'Ptolemy'. He then proceeded to identify other names and used these to help him deduce the meaning of symbols and work out more of the principles on which the script was based. He wrote up his findings in 1818 and they were published in his article 'Egypt' in *Encyclopaedia Britannica* in 1819. There he showed that he had discovered the principles of the script and its numerical notation, correctly identified many names and provided a hieroglyphic vocabulary of 218 words. He had cracked the code and opened the way for others to work out the complete language. In later years, Budge [11] described Young's article as 'practically, the foundation of the science of Egyptology'.

Often the credit for decoding Egyptian hieroglyphs is given to the French scholar Champollion, who prepared the first comprehensive hieroglyphic dictionary. However, Champollion made no progress at all until he met Young in 1822, 4 years after Young's original article was written. All his important published work appears to have been done after that date. In later years, Young concentrated his attention on the Egyptian demotic script, and he was completing the first dictionary for this at the time of his death.

Engineering

The preface to the first set of Young's Royal Institution lectures announced that the 'passive strength' (by which he meant elasticity) of materials of all kinds has been very fully investigated, and many new conclusions formed respecting it, which are of immediate importance to the architect and to the engineer'.

This is where Young's Modulus makes its first appearance:

'We may express the elasticity of any substance which may be denominated the modulus of its elasticity, and of which the weight is such that any addition to it would increase it in the same proportion as the weight added would shorten, by its pressure, a portion of the substance of equal diameter' (p. 137). [12]

Young showed that this modulus applied both to compression and to extension of rods and also extended its application to liquids. He also drew attention to the fact that Hooke's Law holds up only to the elastic limit, after which plastic deformation takes place. What is interesting is that Young's definition of the elastic modulus is not quite the same as the one we use today: our modern definition came from Navier in 1826.

Young's lectures also give the first correct calculation of the stress distribution in an eccentrically loaded bar. He worked out the neutral axis position and discovered the 'middle third' rule.

The Swiss mathematician Euler had derived the formula for the buckling load of a perfectly straight strut: $P = \pi^2 EI/L^2$). However, Young drew attention to the effect initial imperfections could have on column strength and also noted that, in stocky columns, failure will be by crushing rather than buckling.

He proceeded to work out the formula for the deflection of an imperfect or eccentrically loaded strut:

$\delta = \delta_0/(1-(PL^2/EI\pi^2))$ where

δ is the total deflection
δ_0 is the initial load eccentricity
P is the vertical load
L is the length
E is the elastic modulus
I is the moment of inertia

(see Fig. 11)

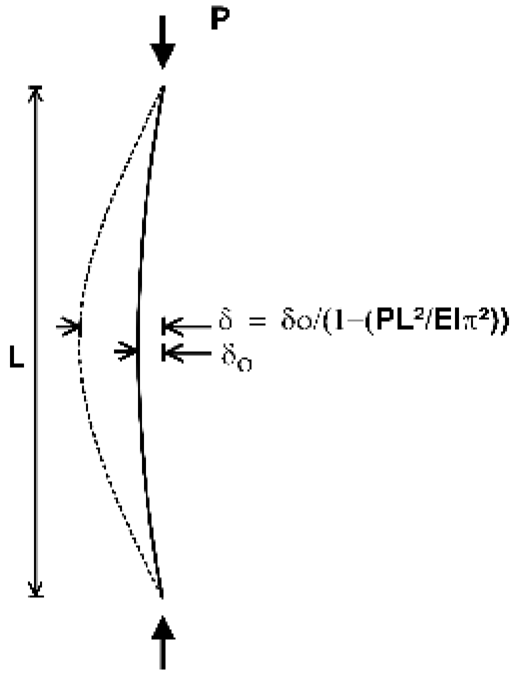

Fig. 11 Formula for the deflection of an imperfect or eccentrically loaded strut

Young's buckling equation was the basis of the Perry equation adopted for steel column design in the steelwork design Code BS449. In 1993, Chapman & Buhagiar [13] applied Young's equation to torsional buckling, showing that it can be used to give results that match the most advanced finite element analysis available (see Fig. 12). They claim that it has great potential, opening the way for a systematic comparative study of torsional buckling. They say:

'The equation was a drop in the ocean of Young's contributions to science, medicine, engineering and philology, but it was seminal to the design of compression members'.

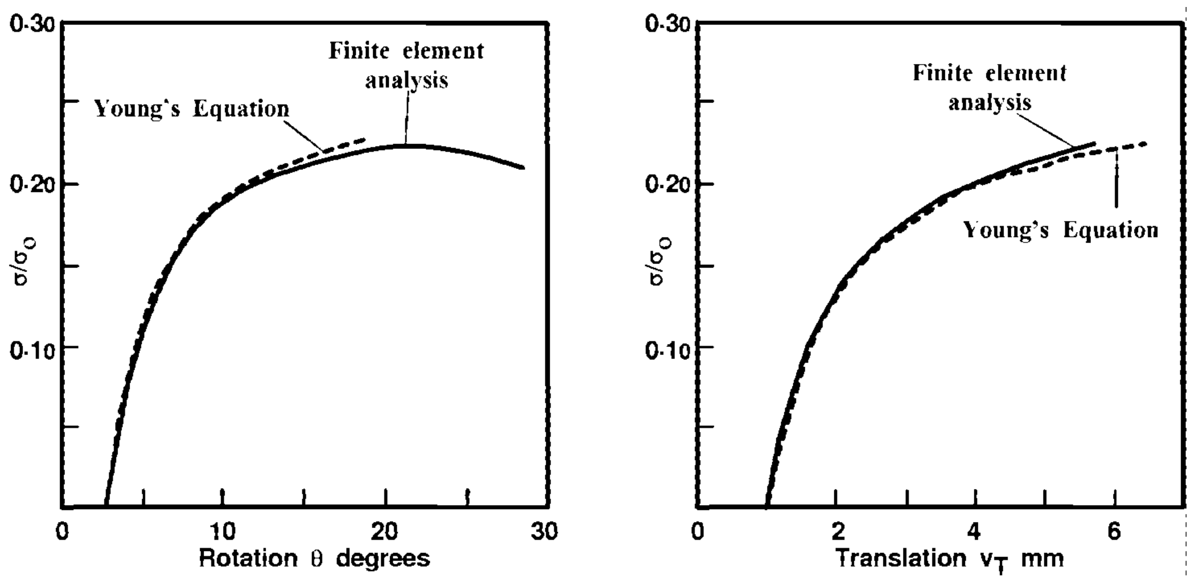

Fig. 12 Application of Young's equation to torsional buckling (after Chapman & Buhagiar Fig. 17)

The published version of Young's lectures also presents a full analysis of the stresses and deflections associated with torsion, for both solid bars and thin-walled tubes.

Another important concept that made its first appearance in Young's lectures is kinetic energy:

'... the term energy, which indicates the tendency of a body to ascend or to penetrate to a certain distance in opposition to a retarding force.' [14]

Young went on to make various calculations assessing its consequences, including the fracture of beams under impact loads and he calculated the velocity of the compression wave that travels through a material following an impact.

In his later work for *Encyclopaedia Britannica,* Young prepared a major article 'Bridge' on bridge design, which included analysis of the statics of arches. This showed for the first time that, if the loading is uniform, the arch should be parabolic and, if the arch is circular, the load distribution must follow a cubic curve. His article 'Carpentry' included his previous work on elasticity and buckling theory and also recommendations 'which relate to the form and direction of the abutments of rafters; a subject which seems to have been very incorrectly treated by former writers on carpentry' [15].

Review

In the space of this short paper, we can only scratch the surface of Thomas Young's life and his contributions to human knowledge. The man who gave us 'Young's Modulus' turns out to have been not some obscure engineer but one of the most outstanding and productive intellects the world has ever seen: greater than Einstein, greater than Hawking, possibly greater even than Newton. However, this leaves a mystery: how has this extraordinary man become almost completely forgotten, leaving his name on only a few experiments and equations?

One factor may be that his work was often published anonymously or under pseudonyms: he had his medical practice to maintain and he feared that, if his name appeared too much in print, his patients might think he was not giving enough attention to them and take their custom elsewhere. However, many of his contributions were so important that the identity of their author was widely known in the relevant circles (both here and on the Continent). In any case, by the time he died he had allowed his work to be publicly identified. Some of his obscurity can be ascribed to professional and academic rivalries: Champollion, for example, went to great lengths to try to claim for himself all the credit for translating Egyptian hieroglyphs, denying the importance of Young's work.

People who spread their talents so widely can also be frustrating to more specialist workers: e. g. Peyron wrote to Young, pleading for him to do more on Egyptian matters:

'... you have the power to surpass not only myself but all the philologists of Europe, so that there is universal regret that your versatility is so widely engaged in the sciences [of] medicine, astronomy, analysis, etc., etc., that you are unable to press on with your discoveries and bring them to that pitch of perfection which we have the right to expect from a man of your conspicuous talents; for you are constantly being drawn from one science to another, you have to turn your attention from mathematics to Greek philosophy and from that to medicine, etc. ...'

There were other problems, too. A man who knew Young well when he was a student at Cambridge said:

'He never obtruded his various learning in conversation; but if appealed to on the most difficult subject, he answered in a quick, flippant, decisive way, as if he was speaking of the most easy; and in this mode of talking he differed from all the clever men that I ever saw. His reply never seemed to cost him an effort, and he did not appear to think there was any credit in being able to make it. He did not assert any superiority, or seem to suppose that he possessed it; but spoke as if he took it for granted that we all understood the matter as well as he did ... His language was correct, his utterance rapid, and his sentences, though without any affectation, never left unfinished. But his words were not those in familiar use, and the arrangement of his ideas seldom the same as those he conversed with. He was, therefore, worse calculated than any man I ever knew for the communication of knowledge...' [17]

According to Salmon:

'The credit for first giving the analysis for eccentrically loaded and initially curved columns is due to Young, and had he been gifted with the power of lucid expression, succeeding generations might have been saved much mathematical disputation.' [18]

People who make their whole career out of one area of work are more likely to be remembered and honoured than someone who ranges across the whole of knowledge, and often recognition has gone instead to those who followed on from Young, taking advantage of the breakthroughs he had made. Indeed, this is not altogether unfair, as Tscherning remarked:

'If you take Young as the first man in the theory of light, the name of the second man is Fresnel; in the question of the anomalies of refraction of the human eye, the name of the second man is Donders; in the question of colour sense, you can call the second man Clerk Maxwell or Helmholtz; in the question of hieroglyphics the name of the second man is Champollion; in the question of terrestrial radiant heat the name of the second man is Wells and I have not yet finished the list. For his own reputation it would certainly have been better if Young had completely developed but one of his ideas. But for the advancement of science it was better that he did as he did.' [19]

Perhaps the simplest explanation of Young's obscurity was given by Helmholtz, who rediscovered Young's work on light and colour and is noted for his own work in this area:

'This solution was found and published by Thomas Young, who first showed the right method of arriving at the interpretations of Egyptian hieroglyphics. He was one of the most acute men who ever lived, but had the misfortune to be too far in advance of his contemporaries.' [20]

So that is who invented Young's Modulus. Most engineers will remember being taught about Young's Modulus and Young's Fringes in their student days, but how many of them know that both of these 'Youngs' were the same man or that he was one of the most outstanding geniuses of recorded history?

Maybe we engineers cannot really claim him as one of our own, a great engineer to enrol in the hall of fame alongside Telford, Stephenson, Rankine, Freyssinet, and so on: after all, he was just a medical doctor who dabbled in engineering in his spare time. However, there is something of the engineer in Young's direct and simple approach to attacking and solving problems and there is inspiration in his affirmation that science does not belong only to narrow specialists. Even if we cannot match his intellectual powers, we can share his open mindedness and broad interest in the world about us. Of all the people whom engineers might have chosen to commemorate in the name of a fundamental term used every day, we could hardly have made a better choice.

Our old friend 'Young's Modulus' turns out to have rather a distinguished pedigree, and for engineers it provides a living link between our everyday work and a forgotten giant of science.

Acknowledgements

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