B2 Engineering Ethics (4 lectures)

Syllabus

Introduction to ethics. Professionalism, public trust and engineering codes of ethics. Potential ethical dilemmas: engineering decision-taking and problem solving techniques. Responsibilities: ethical and legal obligations, whistleblowing and barriers to ethical decision making. Engineering ethics case studies.

COURSE DETAILS

Current lecturer: Steve Sheard

Teaching modes: 4 Lectures in HT of Year 2. Tutorial work to be completed in long vacation between years 2 and 3, followed by a college based tutorial in MT term of Year 3.

RECOMMENDED BOOKS AND WEBSITES

1. Engineering Ethics, Third Edition, by Charles B. Fleddermann, Prentice Hall, 2008, ISBN: 0-13-230641-7
2. Ethics in Engineering, Fourth Edition, by Mike Martin and Roland Schinzinger, McGraw Hill, 2005, ISBN: 0-07-283115-4
3. Hold Paramount, The Engineer's Responsibility to Society, by Alastair Gunn and P. Aarne Vesilind, Thomson, 2003, ISBN: 0-534-39258-X
4. The Decision Makers: Ethics for Engineers, by Ross Dixon, Simon Robinson and James Armstrong, Thomas Telford Ltd, 1999, ISBN: 0-72-772598-X

5. Why Buildings Fall Down: How Structures Fail, by Matthys Levy, Mario Salvadori and Kevin Woest, Norton & Co., 1994, ISBN: 0-39-331152-X
6. http://ethics.tamu.edu/ (accessed 9th July 2009)
7. http://www.raeng.org.uk/policy/ethics/default.htm (accessed 9th July 2009)
8. http://www.nspe.org/Ethics/index.htm (accessed 16th July 2009)

Learning outcomes

To understand why engineering ethics is being taught. To become aware of the responsibilities, both societal and legal, of a professional engineer. To learn how to apply problem solving techniques to ethical dilemmas, how to utilise case studies to demonstrate ethical or unethical practice, and to see the need to include ethical principles in engineering projects. To determine when a conflict of interest might arise and when it's appropriate to act as a whistleblower. To be able to incorporate the above into an effective discussion.

Disclaimer

These notes have been prepared for educational purposes only and the facts relating to companies, persons and events referred to in the case studies and subsequent discussion may contain unintentional errors.

Chapter 1

This chapter aims to convince you that there is a need to study engineering ethics and the topic will have an impact on the decisions you take in the future as a professional, ideally as a Chartered Engineer. A few case studies in each chapter will be used to illustrate the need for ethical practice in engineering, starting with the Ford Pinto scandal (case study 1). This study illustrates how bad engineering, coupled with unethical decision making prolonged unacceptable risks to road users. Before introducing the study let’s first establish what engineering ethics is.

WHAT IS ENGINEERING ETHICS?

Engineering ethics is a subset of applied ethics which examines and sets standards for engineers' obligations to the public, their clients, employers, the environment and the profession. Ethical behaviour applies to all of us, but in particular to anyone regarded as a “professional” (i.e. a person with a special function in society – more about this later). If you intend to become a Chartered Engineer then you will be bound by a specific Code of Ethics as a condition for maintaining the Charter. Breach of this code may result in removal of Chartered status, being struck off as a professional or criminal prosecution resulting in fines or imprisonment. Consequently, it is now common for engineering degrees to include a course on ethics as part of their accreditation requirements. Indeed, in the US for example, taking courses on ethics is a prerequisite for obtaining a Professional Engineer licence (PE licence). This is a bit like having a licence to practice medicine, and in the US a structural engineer working for civil engineering contracts is required to maintain a PE licence in order to be employed on that job.

Historical context

There have been many very successful engineers throughout recent history; take Brunel for example. But there have been cases when poor engineering design has resulted in disaster. Take for example the original Tay Rail Bridge that spanned a 3 km section of the Firth of Tay in Scotland (between Dundee and the suburb of Wormit in Fife). The bridge was constructed of iron sections forming a lattice grid structure that was common in bridges of its day (and the Eiffel tower, as it happens). The engineer responsible for its design was a previously successful railway engineer called Thomas Bouch, who was knighted for his efforts on completion of the project. The work began in July of 1871, and the bridge was officially opened on 1st June 1878. It was reported to be the longest bridge in the world. Sadly it collapsed in December of the following year in a storm, killing 75 people who were crossing by train at the time. Investigations put the blame on Sir Thomas for the following reasons:

1. Excavations of the river bed had not been done competently. When laying foundations across the river to support the pillars for the bridge it was discovered that the river bed was deeper and softer than anticipated.
2. Sir Thomas redesigned the foundations, but made errors that were not spotted at the time.
3. To compensate for the construction delays Sir Thomas decided to reduce the number of pillars and lengthen the span between them.

This was not the first iron bridge to collapse due to design flaws and inappropriate use of iron as a construction material. If you are interested you can find a list of bridge disasters on the following Wikipedia site: http://en.wikipedia.org/wiki/List_of_bridge_disasters (accessed 10th July 2009).

Clearly there became a need to regulate engineering practice to ensure that engineers are held accountable for their work and to ensure that the public can have confidence in the structures they build. In the UK the Engineering Council now regulates the engineering profession and awards Charters to those that have reached an established level of proficiency. This process is effectively delegated to various institutions, for example:

1. The Institution of Civil Engineers, founded in 1818.
2. The Institution of Mechanical Engineers, founded in 1847.
3. The Institution of Engineering and Technology, founded in 1871 as the Society of Telegraph Engineers.
4. The American Society of Civil Engineers (ASCE), 1851.
5. The American Institute of Electrical Engineers (AIEE), 1884.

More recently these institutions have introduced a formal code relating to ethical practice as part of the conditions of maintaining professional status. The Royal Academy of Engineering (founded 1976) has a useful set of resources on its website and regularly organises conferences on ethics.

People have debated “ethical thinking” for thousands of years and huge volumes of books and articles have been published on this topic. Personal ethics is a complex subject and, some might argue, slightly different dependent on a person’s culture or religion. Maybe there are fundamental ethical principles that transcend these complexities? You might even feel that you can summarise your own unchallengeable principles of ethical behaviour. After all, if everyone behaves ethically then it’s good for society as a whole, even if it does mean restricting freedom of choice - agreed?

What is going to be different about this course compared to a general course on “Ethics and Philosophy” is that we will stick to issues that are relevant to engineering. We might illustrate our course objectives here with a simple but common example. Suppose you are an engineer working on a …

<u>Large hydro-electric dam</u>

In fact you might be the project manager responsible for making most of the decisions. The dam will improve the lives of many people and be better in terms of climate change compared to a coal burning power station. But the local environment will be devastated; the small population living in the immediate vicinity will be forcibly relocated with many of them losing their jobs and having no chance of re-employment; some wildlife will inevitably disappear. Put simply, is it justifiable to create a little human suffering if the larger community has overall benefit?

Machines of war

Similarly, as an engineer would you be happy to work on a project developing a weapon that has only one purpose, i.e. to kill as many people as possible? Surely, it's a matter of defence and it's OK provided we don't sell weapons to other nations. Or perhaps your view is very different. In fact the UK is a significant exporter of weaponry. Not surprisingly ethical decisions are complicated by the need to make money.

Returning to our agenda, the first case study follows, which shows how the Ford Motor Company attempts to unethically balance the profits associated with running a business against the impact of injury and loss of life.

CASE STUDY 1: FORD PINTO SCANDAL

For about a decade in the 1970s the Ford Motor Company produced a car called the Ford Pinto. It was primarily for the North American market, but it has much in common with the popular Mk 1 Ford Capri in the UK – in fact they had the same engine design. The Pinto was very successful in the US (selling several 2 million), and presumably made Ford a lot of money. A tragic accident occurred in 1978 when a Ford Pinto was hit from behind by another car. Although this accident in itself was not that serious the fuel tank suffered a leak, and the vapours ignited. The three teenage girls in the car were tragically killed. The case explains that the Ford Motor Company knew about a design flaw relating to the position of the fuel tank with respect to the rear axle. They understood this to be a serious safety issue, but decided to continue manufacturing the car and pay compensation to the victims or their families. They unethically used cost-benefit analysis to demonstrate this was the most profitable course of action.

The case

The car didn't have a strong rear bumper. The fuel tank was placed in close proximity to the rear axle, which was a simple solid axle construction with leaf spring suspension. (The arrangement was different to that used in the Ford Capri.)

There were 27 fatalities and many more burn injuries prompting claims that a rear impact around 30 mph caused the back-end of the car to crumple, forcing the fuel tank into the protruding Differential Housing (DH) that stuck out from the rear axle. The 4 bolts that secured the DH would rupture the fuel tank causing petrol to spill on to the road, sometimes filling the car with fumes. Occasionally, the fumes would ignite before the occupants could escape. (Martin and Schinzinger report that there could have been as many as 3000 unconfirmed fatalities.)

It is claimed that Ford had conducted their own safety tests both before mass production started and during. Allegedly, these tests confirmed the reports made by the accident investigators and witnesses, i.e. that impact at speeds over 25 mph resulted in a ruptured fuel tank. Ford considered a redesign that was simple; a plastic strap that fitted around the fuel tank at a cost of $11 (at the time). They carried out a cost-benefit analysis to determine whether or not to implement it. Basically, they compared the additional manufacturing costs associated with redesign (i.e. $11 per vehicle) against the estimated costs of lawsuits, compensations and damages associated with accidents in the event of no redesign. They came to the harsh business decision that it was cheaper to continue selling the Pinto without making any changes to the production and pay the lawsuits. They defended their decision further by saying that the US National Highway Traffic Safety Administration required them to carryout the cost-benefit analysis and that they were not breaking any law by implementing their findings.

Consequences

1. Ford was taken to the US courts on a product liability case; Grimshaw versus Ford Motor Company, 1981. The court ordered compensation payments to the Grimshaw family equivalent to $6 million, and Ford was fined the equivalent sum of $8.4 million.
2. Ford suffered considerably from the bad publicity, with their reputation for safety and regard for human life damaged.
3. A total of 27 confirmed deaths resulted because of the bad design, with many more people suffering permanent disability.

Who’s responsible

1. The original design engineers who made alterations to a safe fuel tank configuration without identifying potential risks.
2. The engineers at Ford who conducted the rear impact trials and failed to make public their results.
3. The management at Ford, who put profits before human welfare.

Discussion questions on ethical issues introduced by this case study

1. Should engineers get involved with ethical decisions? Surely, we are just paid to do a job and we have a responsibility to our boss to get the job done without making a fuss. If my company obtains the

legal approval to carry out the work, then that's good enough for me. Discuss.

2. Clearly there are risks involved in everything. For example, in the UK 3,300 people die every year in road traffic accidents (that's about 9 every day using 2009 figures). This doesn't stop us from driving, and we all accept the fact that a serious car accident might happen. Based on this argument do you think Ford were justified in using a cost-benefit analysis as part of their decision making process?
3. Ford got away with their actions by paying compensation and fines. This was probably covered by their insurance and clearly they had anticipated such payouts in their cost-benefit analysis. Do you think anyone from Ford should have gone to prison for their actions? Give reasons.
4. It could be argued that 27 deaths out of a total of several million vehicles sold is an acceptable level of incidents. How would this argument need to be justified?
5. Why was it unethical to use cost-benefit analysis to determine Ford's response to known safety issues? After all, don't we do the same (i.e. put our needs first) when deciding whether or not to purchase fair-trade coffee or donate to charities, for example?

<u>Further reading (WebPages accessed on 9th July 2009)</u>

1. Ford Pinto, Wikipedia entry.
2. Grimshaw vs. Ford Motor Company, see for example: http://online.ceb.com/calcases/CA3/119CA3d757.htm.
3. The Myth of the Ford Pinto Case, www.pointoflaw.com/articles/The_Myth_of_the_Ford_Pinto_Case.pdf.

End of Ford Pinto case study

The next study doesn’t include a disaster, in fact it prevents one. This is the case of a structural engineer who went public on a construction fault that might have cost him his job, respectability and career. In fact, he won much credit for speaking out and he has gained some notoriety in the form of a well read case study as an example of ethical behaviour.

CASE STUDY 2: CITIGROUP CENTER

How do you build a skyscraper with 59 floors on a site occupied by a church in New York City? Simple: You build the skyscraper on stilts, with the church beneath it. This had never been done before 1977, but it was an exciting challenge and would certainly become a tremendous tourist attraction. Both the client, the financial company Citibank Corporation (at the time), and the church goers were very happy. But, this building required very careful design in terms of its structural engineering as a freak wind, for example, can easily bring down a badly designed skyscraper. The finished building is shown in the graphic below.

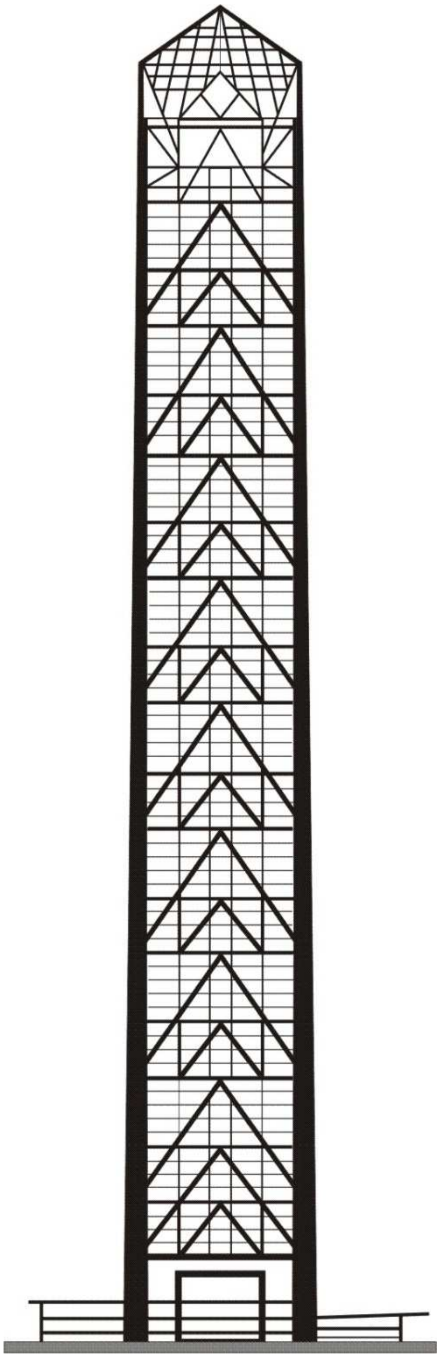
The Citygroup centre is located at 53rd Street between Lexington Avenue and Third Avenue in the middle of Manhattan. You can get an impression of its height from the photograph, and in fact it is the 5^{th} largest building in New York City. The building cost nearly \$200 million and was completed in 1977.

Sometime after the building was finished, the structural engineering responsible for the design discovered that the construction had been compromised to save costs. To avoid a disastrous collapse of the structure he went public on the errors made.

The case

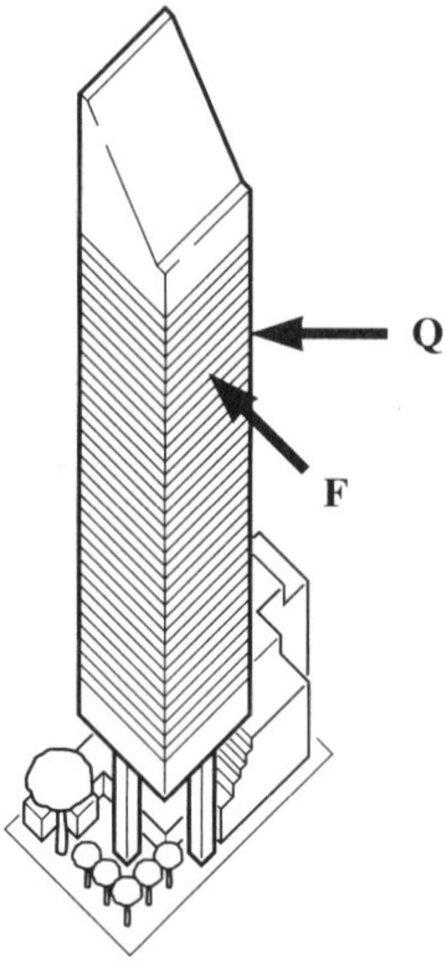
The building was unusual right from the start. Even in the 70’s it was decided to have a 45 degree sloping roof to allow solar panels to be fitted at some stage in the future. St Peter's Evangelical Lutheran Church (which had been on the site since 1905) was knocked down and rebuilt under one of the corners of the new building. The resulting cantilever design is shown below, where the pillars that support the skyscraper can be clearly identified.

The architect was Hugh Stubbins Jr., but architects are not engineers and they rely on a structural engineer to make their imaginative creations reality; in this case the blameworthy person was structural engineer William LeMessurier. He opted for an inverted chevron arrangement of steel girders (i.e. stacked load-bearing braces) in order to achieve the cantilever over the church. The chevrons directed the load towards the centre of the building, and then downwards. He added another novelty: the top of the building contains a mass damper to reduce the effect of wind sway. The inverted chevron configuration is shown in the next figure. It required welding of each of the individual braces together to achieve sufficient strength to cope with a once in a 200 year storm, for example.



In 1978 a Princeton University professor in mechanical engineering was trying to think of a new undergraduate project for an able student and by chance came across a copy of the "build plans" for the Citigroup Centre. [The build plans differ from the construction plans; they are progressively modified to show how the building as ACTUALLY constructed.] He gave these to the student as an exercise on how to carry out the structural engineering calculations to determine the dead (i.e. static) load and live (i.e. wind) loads. He was surprised when the student came to the conclusion that the building would collapse in a 113 km/hour wind (i.e. a once in 16 year storm). The professor, perhaps, suspected that the student got it wrong (as supervisors do); so he suggested the student contact LeMessurier and discuss it with the expert. At first LeMessurier dismissed the student's calculations too, but it played on his mind. So he did a bit of investigating, checking the build plans himself and speaking with the construction company that carried out the work.

To his horror he learned that the subcontractor providing the load bearing braces had concluded that it was too expensive to weld each of the girders together and had instead opted for the cheaper alternative which was to bolt them. None of the various inspectors, including the New York City regulators, had considered the impact this would have on the strength of the building. After repeating his calculations LeMessurier concluded that the student was wrong; although the building was much weaker it was just sufficient for all wind force loads required by the regulators. Had the student done something different? LeMessurier's calculation had not considered a wind force acting through the corner of the building and due to the angled roof this load would be of different magnitude depending on which corner the wind was directed. The calculation choices are shown below (taken from Martin and Schinzinger).



The diagram shows the church at the bottom left corner of the skyscraper. Forces F and Q represent frontal and quartering wind loads respectively. LeMessurier's calculations based on quartering wind forces did confirm the student's conclusions; in a fairly typical severe storm the building was at considerable risk of collapsing. What to do next? LeMessurier was responsible for the design, but clearly he was not responsible for the decision to bolt the girders together. However, he had not stressed enough the importance of welding these joints, nor had he monitored the construction process as it had occurred.

He could keep quiet; perhaps by some fluke the building was strong enough; perhaps the counter balance would save the building by reducing deflection in a strong wind. If he confessed to the error it could ruin his career and reputation, get him struck off as an engineer, ruin his family finances, he might never work again, etc. But if he did nothing people's lives would be at risk.

He decided to do the ethically correct thing and arranged a meeting with the building's owners, architects and city planners. Everyone was horrified but agreed that something had to be done immediately. The general public, for one reason or another, were not fully informed of the risk. There was a hurricane on its way, so work began quickly. Parts of the building were evacuated and the braces stripped back to bare surface. This exposed most of the bolted sections that had led to weakening the building. LeMessurier's new calculations showed that welding just some of these sections would restore the building's structure to almost the original specifications for all wind directions. This was indeed done at an additional cost of $12 million and the building is now safe. The regulating authorities fined LeMessurier an amount exactly equal to his professional insurance limit ($2 million), but in all other respects praised him for coming forward.

Consequences

1. The public trust professional engineers to do their job correctly and the regulators expect it. The authorities were correct to fine LeMessurier for his mistake.
2. The building is now safe, but the owners of the building ended up paying for the additional costs and inconvenience.

3. LeMessurier kept his professional engineer (PE) licence.
4. The student got a high mark for his project (just guessing).

Who's responsible

1. The architect is not responsible.
2. The contractor who proposed the change is not responsible.
3. The engineering supervisor who agreed the change was responsible, even though they probably thought they were going to be congratulated for saving costs.
4. The regulators clearly thought LeMessurier was responsible, but they treated him leniently.

Discussion questions on ethical issues introduced by this case study

1. Do you think that LeMessurier deserved to be fined? Was this done, do you think, to create the perception that the regulators had dealt with the issue strictly?
2. Suppose no one had discovered the construction error and the building had subsequently collapsed with fatalities. Following an inspection, who do you think would be found guilty and prosecuted? Surely the contractor that replaced the welded joints with bolts cannot be blamed?
3. LeMessurier was honest and owned up. Is honesty a necessary characteristic of a professional (e.g. engineer, medical doctor, lawyer, journalists, etc.)? Are there any circumstances when a professional should refuse to answer a question for fear of breach of honesty?
4. LeMessurier had worked out an evacuation plan in event of a major storm. In fact, a major storm was forecast at the time (hurricane

Ella) but fortunately it changed direction and missed New York City. But, surprisingly, there was no mass media broadcast of the dangers, no immediate evacuation of the skyscraper and neighbouring buildings. In fact the general public did not learn about the engineering error until 20 years later, when it was published in the New Yorker (1995). Do you think keeping the public in the dark like this was taking a justifiable risk? Why wait so long before publishing all the details?

5. In such case, what role should the media play in reporting construction errors? Consider that the issues relating to safety have not yet been properly resolved, and what will be the reactions of the building and local inhabitants.

Further reading (WebPages accessed on 9th July 2009)

1. Citigroup Center, Wikipedia entry.
2. Joe Morgenstern, The Fifty-Nine-Story Crisis, The New Yorker, 1995, pages 45–53.
3. http://www.pbs.org/wgbh/buildingbig/wonder/structure/citicorp.html

End of Citigroup Center case study

PROFESSIONALISM AND PUBLIC TRUST

Many books on engineering ethics will have a section dealing with professionalism and what it means. From the perspective of this course, it is expected that you understand that an engineering career is a "profession", in a similar manner to a doctor or a lawyer. This can be expanded to a typical list of attributes that help us recognise what it means to be a “professional”.

1. A profession requires work that can only be done if particular sophisticated skills have been mastered, and requires the professional to use judgement and exercise discretion.
2. Becoming a professional requires extensive long term education that goes beyond the practical training available for an apprenticeship, for example.
3. Professional standards are set and enforced by a special society or organization. Professionals must have membership of one of these societies in order to practice.
4. The general public recognises a profession because it does some good in society.

It is helpful to view Chartered Engineering status as being similar to that of a medical practitioner. For example, if a client wants you to build a bridge because you are a professional engineer, then there is trust that your design will not collapse. This is similar to going to the doctor and trusting that the medicine prescribed is likely to make you better. But why use a chartered engineer, when surely there are many examples of bridge structures that could be copied by someone with little training? One big difference is, of course, that you as a professional engineer will have been trained in mathematics to design the bridge cost-effectively, rather than using the old Brunel approach which often relied on obvious over-engineering. Basically, in Victorian days if it looked as though it was going to stand-up, then it possibly might! The general public will need to put trust in your competence if the job is going to be completed safely and at reasonable cost; this is quite a responsibility.

Accidents occur for a number of different reasons, but for the benefit of promoting discussion it is worth grouping these into three identifiable categories: engineering, systemic and procedural. An original design could be defective due to incompetence, the materials not up to standards, poor construction and negligence of details. These constitute engineering failures, and can lead to criminal prosecution. There can also be a failure of the system arising because the operators have made a mistake. We will call this a systemic failure, occurring when the complexity of a system is just too great and depends on many inter-related mechanisms. Systemic failures are typified by errors in the National Health Service and the air travel industry, for example. An insignificant error somewhere in the system might lead to a major accident. (In such cases, governments might believe that there is a tolerable level of accidents and removing these by spending more money not justifiable.) There are also failures that occur as a result of bad decision taking or improper use. Perhaps operators were not properly trained, didn't follow the rules or they took unnecessary risks. These are categorised as procedural errors, such as occurred in the terrible explosion at the Chernobyl nuclear reactor in 1986 in the Ukraine. Procedural failures shouldn't happen, but occur as a result of human nature rather than bad engineering.

The Chernobyl engineering and human disaster

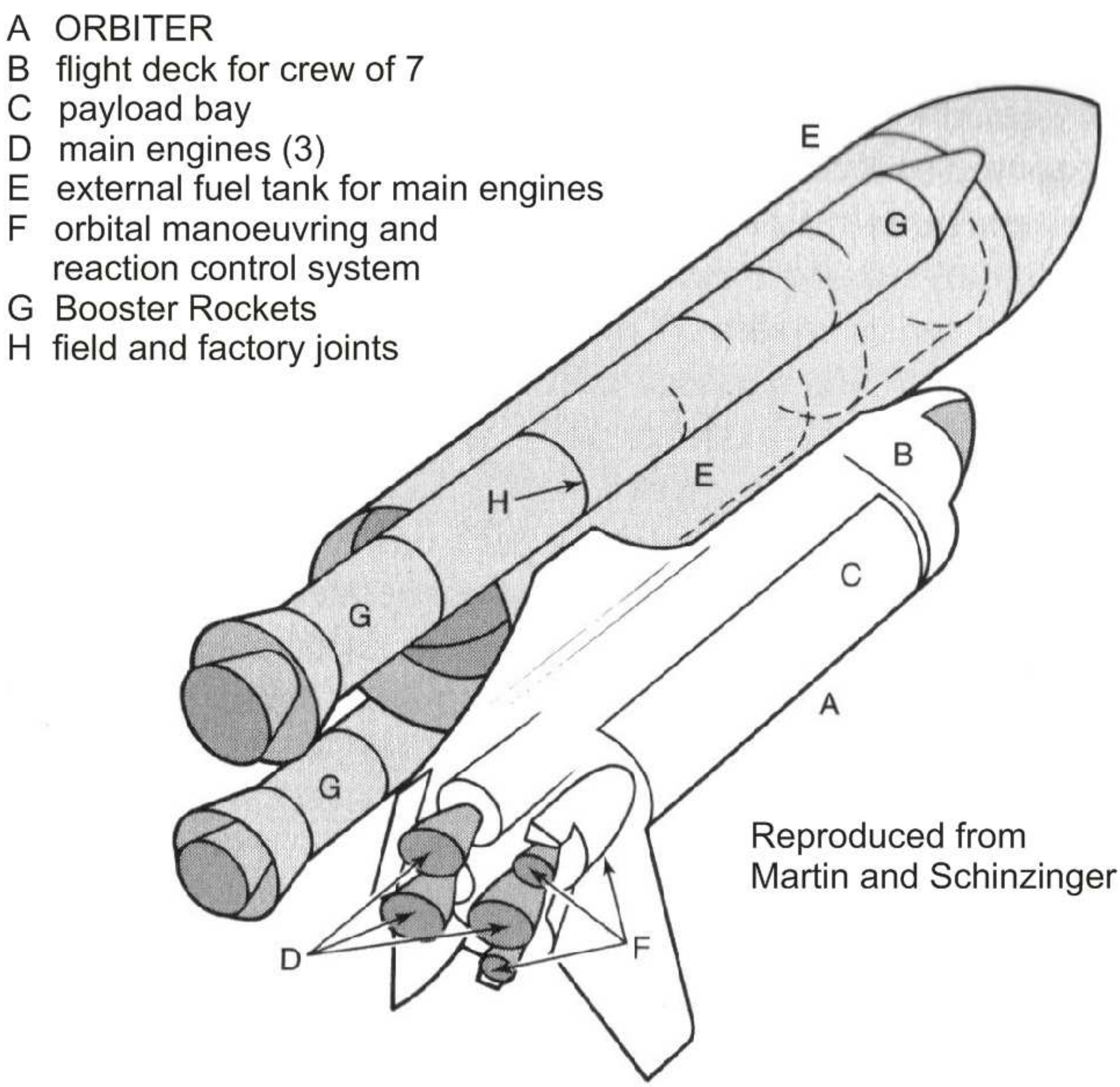
Engineers working on the Chernobyl nuclear reactor were carrying out a series of experiments to evaluate the range of parameters over which the reactor could operate and to collect data for research. However, the reactor had many in-built safety features that prevented the parameters from going beyond a certain range. This caused great frustration to those conducting the experiment. They were very confident that they understood their reactor and believed that it was inherently stable. So, wishing to proceed with the experiments, they disabled or bypassed the safety systems: including the ECCS (Emergency Core Cooling System), LAR (Local Automatic control system), and AZ (emergency power reduction system). What happened next has been a major human tragedy at a scale that is not fully understood even today. As they pushed the reactor beyond its design limit it went out of control and exploded, sending radioactive waste over a large geographical area. The total amount of radioactive fallout was 400 times that produced in the Hiroshima nuclear bomb.

CASE STUDY 3: THE SPACE SHUTTLE CHALLENGER DISASTER

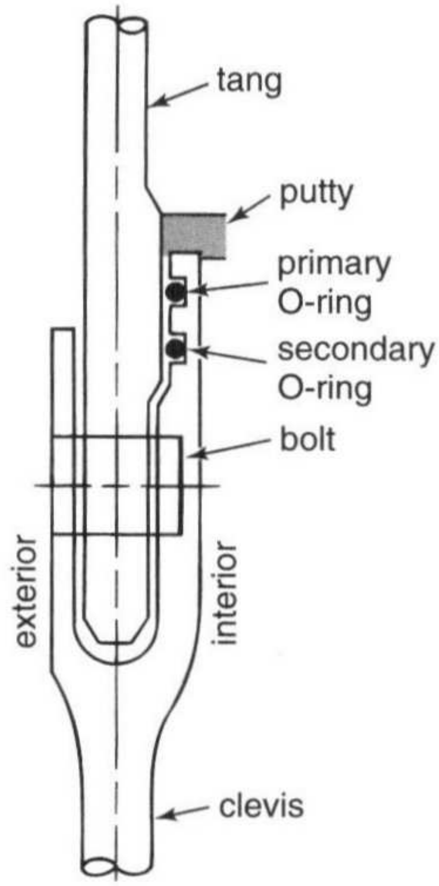
In 1986 the space shuttle Challenger exploded just after launch, killing all seven astronauts. The engineers at the company that designed the Solid Rocket Boosters (SRB), Morton-Thiokol, were partly responsible for this tragedy. Why? Because they did not have technical data proving that the rubber O-rings used in the SRB jointed sections would meet safety specifications below 12°C. Political pressure, combined with the worry of losing a lucrative government contract forced the engineers to make a decision on whether or not to launch when presented with the uncertainty created by insufficient test data. Famously, the engineering project leader who voted NOT to launch was asked by his manager to “take off his engineering hat and put on his management hat” when making the decision; he changed his vote. They decided to launch and 72 seconds later deeply regretted that decision. From this case study we will discover how unreasonable pressure can lead to poor decision making, or taking stupid risks.

The space shuttle is mostly re-usable and, on its maiden orbital flight in 1981 represented a new era in space travel. The shuttle is launched with detachable rockets, but glides back to Earth after each mission. There have been 125 successful missions so far (2009). The contract to supply the rockets was won by a company called Morton-Thiokol, with headquarters in Utah. Their proposal was for a design that had been used on the previously successful Titan missile that used solid fuel rather than liquid oxygen. Solid fuels are safer, but once they start to burn they can't be extinguished. Morton-Thiokol continues to supply these SRBs to NASA for the shuttle programme.

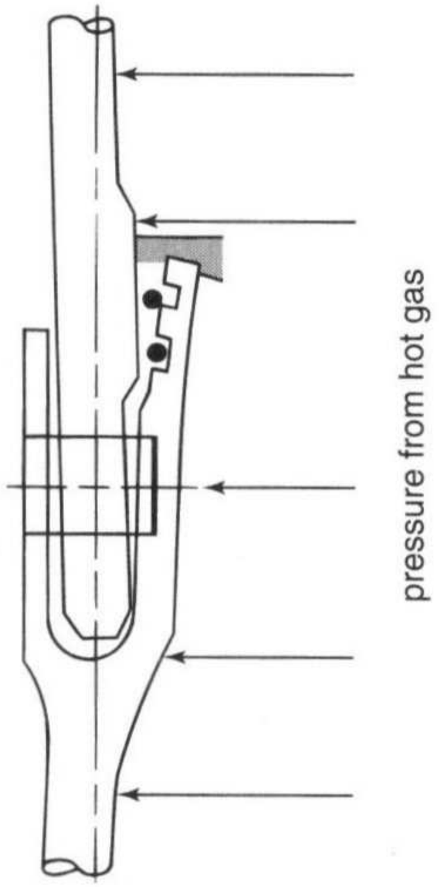
The space shuttle is an extremely complex project and consequently one small change in the construction might require a full review of the shuttle design. A statement I've heard in the past is that humans are not very good at dealing with more than 20 objects (or issues) at a time. So, with something so complicated it is necessary to break the project down into manageable chunks, with a project leader dealing with the whole system at the interconnecting level of the sub-divide. Engineers working on one small aspect of a complex project can develop a "silo mentality" that makes them less aware of the main project objectives. This will result in poor communication between the various companies involved in the project and the impact of design changes or problems don't get the attention they require. In October 1985 engineer Bob Ebeling working on the SRB project for Morton-Thiokol wrote a now infamous "Help!" memo to his senior management stating concerns that he had about the integrity of the O-ring seals for low temperature launches of the shuttle. He felt that he had been effectively cut-off from the decision making process between his parent company and NASA. Evidence from previous shuttle flights in 1981 and 1985 had shown mild failure of the O-rings and corrosion. Inspections of the spent boosters revealed black soot and grease ejected past the O-rings by gas escaping from the seal when in operation. This had prompted Morton-Thiokol to carry out tests of the O-ring performance at lower temperatures and they planned to make further modifications to the design. In order to understand what went wrong with the O-rings it is necessary to explore the design of the shuttle and booster rockets in some detail. Below, is a figure showing the entire shuttle system taken from the book by Martin and Schinzinger.



Only the shuttle itself escapes into orbit, the rocket sections are released when the fuel is spent, falling to ground for later recovery. The SRBs are labelled as G, and the "field joints" that failed are labelled H. The boosters are made in sections at Morton-Thiokol's plant in Utah and then transported to the Kennedy Space Center, Florida for assembly and loading with fuel. The joints are the same "tang and clevis" design used for the Titan rockets, which also used O-ring seals; but the shuttle's SRBs had two O-rings per joint as an extra safety measure. The engineering drawings are shown below, again reproducing a figure from the same book.



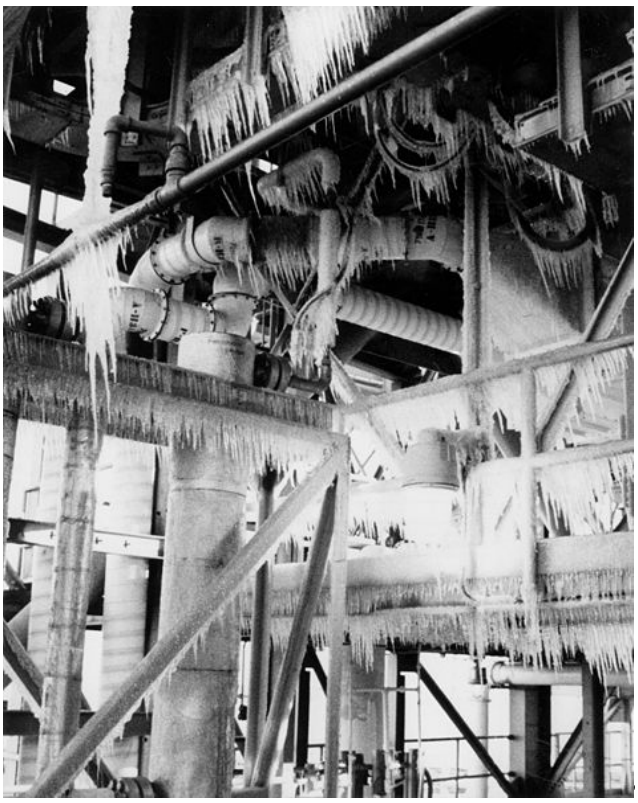
Field Joint
Before Ignition



Field Joint
After Ignition
(movement shown
is exaggerated)

On the left is the joint before the rocket has started to burn, i.e. when cold. The right drawing shows how the expansion forces acting on the SRBs push outward, increasing its diameter causing the tang to "rotate" inside the clevis. This is normal behaviour, as the soft O-rings should deform and expand as the joint rotates without allowing hot gasses to blow past. The putty is included to keep the joint clean and seamless. Clearly, if the O-rings fail the intense heat and pressure inside the solid fuel section of the SRB will rip the rocket sections apart. This is what the engineers were concerned about.

The Morton-Thiokol engineers knew that the elastic performance of the rubber used for the O-rings was very temperature dependent. As a simple test, if you stretch an elastic band over a box and put it in the freezer until frozen then take it out, you discover that it struggles to return to its original shape whilst cold. No doubt the rubber used for the O-rings had all the necessary qualities of durability, heat resistance, etc. but it would still be affected by the cold. Below is a photograph of the underside of the launch platform supporting the space shuttle Challenger on the morning of the launch before they scrapped off the ice. Unusually for Florida, it was -5 degrees centigrade.



Experiments were conducted on the O-rings building up to the scheduled launch date, to establish resilience under various conditions and temperatures; but there was more focus on temperature. Laboratory experiments don't best show how things operate in practice, so they looked very carefully at joint inspection data from the 24 previous shuttle flights. Twenty flights had been launched on days when the outside temperature had been higher than 18°C. Seventeen of these were considered normal, showing no sign of O-ring distress. Three launches had been on days at 14-17°C, and these had shown evidence of erosion or escape of hot gases. The last data point corresponded to the Space Shuttle Discovery (January 1985) which was launched at 12°C and this had produced 3 incidents of O-ring compromise. By the time the Challenger shuttle was launched later in the day the temperature sensor on the booster recorded -2°C.

Building up to the launch there had been many delays due to technical problems and the team at NASA were under considerable political pressure. Firstly, they were undergoing a funding review, and they knew that further funding was linked to the frequency of launches. Secondly, the launch pad would be required for another time critical mission to launch a probe to examine Halley's Comet (before a similar Russian mission). President Reagan had a keen interest to promote education through the space shuttle programme and one of the crew members, Christa McAuliffe, wasn't an astronaut at all but a school teacher. The President was intending to use this topic as part of his State of the Nation address scheduled for later that day. The NASA team at the Marshall Space Flight Center (MSFC) received the 12 hour weather forecast the night before the actual launch day.

Staff at MSFC remembered that Morton-Thiokol had issues over launch temperature, so they contacted them for advice on whether or not to launch. The three engineers involved with the SRB construction were Roger Boisjoly, Arnold Thompson and Robert Ebeling. Their bosses at Morton-Thiokol were Alan McDonald, Director of the Solid Rocket Motors Project, and Bob Lund, Engineering Vice President.

Apparently, a manager at Morton-Thiokol asked Robert Ebeling if it was safe to launch at temperatures as low as -7°C. It is reported that Ebeling replied with astonishment saying that they would be in "no man's land, we're in a big grey area"; the O-rings were only qualified down to +4°C. Senior staff and the three SRB engineers at Morton-Thiokol had a teleconference with the launch team at MSFC just 15 hours before the launch and Bob Lund recommended that the launch be delayed until the weather had warmed up. After presenting compelling data on the likelihood of catastrophic failure of the O-ring joints they had expected NASA to agree with their recommendation, but a NASA senior manager (Jud Lovingood) complained afterwards saying that "they couldn't make that recommendation; they had to give us a temperature that we could launch with". They were also accused of being "emotional" with the data and the NASA team pointed out that they didn't have any data taken at such low temperatures that categorically proved a failure was inevitable; their case was basically "pulled apart". NASA wanted a "go for launch" decision even though they knew that they couldn't launch unless Morton-Thiokol recommended it. A heated debate followed, demonstrating that NASA and Morton-Thiokol had different interpretations of the agreed SRB specifications on the figures for storage and operating temperatures. Larry Mulloy (MSFC's Solid Rocket Booster Project Manager who had argued about the validity of the data) decided to bypass Lund and asked a more senior manager at Morton-Thiokol, Joe Kilminster, to speak for the company. Kilminster put NASA and MSFC on hold in order to speak frankly with the engineers. Two independent conversations then ran in parallel. The launch team at MSFC agreed not to launch unless Morton-Thiokol recommended it. This was very significant, but Kilminster was unaware of that conversation. Instead the team at Morton-Thiokol appeared to be in conflict with management. Their conversation was characteristic of an engineering firm feeling intimidated by their more powerful client. The management agreed that the O-rings would suffer corrosion during the SRB burn stage, they recognised that this would compromise their performance but they disagreed with the engineers on the risk of catastrophic results; they believed the O-rings would hold for long enough and they were in favour of proceeding with the shuttle launch. A senior executive, Jerald Mason, stated boldly that a management decision was required. Mason turned to Lund, who had been stubbornly supporting his engineering team, and famously asked him "to take off his engineering hat and put on his management hat" and re-cast his vote. (After all, NASA was their most important customer.) When the teleconference resumed 30 minutes later, to the surprise of Lovingood and McDonald (who was with NASA management in Florida), Kilminster recommended launch. It is reported that MSFC did not ask why the engineers had changed their minds.

Boisjoly is reported to have said later in an interview when referring to that day "I went home, opened the door and didn't say a word to my wife. She asked me what was wrong and I told her oh nothing ..., we just had a meeting to go launch tomorrow and kill the astronauts, but outside of that it was a great day."

On 28th January at 11:38 am Space Shuttle Challenger was launched. It was so cold that the O-rings would not elastically change shape to take account of mechanical distortion at the field joints. At the point when the SRBs were ignited a plume of black smoke was seen to come out of the joints as hot gas blew-past the rubber O-rings and the sealing putty was visibly blown away. Internal debris blowing through the joint temporarily sealed the gap and saved the Challenger from exploding on the launch pad. (Ebeling and Boisjoly had originally feared that it would explode on the launch pad.)

As the shuttle progressed upwards the hot gases escaping from the joints burned through the external fuel tank and 72 seconds after launch the fuel tanks and boosters exploded projecting the crew compartment (crew cabin) away from the break-up. The cabin hit the ocean a few minutes later at over 200 mph.

Consequences

1. All seven Challenger crew members were killed in this accident.
2. After this tragedy SRB joints were redesigned and tighter regulations enforced. The solid rocket boosters are now considered one of the safest features of the shuttle. It took 3 years before another shuttle was launched.
3. NASA was originally accused of a cover up, but subsequently a period of diligent attention to safety and openness followed.
4. Investigations: (i) Rogers Commission and (ii) U.S. House Committee on Science and Technology. The committee (ii) agreed with the Rogers Commission (i) that it was an accident waiting to happen, and went further stating

“...the Committee feels that the underlying problem which led to the Challenger accident was not poor communication or underlying procedures as implied by the Rogers Commission conclusion. Rather, the fundamental problem was poor technical decision making over a period of several years by top NASA and contractor personnel, who failed to act decisively to solve the increasingly serious anomalies in the Solid Rocket Booster joints.”

5. Roger Boisjoly left his job at Morton-Thiokol and became a speaker on workplace ethics.

Who’s responsible

The protagonists in this case study are:

1. Larry Mulloy, at MSFC
   Role: In charge of the booster rocket development.
   Participation: Challenged the engineers’ decision not to launch.
2. Jud Lovingood, at MSFC
   Role: Senior Manager
   Participation: Launch team member, attended teleconference.
3. Alan McDonald, at Morton-Thiokol
   Role: Director of the Solid Rocket Motors Project
   Participation: He was with NASA management at the time of the launch. He unsuccessfully argued against the shuttle launch, supporting his engineers.
4. Bob Lund, at Morton-Thiokol
   Role: Engineering Vice President
   Participation: He had opposed the launch but changed his mind.
5. Joe Kilminster, at Morton-Thiokol
   Role: Engineer in a management position

Participation: Negotiated with MSFC during teleconference, reported final decision to MSFC.

7. Jerald Mason, at Morton-Thiokol
   Role: Senior executive
   Participation: Persuaded Lund to change his mind and vote for launch.
8. Engineering team working under McDonald at Morton-Thiokol
   Roger Boisjoly, Robert Ebeling, Arnold Thompson

Discussion questions on ethical issues introduced by this case study

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1. The three organisations involved can be ranked in terms of their authority: NASA, MSFC and Morton-Thiokol. Which is most blameworthy and why?
2. Do you think work place intimidation is rare or common? Is it ever necessary?
3. The engineers appear to have placed loyalty to their company above anything else. Is this true? Consider, for example, Roger Boisjoly. He may have been concerned about loosing his job and supporting his family.
4. Should any of the engineers have done something drastic outside of the workplace that would have stopped the launch; going public for example? As they didn’t, does that make them more responsible for the tragedy, or do you feel that they had done enough reporting their views to senior management?
5. In an engineering company should all managers have an engineering background? Would this have made any difference to the decision making process?
6. MSFC staff argued that the engineers failed to make a strong enough case and had bungled their presentation during the

teleconference. Are they justified in making this statement or are they simply trying to avoid blame?

7. What does this study demonstrate about group decision making as opposed to a single person considering all the facts?
8. Do you think that any professional responsibilities were neglected and could you argue that that the engineers failed in their implied contract to the general public relating to codes of ethical behaviour?

Further reading (WebPages accessed on 9th July 2009)

1. Space Shuttle Challenger disaster, Wikipedia entry.
2. http://www.nasaspaceflight.com/2007/01/remembering-the-mistakes-of-challenger/
3. Roger Boisjoly, Ethical Decisions - Morton Thiokol and the Space Shuttle Challenger Disaster: Telecon Meeting.
www.onlineethics.org/CMS/profpractice/ppessays/thiokolshuttle.aspx
4. Engineering Ethics: The Space Shuttle Challenger Disaster, Department of Philosophy and Department of Mechanical Engineering, Texas A&M University.
http://ethics.tamu.edu/ethics/shuttle/shuttle1.htm

End of Space Shuttle Challenger case study

ENGINEERING CODES OF ETHICS

We have already acknowledged that a professional engineer has a responsibility to the general public; a form of social contract. We can see from the Space Shuttle Challenger case study that the engineers also believed they had a loyalty to their employer. But perhaps you are more concerned about your legal obligations and how liability laws might affect your career as an engineer. After all, it was a product liability case against the Pinto that exposed the dealings of the Ford Motor Company. A useful framework for exploring how the engineering profession sees these obligations is to examine the various codes of practice published by its governing institutions and regulators. These are the bodies that will issue you with Chartered status (or PE licence in the US) once you are deemed sufficiently experienced.

All the professional institutions will have a published code of practice, or ethical code; a few also include a specific entry on sustainability and environmental ethics. These are not simply statements of the legal requirements in order to practice engineering, nor are they guidelines on how NOT to get caught out. They should be seen as a starting point for making ethical decisions and for defining as coherently as possible the roles and responsibilities of the engineers that are required to uphold the code. In some cases, strict adherence to the code might offer protection against subsequent litigation; the Citigroup Center case study might be a good example of this. Remember, other professions have their actions regulated by codes of practice: such as the guaranteed patient-counsellor confidentiality, a lawyer's commitment to represent his or her client even if suspected of being guilty and the Hippocratic Oath beholden by doctors to do their patients no harm. Similarly the central theme of the engineering codes of ethics is the safety of the public, and then their rights. For example the American Society of Civil Engineers (ASCE) has as its first cannon the following: “Engineers shall hold paramount the safety, health and welfare of the public and shall strive to comply with the principles of sustainable development in the performance of their professional duties.”

In the UK we might employ the following statement on ethical principles published by the Royal Academy of Engineering (RAE) in collaboration with the Engineering Council and other engineering institutions. The RAE tells us to aspire in our working habits and relationships to meet the standards set out in their code. Not surprisingly it has a lot of overlap with the more detailed ASCE code which is presented afterwards.

<u>RAE Statement of four Fundamental Principles (brief version)</u>

1. Professional Engineers have a duty to ensure that they acquire and use wisely and faithfully the knowledge that is relevant to the engineering skills needed in their work in the service of others.
2. Professional Engineers should adopt the highest standards of professional conduct, openness, fairness and honesty.
3. Professional Engineers should give due weight to all relevant law, facts and published guidance, and the wider public interest.
4. Professional Engineers should aspire to high standards of leadership in the exploitation and management of technology. They hold a privileged and trusted position in society, and are expected to demonstrate that they are seeking to serve wider society and to be sensitive to public concerns.

The American Society of Civil Engineers (ASCE): Fundamental cannons

1. Engineers shall hold paramount the safety, health and welfare of the public and shall strive to comply with the principles of sustainable development in the performance of their professional duties.
2. Engineers shall perform services only in areas of their competence.
3. Engineers shall issue public statements only in an objective and truthful manner.
4. Engineers shall act in professional matters for each employer or client as faithful agents or trustees, and shall avoid conflicts of interest.
5. Engineers shall build their professional reputation on the merit of their services and shall not compete unfairly with others.
6. Engineers shall act in such a manner as to uphold and enhance the honour, integrity, and dignity of the engineering profession and shall act with zero-tolerance for bribery, fraud, and corruption.
7. Engineers shall continue their professional development throughout their careers, and shall provide opportunities for the professional development of those engineers under their supervision.

Chapter 2

In this chapter we will use different methods to find solutions (or compromise) to ethical dilemmas. To begin with, it is useful to explore what is meant by the phrase "ethical theories". Certainly, it is impossible to have a mathematical expression such as "f = ma" to reach a quantitative answer to any ethical issue. It is even worse, because ethical dilemmas are typically fuzzy in nature and there may be several right answers getting in the way of the best one. What we can say, however, is that an ethical theory is a philosophical set of guidelines based on moral principles that can be employed to influence our behaviour. Clearly these are not new topics, but have exercised the intellect of moral philosophers throughout history. Our job is to discover how the application of these theories will help provide clarity and practical guidance on organising moral values; conclusions must be consistent with moral convictions, but we will cautiously observe that different conclusions can be obtained depending on what ethical theories you decide to adopt. As an engineer you will at least aim to operate within the law, and in what follows we will see that an engineer is therefore best served by the application of “Rights Ethics”.

Ethical foundation 1: Utilitarianism

The basis of utilitarianism is quite simple and can be expressed in the following statement. Those actions that are good serve to maximise the benefit to society as a whole and do not promote the wellbeing of the individual. In selecting the best between two options utilitarianists will tell us to add up all the good and bad potential outcomes for both cases and then take the option that has maximum good. Who cares about collateral damage? Consequently there are many examples when strict application of this foundation appears to contravene what we regard as morally acceptable. The detrimental impact of engineering projects on the weakest in communities offers many examples where blind utilitarianism applies, for example (i) displacement of peoples for the purpose of building of dams, (ii) location of incinerators and power stations within poor communities, etc. These cases present issues that might conflict with utilitarianism. In fact, to put it into historical perspective, utilitarianism has enjoyed dominance up to the point in history when slavery was abolished. Ignorant application of cost-benefit analysis is rooted in utilitarianism, but more about that later.

Ethical foundation 2: Duty ethics

In contrast to the above, duty ethics is more self-aware and is based on the principle that we are all bound by moral duties to one another, animals (perhaps) and the environment (maybe). Such duties are obvious in a culturally and religiously uniform society, such as (i) don't knowingly do physical harm to others, (ii) don't steal, (iii) be honest, (iv) don't deceive, etc. You might wonder, for a moment at least, whether ethical duties have a fundamental basis that binds all humans together. Surely we are taught to behave ethically by the chastisements of our parents and society in the formative years of our lives? So isn't it relative, depending on how we were brought up and our formative influences? What about people who don't have any concern about the suffering of others (psychopaths, for example). Relativistic morality is an emotive topic, and you may have opinions you wish to express during the lectures. But, clearly, strict application of duty ethics to solve dilemmas would seem very narrow minded and doesn't necessarily take the good of the whole situation into account. It would, for example, prevent you from telling a lie to save a friend.

Ethical foundation 3: Rights ethics

This is very similar to duty ethics, but establishes the fundamental principle that everyone has rights and that these should be upheld. In fact, rights ethics can be seen as a mirror image of duty ethics; if I have certain rights then you should be duty bound to attend to them – if I have a duty or obligation it's because you have rights that I need to respect. Duty and rights ethics are, correspondingly, often considered together under a single heading; they represent a stark contrast to utilitarianism by putting the rights of the individual above the overall good outcome. They ensure that extremes are not taken to the detriment of an individual. Rights ethics were extremely popular around the time of establishing American Independence, and consequently the Declaration of Independence is based on the principles of rights ethics: "that all men are created equal, that they are endowed by their Creator with certain unalienable rights, that among these are life, liberty and the pursuit of happiness". Similarly, the 1998 Human Rights Act in the UK is based on such principles. (Out of interest, the wording used in the Declaration of Independence was strongly influenced by the work of John Locke, 1632 – 1704, who studied medicine at Christ Church, Oxford. Locke was one of the founding philosophers promoting fundamental rights of life, of liberty and property.)

Ethical foundation 4: Virtue ethics

If everyone was a good person then the world would be a better place. Being a good person, or virtuous, is the basic principle in virtue ethics. Decisions should be based on whether or not they are compatible with a set of virtues that everyone should be judged by. In an engineering context these might include: competence, honesty, courage, fairness, loyalty and humility. In contrast, a list of "vices" would include the opposite qualities. You might be surprised to see that "competence" is top of this list, but it is a fact that 98% of all engineering failures are due to incompetence rather than a deliberate decision to engage in unethical behaviour. Competence means: having the right set of skills and experience, exercising due care, persistence and diligence and attending to detail and being conscientious. Once again, this foundation seems to be centred on personal choice and doesn't help us define what actions might be a virtue or a vice when faced with a difficult ethical dilemma. It is also open to deception, as dominant characters could convince large portions of society that terrible actions are in fact virtuous. I won't give any examples, but I'm sure you can think of many throughout history. In fact, virtue ethics has been described as too vague for engineering practice and it is more a matter of establishing the mean between a virtue and its corresponding vice; take honesty for example, if you are too honest then you will offend your friends by stating facts they won't want to hear. It appears acceptable to be somewhere in the middle between 100% honesty and dishonesty. Aristotle referred to this as the Golden Mean between extremes.

ETHICAL DILEMMAS

These notes introduce case studies that allow us to explore ethical dilemmas that actually occurred. An ethical dilemma presents itself when there are several "right" options to take, but clearly some are better than others; if there are just two choices, one being right and the other wrong, then there is no dilemma. Below is a simple example that requires ethical decision making; we will apply the various ethical theories to determine a solution. Indecision is not an option.

<u>Incinerator for domestic waste</u>

You are an engineer working for the local council in their waste management services. After your degree you took an MSc in environmental sciences and sustainability; consequently you have a keen interest in working on related projects. You have been asked by your boss to look at a proposal for a domestic waste incinerator plant to serve three wealthy London boroughs. Under the proposal, refuse collected from each of these boroughs will be brought to the new incinerator located outside London in a deprived area of high unemployment, the closest town is Slough. One of the main proponents of the project has strongly argued that this community needs the additional jobs (Slough industrial estate – once the largest in Europe - has been heavily hit by the recession, yet the population has been increasing dramatically due to the influx of optimistic migrant workers), that good transport routes exist between the proposed site and London and that locations of the associated landfill areas have been identified close by. (You remember that incinerators don't completely remove all of the waste: around 10% to 30% of incinerated waste is in the form of non-hazardous ash that is disposed of in landfill sites. Approximately 5% of incinerated waste forms an ash containing toxic chemicals which has to be sealed into containers and disposed of as hazardous waste.) The boroughs are keen to establish long term use of this facility as the cost of building the incinerator is expensive and London taxpayers will be demanding good value for money. An alternative site in a less densely populated rural area was rejected on the grounds of increased running and maintenances costs, and failure to secure planning permission on greenbelt land. Your boss has asked you to counter objections raised by the Slough community who are concerned about dioxins being expelled into the air by the combustion process. These dioxins have been linked to cancer, reproductive problems and congenital disorders in children. In any case, the residents of Slough are arguing that it is not their waste, and why should they suffer processing waste from wealthy Londoners. Confidentially, you have been informed that several business men are making huge profits from this deal, but this should not factor in your assessment. In the project file you come across a personal letter from a Slough resident who has recently purchased a starter home very close to where the new incinerator is planned to be build. They are worried about the health issues this might have on their young family and also the reduction in the value of their home. They had been trying for many years to get on the property ladder, and finally moved into their first home last Christmas.

<u>Solutions to dilemma</u>

Fact: Incinerators are better than bulk landfill, and have merits in terms of environmental and sustainability issues. Greenbelt land should be protected for future generations. In the UK we should handle our own waste locally and you note that Slough town is reasonably close to London; but the Slough residents have raised valid objections. Using utilitarianism ethics you reason that the incinerator should be built as the overall good outweighs any hardship experienced by the Slough community, at least in the short term. This is also supported by the fact that there is no proven link between dioxins and the health issues identified by the objecting residents, and of course the incinerator has to go somewhere; so the argument about property prices is completely relative. You write an internal memo saying that you wish to be project leader on this exciting new construction.

In contrast, if you employ duty or rights ethics the conclusion might be the opposite. The people of Slough have rights too, and they may have legitimate worries about the health factors. Someone is clearly making a lot of money out of this deal, and that seems to be the issue that is playing on your mind. You argue in your mind, that if the incinerator is safe and clean, then why can't it be built in one of the London boroughs creating the waste. Presumably, employing virtue ethics would bring you to the same conclusion? Rights and duty ethics should really take priority over utilitarianism views, because in modern society we believe that the rights of an individual should be weighted more strongly than the needs of society. No matter how much good an action does, if it leads directly to the suffering of a single person then it is viewed negatively. A case study that highlights the terrible impact of utilitarianism and blatant disregard for the rights of people living in Bhopal (India) is presented below.

CASE STUDY 4: THE BHOPAL GAS TRAGEDY

The Union Carbide Corporation (UCC) is a chemical company started in 1917. Since 1999 it has been a subsidiary of The Dow Chemical Company. In December 1984 a Union Carbide pesticide plant in the Indian city of Bhopal, Madhya Pradesh (central India) accidentally released 42 tonnes of toxic gas into the air, killing up to 2,000 people and allegedly leading to the cumulative total of 25,000 related deaths. This case study explores the safety measures adopted by the engineers when designing the chemical plant, and how it differed from similar plants operating in the US. It is often quoted as being one of the worst industrial disasters ever. To date, there is still a dispute as to how the accident occurred, but the main issue relates to the design of the plant, its safety measures and the lack of adherence to the adopted safety practices.

The case

The pesticide plant at Bhopal was owned by Union Carbide India Ltd. (UCIL). At that time, the parent company UCC had a 51% share. Since 1969 UCIL's main product was the pesticide carbaryl (1-naphthyl methylcarbamate, trade name SEVIN). It is a well known insecticide, toxic to humans and carcinogenic. One of the ingredients required in the carbaryl production process is methyl isocyanate (H3C-N=C=O, MIC). In 1979 the plant at Bhopal was upgraded to manufacture its own MIC in large quantities, eliminating the need to import this chemical. Apparently Union Carbide were aware of less toxic alternatives to MIC but had dismissed these on the basis of cost; the German company Bayer manufactures carbaryl without using MIC, for example. The world demand for carbaryl pesticides prior to this disaster had declined, but production continued at a steady rate. It was therefore necessary to use large storage tanks to hold stock of MIC on site.

Union Carbide has a similar plant in West Virginia, producing and storing MIC. Following site visits by UCC engineers to Bhopal an internal memo circulated in September 1984 warned of a "runaway reaction that could cause a catastrophic failure of the storage tanks holding the poisonous (MIC) gas". As far as we know today, this memo was ignored.

During the night of 2nd December 1984 1000 litres of water was accidentally pumped into tank 610; Union Carbide claimed (at that time) this was an act of sabotage by an employee seeking revenge for some work related incident but this has never been proven. Site workers maintain that entry of water through the plant's piping system was possible because the pipe network and safety valves were compromised due to lack of maintenance. Alternatively, it could have been a simple accident. The utility station at the plant did provide both water and nitrogen pipes that were located side-by-side. Nitrogen was used to pump out MIC from the bottom of the tanks, and it is possible a worker got these confused.

MIC is a very aggressive chemical and it reacts violently with water and certain metals (such as iron) producing excess heat. Consequently the pressure inside the tank increased dramatically and it is likely that the temperature of the water and MIC solution reached over 200°C. The boiling point of MIC is a mere 39°C. Inevitably the pressure relief value on tank 610 burst, releasing a huge MIC cloud into the air. It is reported that the MIC further reacted with iron in the plant's steel pipe-work accelerating the MIC reaction with bellowing steam, causing explosions and further toxic chemicals. The city of Bhopal was engulfed in the toxic fumes exposing an estimated 500,000 people to the short-term and long-terms effects of MIC. Low exposure levels (0.4 ppm) leads to coughing, chest pain, difficulty breathing, irritation of the eyes, and skin damage. Higher levels of exposure (> 21 ppm) will result in severe breathing difficulties, permanent damage to throat and lungs, burning of the eyes and skin, and eventually death. As MIC has a distinctive odour it can often be detected at levels down to 5 ppm, and at this level it has an effect similar to tear gas. Many people in the city woke up with burning sensations, thousands died within 72 hours either directly from the gas or as a result of the mass panic causing many people to be trampled to death. There have been reports, denied by UCC, that other toxic chemicals were released in this incident creating a more deadly gas than first identified, being heavier than air. There have been several studies of the chemical reactions occurring in tank 610, based partly on the residual material left at the bottom of the tank and experimental attempts to reproduce the conditions of heat and pressure (see for example: D'Silva, et al, J. Org. Chem. 1986, 51, 3781-3788).

Further context can be drawn from the following related facts. In January 1985 the Environmental Protection Agency in the US announced that there had been 28 leaks of MIC at the Union Carbide plant in West Virginia during 1980 to 1984. In February of 1985 Union Carbide confirmed that there had been as many as 61 leaks of MIC. In February 1990 there was a significant MIC leak that injured seven workers and led to 15,000 residents being ordered to remain indoors.

Consequences

1. The leak of toxic gas over the slums of Bhopal led to thousands of people losing their lives, and many more disabled or needing permanent medical treatment.
2 A BBC investigation broadcast on Radio 5 in November 2004 reported that the site was still contaminated with thousands of tons of toxic chemicals. A sample of drinking water from a well near the site had levels of contamination 500 times higher than the maximum limits recommended by the World Health Organization.
3. UCC immediately put \$2 million into a disaster relief fund. In August 1987, Carbide made an additional \$4.6 million in humanitarian interim relief available. Following repeated litigation attempts by the Indian Supreme Court an out-of-court settlement was reached in 1989. UCC paid \$470 million for damages caused in the Bhopal disaster and by the end of October 2003 compensation had been awarded to 554,895 people for injuries received and 15,310 survivors of those killed. The average amount to families of the dead

was $2,200. UCC also funded a hospital in Bhopal, at an estimated $17 million, to specifically treat victims of the Bhopal disaster.

4. The Chairman and CEO of Union Carbide, Warren Anderson, had been arrested and released on bail by the Madhya Pradesh Police in Bhopal on December 7, 1984. This caused controversy as his trip to Bhopal was conditional on an initial promise by Indian authorities not to arrest him. Anderson has since refused to return to India.
5. Beginning in 1991, the local authorities from Bhopal charged Warren Anderson with manslaughter. Anderson has so far avoided an international arrest warrant and a US court summons. He was declared a fugitive from justice by the Chief Judicial Magistrate of Bhopal on February 1, 1992 for failing to appear at the court hearings in a culpable homicide case in which he was named the chief defendant. An extradition request is still in operation.
6. Seven Indian UCIL employees have since been convicted of negligence and are currently serving jail sentences of 2 years each.

Who's responsible

After prolonged investigations carried out by the Indian authorities on behalf of UCIL and Arthur D. Little on behalf of UCC various criticisms were raised against both companies.

1. It was not ethical to locate such a plant with well known and predicted extreme health issues so close to a densely populated area. The plant design was criticised for choosing such a dangerous method of manufacturing carbaryl when safer alternatives were possible. There were no catastrophe plans established with the local government and healthcare facilities.
2. The storage tanks containing MIC were unnecessarily large and poorly maintained. The leak-alarms on many of the tanks had not

worked for several years and there was only one back up alarm system; in the equivalent US plant there are 4 stages of back up alarms.

3. The company had an emphasis on cost-cutting which had resulted in less stringent safety regulations. Leaking pipes were frequently turned off, rather than being repaired and many of the safety features were dependent on manual operation only. There was a very severe downturn in morale affecting the skilled workforce. The workers were ignored when making complaints about the cuts. It is even reported that one employee was fired for going on a hunger strike after 15 days. On the night of disaster, no maintenance supervisor was placed on the night shift.
4. It is alleged that differences between the cultural working practices in India and the US contributed to the lack of safety measures put in place and how they were maintained and regulated. Plant construction was compromised by the use of less proven indigenous materials and products. Some of the electronic instrumentation and actuators were removed from the plant specifications or substituted with lower grade equivalents.
5. As part of the safety system the plant used several methods to reduce the impact of a gas leak. These included a flare tower (i.e. continuous flame designed to burn off escaping toxic gas before affecting the local population) and gas scrubbers that would neutralise MIC by reaction with sodium hydroxide. Both of these systems had been out of service for 5 months before the leak. Although it is unlikely that these systems would have coped with the volume of MIC released they would have helped to reduce its impact and perhaps allowed more time for a successful evacuation. Investigations showed further that the tank temperature alarms were

incorrectly set, and that the flare tower itself was improperly designed (insufficient for coping with the volume of MIC on site).

6. Due to its low boiling point, the tanks for storing MIC had refrigeration units to hold them at a constant 4.5°C, but to save costs the refrigeration system was turned off and the coolant used elsewhere in the plant. Again, this didn't cause the incident, but reveals the culture of neglect that had developed at UCIL.
7. UCC had ignored warning of this exact incident occurring. An internal memo referring to the risks was ignored and never seen by senior staff. Building up to the disaster several related incidents did occur and no change of practice was made. During 1983 and 1984, leaks of the following substances regularly took place in the plant: MIC, chlorine, monomethylamine, phosgene, and carbon tetrachloride, sometimes in combination. In attempting to stop one of the leaks during this period, a supervisor suffered intensive chemical burns and two other workers were severely exposed to the gases.

Shortly after this terrible disaster Union Carbide made the following corporate statement in their annual report: "Bhopal was a shocking tragedy, but Union Carbide was well served by our quick and compassionate response, and by the way the situation was managed. We moved swiftly to provide emergency relief while concentrating management of the crisis among a small group of executives, so that unaffected businesses could proceed with their normal routines. Many were shocked that the accident had happened to Union Carbide, a company with an excellent safety record. Expressions of support for Carbide poured in from customers, suppliers, and friends around the world. Carbide was also sustained by the performance of our employees, who never faltered throughout the December crisis.” “Numerous lawsuits have been brought... alleging, among other things, personal injuries or wrongful death from exposure to a release of gas... Some of these actions are purported class actions in which plaintiffs claim to represent large numbers of claimants alleged to have been killed or injured as a result of such exposure...”

Discussion questions: ethical issues introduced by case study

1. Should manufacturing safety standards be internationally the same, or could there ever be a situation when safety can be compromised to reduce running costs? In your discussion use the ethical theories (e.g. utilitarianism, rights and duty ethics) as a basis of your reasoning. You might consider balancing the need to secure work for developing nations against competitive bidding for new factories. Should nations be able to set their own safety standards according to the level of resources available to them?
2. Consider, for example, the RAE statement of four fundamental principles on engineering ethics introduced in chapter 1. On a scale of 1 to 10, rate the level of violation of each of the 4 principles by the engineers a) designing the Bhopal plant and b) responsible for maintaining safety equipment and regulations.
3. Do you believe that the US parent company, UCC, neglected a responsibility to guarantee safety to the people of Bhopal, or was this a matter for UCIL? Was UCC justified in defending themselves, stating that the accident was a result of sabotage by a disgruntled employee?
4. Has UCC paid its debt to the people of Bhopal? Is it fair that Warren Anderson is now classed as a fugitive by the Indian courts?

Further reading (WebPages accessed on 9th July 2009)

1. Bhopal disaster, Wikipedia entry.
2. Peterson M.J. “Case study: Bhopal Plant Disaster”, http://www.umass.edu/sts/ethics/bhopal.html
3. Kalelkar AS, Little AD. (1998) (PDF). Investigation of Large-magnitude incidents: Bhopal as a Case Study. http://bhopal.bard.edu/resources/documents/1988ArthurD.Littlereport.pdf
4. D'Silva TDJ, Lopes A, Jones RL, Singhawangcha S, Chan JK “Studies of methyl isocyanate chemistry in the Bhopal incident”, J. Org. Chem. 51 (20), p 3781–3788, 1986

End of Bhopal gas tragedy case study

Dealing with ethical questions is not like solving a mathematical equation. You can't just plug in the numbers and write down a numerical answer. The situation is much fuzzier, and in many cases it may be difficult to determine all of the facts reliably. Take two scenarios: (i) you are asked to be a contributing engineer on a project to build a new nuclear power station to be located near a community with high unemployment, and (ii) you are asked to put up a mobile phone mast adjacent to a children's nursery when you know local residents are concerned about the unproven health risks to young children exposed to transmitted radio waves. In both cases you might have reservations, but what tools can you apply to help find a solution. After all, you will not be paid to avoid decisions like this and using the argument that goes "well, if I don't do it someone else will" doesn't help you sleep at night.

The simplest method of ethical problem solving is to apply each of the ethical theories (foundations) discussed earlier. However, in this section we will use a more structured approach based on line drawing, flow charts and cost-benefit analysis.

Line drawing

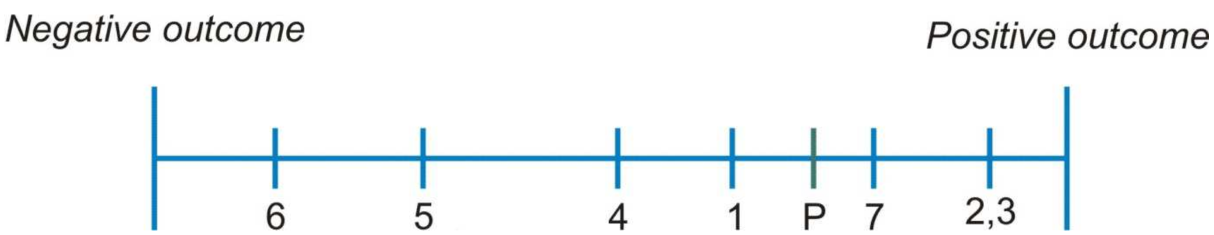
Simple application of ethical theories seems inadequate on its own, and there is advantage in using more formal methods. Firstly, identify clearly what will be the positive outcome of the situation, and in the worst case the unambiguous negative outcome. These are marked on a page as two extreme points of line. The line is helpful, as it can be used to represent the range of issues that need to be considered, and whether they are closer to the positive or negative outcome. Now make a list of all the factual issues, and then make a second list of all the conceptual issues that you can imagine. This second task might be harder, because conceptual issues are more about perceived risk rather than hard data; some may even be controversial. Use the line like a thermometer gauge, representing each of the issues on the list as a discrete point on the line with the more positive issues closest to the positive outcome end. Finally, mark on the line the position of the problem at hand, as a point P, for example. From the arrangement of the position P and the other points along the line it will be easier to determine which action is ethically more appropriate. We will illustrate this process using the same problem proposed in Fledderman's book, section 4.3.

The problem: You need to determine an ethical decision on whether it is appropriate to dispose of slightly hazardous waste by dumping it into a lake. A local town obtains its drinking water from the lake, but your research shows that the average concentration of the waste in the lake would not exceed 5 ppm and regulations allow up to 10 ppm. You obtain evidence that consumers will not be affected by such low levels of waste. The first stage in the line drawing will therefore be:

The next stage is to make a list of the hypothetical issues to include along the line. Following Fledderman's example:

1. At 5 ppm the hazardous chemical will be harmless but the town's drinking water will have an unusual taste.
2. The town has an existing water-treatment system and this will remove the chemical making it safe.
3. The town doesn't have a suitable water-treatment system, but this will be purchased and fully maintained by the company dumping the toxic chemical.
4. As above, but the taxpayer will cover the water-treatment costs.
5. On rare occasions exposure to the chemical can make people feel ill for about an hour with no further harm.
6. As above, but illness lasts for a week if toxicity level reaches 5 ppm.
7. The plant can be modified to reduce waste levels to 1 ppm.

Further issues could be identified, such as how seasonal variation in rain fall and runoff of pesticides from local farms might affect the scenario, but for now the line can be redrawn with the above issues inserted at appropriate points on the line depending on whether they tend toward the positive or negative outcomes. The problem P is also (subjectively) placed on the line.



Looking at the line diagram it is possible to gauge the impact of P in comparison with all the identifiable issues and because P is closer to the positive outcome it would seem a reasonable judgement to conclude that dumping waste was acceptable. However, other options appear to be higher up the scale than P.

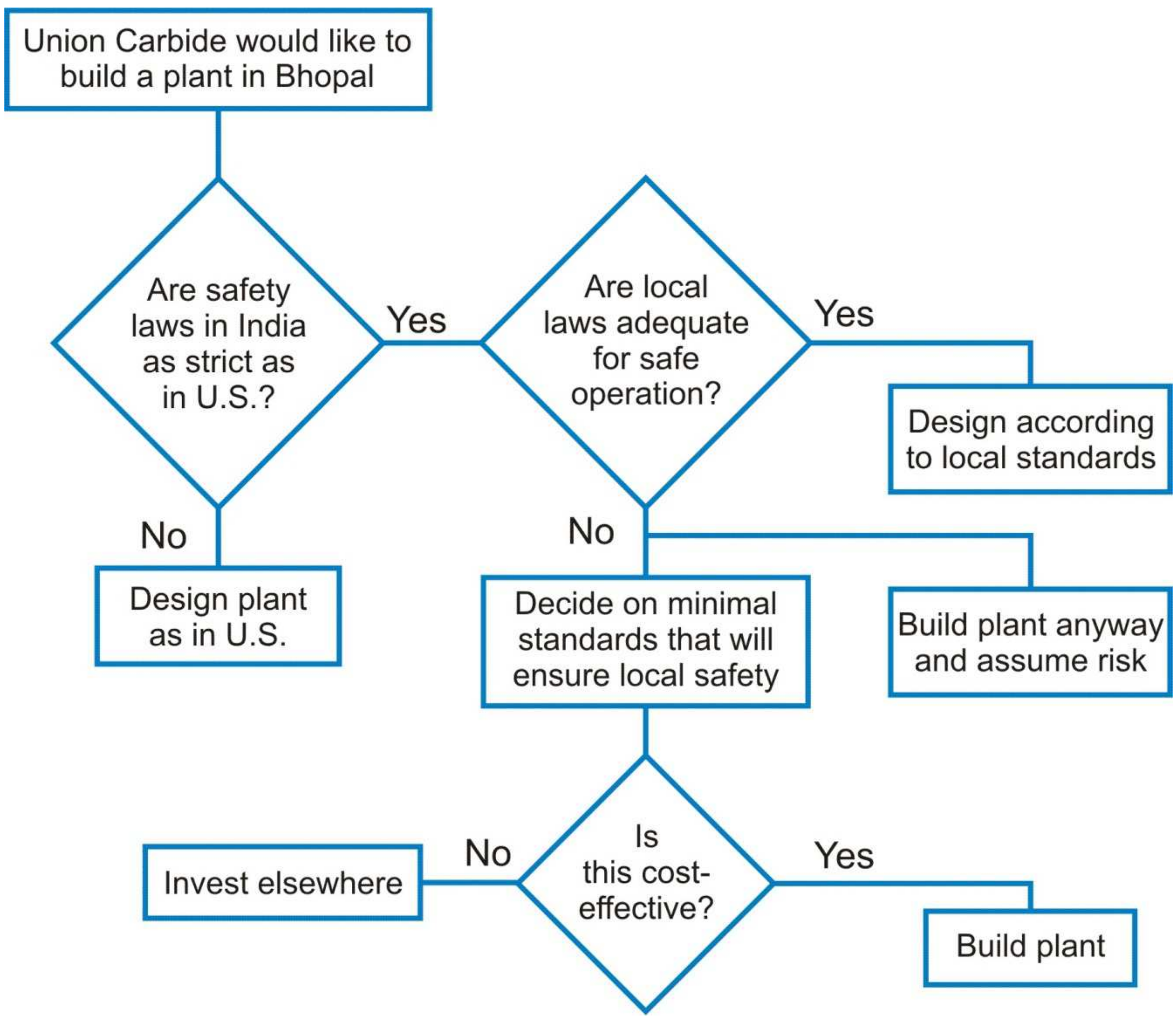
Try out this method of determining ethical behaviour on the following simple case study based on a BBC report concerned about recycling of e-waste. (See: http://news.bbc.co.uk/1/hi/world/south_asia/3307815.stm)

Recycling of electronic goods

It is clearly right to recycle. Take your old computer or mobile phone, for example. But how are these castaway products actually recycled and stripped down to plastics, glass, valuable chemicals and metal for reuse? Current estimates suggest that over 30 million computers are thrown out by the US alone each year. Many of these are sent to India and China for recycling. Occasionally this involves removing parts that can be put into new or existing computers or mobile phone, but what is more likely is that valuable metals such as copper are extracted from the old equipment using very primitive techniques. PVC-coating is typically burnt off the copper, for example, releasing hazardous fumes such as dioxins. The whole process has been criticised further for introducing other heavy metals and dangerous chemical into the local environment and non-recyclable remains are often sold on to go into local landfill sites. It is big business, employing a lot of people at various stages of the recycling process and it is an unregulated industry in India.

In some cases women and children are carrying out this work for less than half a dollar a day and for them it is the choice between poison and a livelihood. Recent health surveys have shown that recyclers regularly suffered from complaints such as respiratory disease and skin rashes.

You will see flow charts elsewhere in the course and they are very useful for laying out the decisions and consequences in a helpful visual format; although in practice if many issues are included the diagram becomes too complicated to follow. Flow charts are also handy for explaining your decision making process to others in the form of reports or briefing documents. They are most appropriate when there is a sequence of events being analysed and all relevant outcomes of those decisions are known. Below is a copy of the flow chart from Fledderman's book dealing with the Bhopal disaster, and the hypothetical decision making process that Union Carbide may have gone through when deciding where to locate the plant.



Cost Benefit Analysis (CBA) is an ethical analysis tool that gives structure to the decision making process, balancing the moral issues in a tabulated format that allows competing positives and negatives to be judged against each other. An outcome is obtained when either the positives or negatives add to the greater sum. At a first glance it appears to be a formal application of utilitarianism, as the conclusion rests with the option that has the higher ratio of cost to benefit; but many would argue that this is not strictly true as the outcome is flexibly dependent on what factors are brought into the decision making process. Using “costs” and “benefits” rooted in the principles of “rights and duties” will inevitably lead to a conclusion that is not utilitarian in perspective. Like an argument presented using flow-charts, CBA is also another useful way to present your conclusions to a critical audience. The pros and cons are laid out for scrutiny, revision and debate. It is strongly advisable to use CBA when selecting between a small number of ethically justified options. If your CBA is biased, then it’s probably not ethical. Take for example the controversial cost benefit analysis carried out by the Ford Motor Company when considering whether or not to implement their safety upgrade.

<u>The estimated cost</u>

The production change required just $11 per vehicle, but for complete coverage the $11 unit cost had to be applied to all Ford cars with similar defective design, i.e. retrofit as well as new. This amounted to a total of 11 million cars and 1.5 million trucks, establishing an overall cost of $137.5 million.

The estimated "societal" benefit

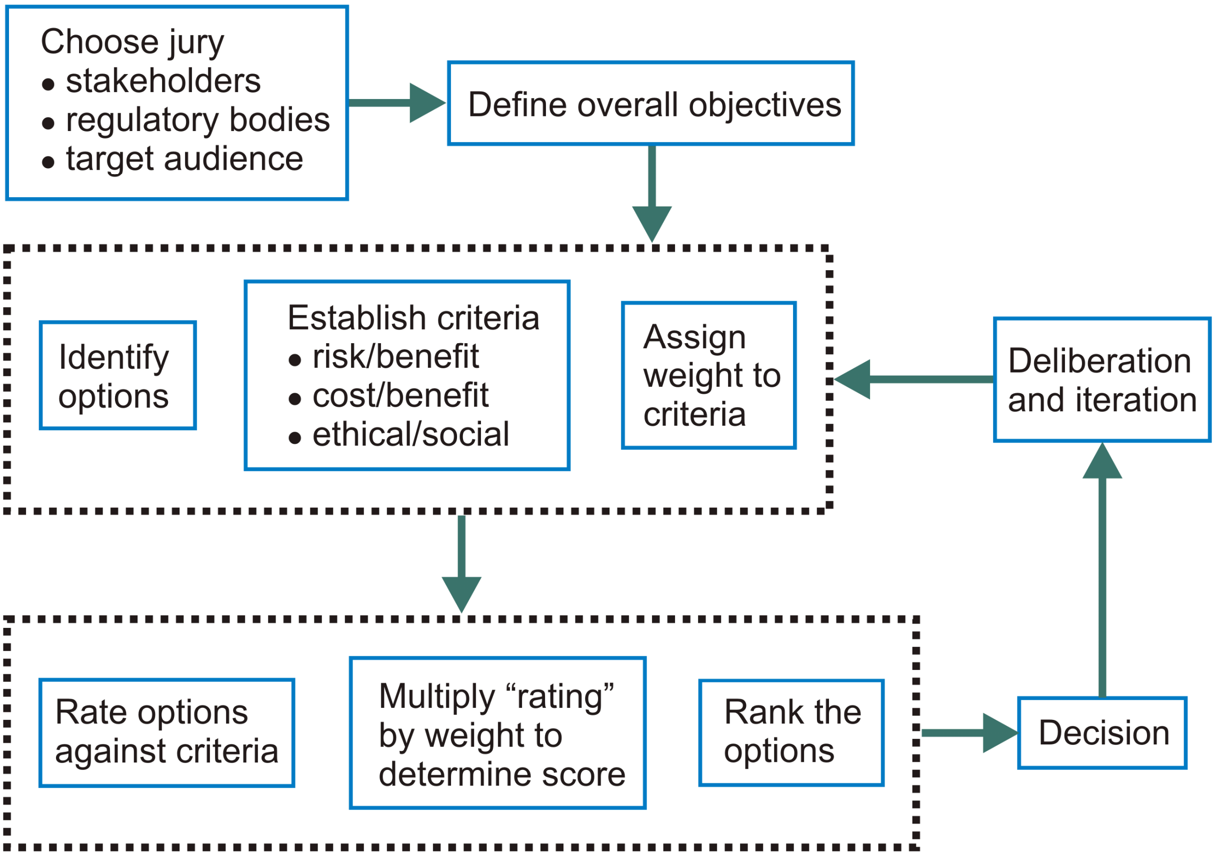
Ford estimated that making the change would result in 180 less burn deaths, 180 less serious burn injuries and 2,100 less burned vehicles. These numbers were then multiplied by figures published by the US Department of Transportation used to determine road safety strategies, i.e. $200,000 per death, $67,000 per injury, and $700 per "written-off" vehicle. This led to a conclusion that the societal benefit of making the safety upgrade was $49.5 million.

It was clearly cheaper for Ford not to implement the safety modification and they felt justified by basing this decision on CBA. If we employed rights ethics from the beginning, then we would never engage in a CBA that weighed corporate financial gain against the life of 180 people! The actual situation was more complicated, of course, with Ford employing the premise that driving any car involved risks, and statistical data could be used to show that the Pinto was no worse than any other vehicle at that time.

There are variations to CBA. Risk Benefit Analysis (RBA) is basically the same, but the different name reflects the fact that a risk is being assessed rather than dollars; it's simply dependent on the task at hand. An extended technique is called Multi Criteria Analysis (MCA) which is better suited to situations having more parameters in tension with each other. CBA and RBA suffer from a blinkered view of the issues, without putting a measurable value on one benefit compared to a particular cost; for example, a cost such as mild deforestation is completely non-quantified with no attempt to gauge its short or long term environmental impact. MCA corrects this weakness in CBA and RBA.

In MCA it is desirable to include both qualitative as well as quantitative factors in the assessment. In fact, establishing a well-considered list of all the factors influencing the decision and determining their relative importance is the essential starting point. Failure to get this right will almost certainly lead to a decision that is difficult to defend, when actually the aim is to identify a single most preferred option that others will agree with.

MCA is a tool for appraising and ranking alternative options against a given set of weighted objectives and criteria. It is more flexible then CBA and can be used to compare options that involve both monetary and non-monetary impacts. The process of undertaking an MCA might be easier if you layout your thoughts using the following structure.



Start by making sure you have a clear objective to the exercise and that the competing options have ethical basis. Label and tabulate the options into a list for comparison. For each MCA option determine the relevant decision influencing criteria involved and assign weights to them. If you don't weight each of the criteria using established evidence then your conclusion will not be very transparent. Ensure that you have presented the objective, options and criteria as appreciated by the target audience, i.e. those you wish to be on your side, and that regulatory practices have been upheld. Cross-reference to the source of any information used to establish the weighting, referring to experts that will support your claims. Now for each of the options determine a score against each of the criteria. Once complete, multiply the scores against the weight of the corresponding criteria and add up these numbers. Use the weighted-scores to rank the options, selecting the one that scores highest. Remember, one of the main criticisms for such analysis is that the criteria used and the values decided on for their weights can be very subjective and there is no evidence of underlying analysis or research. Adjusting the weights of one or two criteria might change the outcome, for example. So it is important to overcome these anxieties by consulting experts and stakeholders when determining the criteria, weightings and ranking. An example below has been applied to the incinerator for domestic waste ethical dilemma presented earlier. The criteria are not very fine-grained, but it represents a starting point, which can be modified after feedback from the various stakeholders.

1. The objective is to determine if it is defendable to locate the incinerator on the outskirts of Slough.
2. Options for location are: (i) outside Slough, (ii) greenbelt site, (iii) within one of the London boroughs.

3. Criteria and weighting from 1 to 5 in brackets: availability and cost of suitable land (3), impact on employment (2), income generation for councils and business revenue (4), environmental impact (5), transportation and ability to scale (2), objections from Slough residents (3).

4. There are several stakeholders: Slough residents, London residents, business community aiming to make money from the scheme and local Council wishing to hear your conclusion. Different MCA weights and scoring may be argued by each stakeholder. [In this case the applied bias has been applied towards the Slough residents but the conclusion, obtained from the highest score, does not go in their favour and suggests that Slough is a defendable location for the incinerator project.]

Criteria	Weight	Outside Slough		Greenbelt land		London Boroughs	
		Rating	Score	Rating	Score	Rating	Score
Suitable land	3	4	12	5	15	1	3
Employment	2	4	8	2	4	3	6
Revenue	4	3	12	2	8	2	8
Environment	5	3	15	1	5	4	20
Transport	2	5	10	1	2	3	6
Objections	3	1	3	3	9	5	15
TOTAL			60		43		58

Data used in the first iteration available from the following fictitious sources: Residents' surveys carried out by StreetCred Ltd, transport data supplied by RoadWatch and independently verified by The Vehicle Association, environmental issues confirmed with Council Environmental Planning Office, etc. (all data created for teaching purposes only).

Chapter 3

RESPONSIBILITIES

We have already looked at engineering codes of ethics and noted that failure to apply the code may result in removal of Chartered status in the UK, or PE licence in the US. Blatant disregard for good practice when it relates to safety, contracts of employment or environmental pollution in some cases represents a breach of the law and can result in criminal prosecution. In this chapter we will now look at a range of legal obligations imposed on the engineering profession that may not be initially apparent from looking at the codes of practice alone. Once again we will stick to topics that are related to "engineering ethics" and not slip into the complexities of statutory employment law and legislation. Engineers have rights too, and if faced with a situation where a contract of employment requires you to pursue an unethical action or engage in suspected illegal conduct then your professional institution will support you for speaking out; public safety comes before contractual obligations.

Ethical and Legal obligations

As a practicing engineer you will discover that the problems you need to tackle will be much more complex than solving the right differential equation with the appropriate boundary conditions. Ethical dilemmas will encompass a variety of non-engineering constraints such as legal and regulatory issues, societal impact, balance of risks, company profits, marketing and image, and moral integrity. At times it may be helpful to return to the engineering codes of practices to establish where the legal boundaries exist. A useful resource is the National Society of

Professional Engineers (NSPE, USA) website which contains a policy document adopted in July 2003 entitled “Labour Organizations and an Engineer’s Obligation to the Public”. They state on this matter “Engineers may be disciplined under state engineering licensure laws and state board rules of professional conduct for failing to fulfil their legal obligations. Included with those obligations are: the responsibility to the public welfare; signing and sealing design documents that conform to accepted engineering standards; and avoidance of conflicts of interests or other circumstances that could influence or appear to influence the quality of the engineer’s judgment or services.” This quote has a lot of context and covers a number of discrete issues. For now, we will concentrate on the following phrase “signing and sealing design documents”. Clearly, if a medical doctor issues a wrong prescription to a patient they may face a malpractice charge, but signing and sealing documents goes further.

All engineering projects are social experiments, with different levels of risk. You might argue that repeating well-proven designs doesn’t involve any risk, and it shouldn’t be referred to as an experiment. But, civil engineers, for example, often have to take an architect’s artistic design and convert it into a real structure that won’t fall down. Stress and strain can be modelled using finite element analysis, materials can be chosen with good track record; but inevitably these are experiments to see what delivers an acceptable risk for acceptable costs. An initial design is just that, and will be reworked several times over before it achieves the desired compromise. The supervising engineer must then sign and seal the plans to confirm that all the necessary calculations have been done, the structure meets the objectives and construction regulations have been met. Failure to apply due care and attention to the safety encapsulated by the building regulations is described in legal jargon as engineering “negligence per se”; i.e. a breach of the code.

There have been many cases, even in recent history, where engineers have failed to adequately check their designs for different reasons. Take for example, the Teton Dam (Idaho, USA, 1976) which breached when being filled for the first time because the construction engineers were so confident that the design was “safe” that they didn’t bother leak testing it first. That error directly resulted in the deaths of 11 people, 13000 cattle drowned and approximated $2 billion in retribution charges. The walkway at the Hyatt Regency Hotel is another example, covered in the next case study.

CASE STUDY 5: HYATT REGENCY WALKWAY COLLAPSE

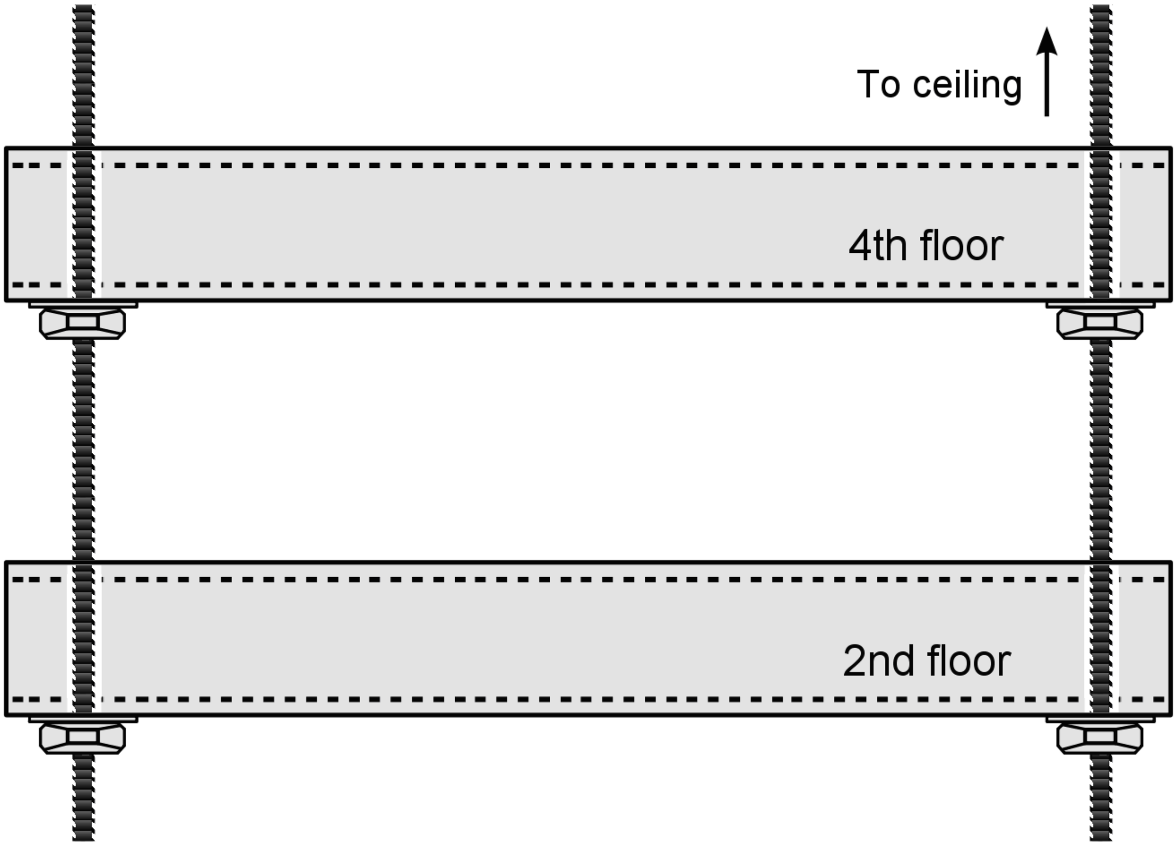
The Hyatt Regency Hotel was to be a grand building of 40 storeys in Kansas City, in the state of Missouri, US. The architect had planned for a large atrium to give the hotel a bright open space in the lobby area. Walkways were to be suspended from the ceiling to allow hotel guests to stroll above the atrium space on an elevated platform. It was left to the civil engineer responsible, Jack D. Gillum, to decide how to achieve this. Once a structural design had been determined by Gillum a contractor then made what appeared to be sensible changes to the fixing points to help with construction and costs. The alterations were incorporated into the new building plans, then signed and sealed by a competent engineer. Unfortunately, nobody bothered to redo the structural calculations. If they had they would have realised that the walkway fixings would no longer support their intended loads. During a party at the hotel there were many people enjoying themselves dancing on the walkways when the top level collapsed from the ceiling and fell on to the lower level killing 114 people and injuring more than 200 others. Gillum was immediately suspended during a State investigation which subsequently found him responsible. His licence to practice engineering in the State of Missouri was removed and his reputation ruined.

The case

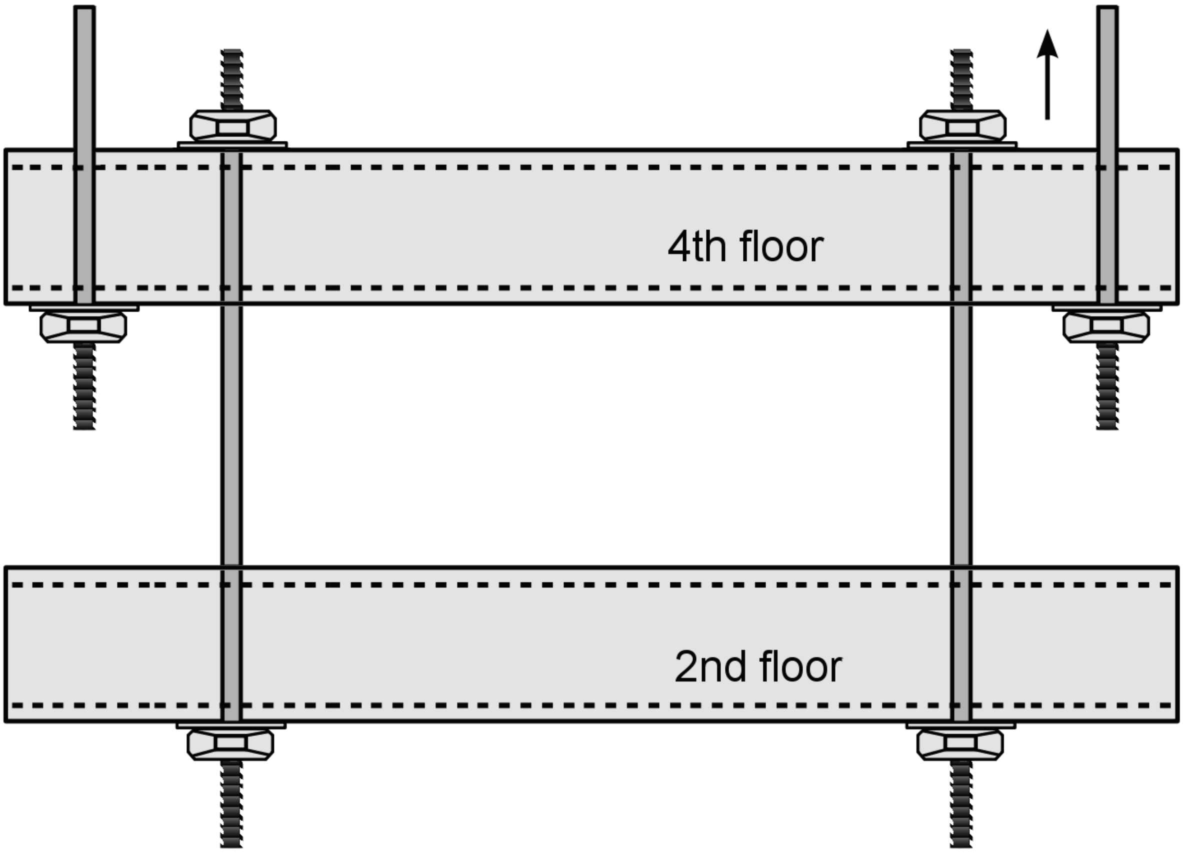
Edward Larrabee was the principle architect for the Hyatt Regency Hotel, which was to be Missouri's tallest building. The engineering part of the project was awarded to a firm called Gillum-Colaco Inc. (GCI), who subcontracted the structural engineering to Jack D. Gillum and Associates (JGA). The construction contractor appointed to carry out the physical building work was the Eldridge Construction Company (ECC), who again subcontracted the fabrication and installation of the walkways to the Havens Steel Company (HSC). Work on the hotel began in 1978 and the hotel was opened in July 1980 after some construction delays.

Edward Larrabee's architectural drawings show a large atrium with walkways between the second, third and fourth levels; he called these "skyways". The arrangement had the third level walkway set aside, in parallel with the other two. Walkways on levels 2 and 4 were above each other, level 4 over level 2. They were suspended from cables attached to the atrium roof. Architects are not engineers, so Larrabee left it to JGA to figure out how to achieve his design.

JGA decided to use concrete walkways, supported on box-shaped beams suspended by steel tie rods. The choice of box-shaped beams was partly cosmetic, as plaster board can be conveniently screwed into the beam to create a flush paintable surface preferred by interior designers. The method originally proposed by JGA for suspending the level 4 walkway above level 2 is shown below (there were actually 3 pairs of tie rods, but only 2 shown in the diagram). Threaded steel tie rods would be bolted to the atrium ceiling with each walkway secured with "washers and nuts" located to hold the box-beams in place.

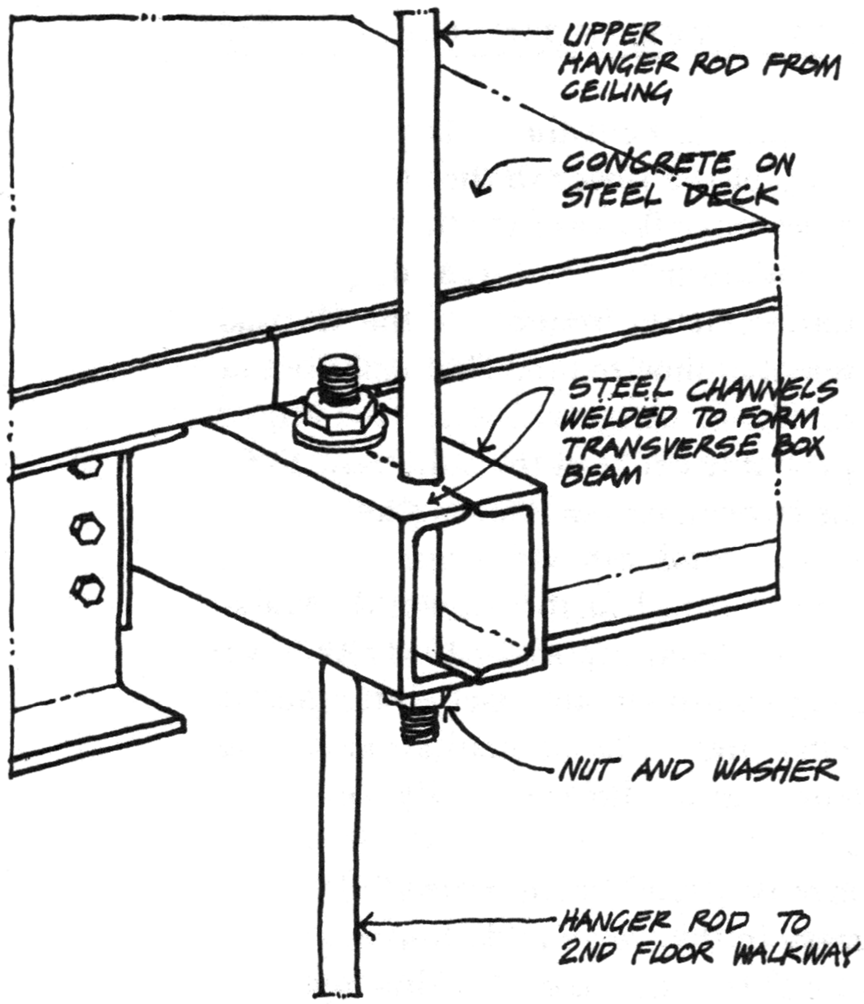


The box-beams were to be made from C-shaped sections welded together to form the box. Some way into the project HSC noted that it was expensive and difficult to produce tie rods with a continuous thread, and they suggested cutting threads on only the ends of the tie rods and doubling up the number of bolts; the reduced cost version is illustrated in the next diagram. The proposed alterations were considered a good idea and incorporated into the building plans. The contractor carried out the work as newly specified. It seemed like such a simple modification, but nobody worked out if the load on the retaining nuts had changed. In their defence JGA later claimed that it was normal practice for the subcontractor to ensure that any alterations complied with State Building legislation; whereas HSC believed it was JGA's responsibility. Before reading on, can you predict how the load on the nuts supporting the 4th floor might have changed?



At the ceiling the bolted tie rod would have to support the weight of both concrete suspended floors and it doesn't matter how they are connected. But let's assume that the load applied to just one of the retaining nuts in the original design was P newtons. Each floor would have 6 nuts experiencing exactly the same load, i.e. the weight of one floor divided by 6. (As it turns out, the enquiry into the negligence charges also proved that the maximum value of P that JGA's original design could support was only 60% of that required by Missouri State building regulations for walkways of this kind – JGA had got it wrong from the start.)

Now consider the load on the nuts suspending the 4^{th} floor in the alternative design suggested by HSC. Notice that the weight of the 2^{nd} floor is effectively combined with that of the 4^{th} floor, such that the 4^{th} floor nuts are now maintaining a load of 2P each. Doubling the load on the 4^{th} floor resulted in an unsafe structure that was just capable of holding its own static load, but would fail catastrophically under a sufficient live load (i.e. it was safe if people didn't walk on it). JGA drew up the new plans and Gillum signed and sealed them, giving his approval as a professional engineer that the safety of the public had been guaranteed. To help illustrate the differences refer to the figure below reproduced from the book by Levy and Salvadori (Why Buildings Fall Down).

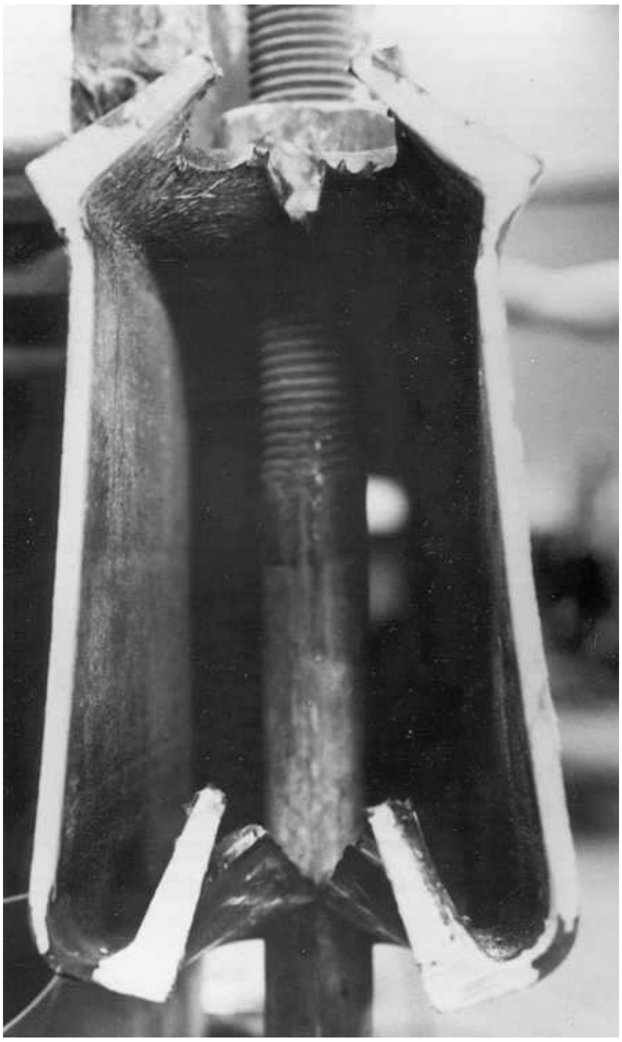


Box Beam Hanger Detail—as Built

Consequences

The hotel had been open for business for approximately one year. Then, on July 17 1981, about 2,000 people had gathered in the atrium as part of a dance contest. Early in the evening there were many people enjoying themselves either dancing on the walkways or looking down at others dancing in the hotel lobby in the atrium area. At exactly 7:05 pm the nuts securing the 4th floor walkway pulled through the box-beam at one end of the suspended platform; causing the 4th floor walkway to fall onto the 2nd floor walkway. Both structures then collapsed onto the floor of the atrium below; 65 tonnes of steel and concrete. People fell from the walkways, many were crushed. A total of 114 people were killed and more than 200 others seriously injured. A photograph of the aftermath is shown in the image below.

Several investigations were held, followed by nearly 5 years of litigation against GCI and JGA by the victims and their families (civil lawsuits approached $140 million). It only took investigators 3 days to confirm that the collapse was due to the design change suggested by the subcontractor and signed off by Jack D. Gillum. Gillum was prosecuted and accepted personal responsibility for the accident. JGA was convicted of gross negligence, misconduct, and unprofessional conduct in the practice of engineering. Gillum's licence to practice engineering in the state of Missouri was withdrawn and so was membership to his professional institution.



A photograph of the end of one of the 4th floor box beams is shown opposite, which clearly reveals how the tie rod was ripped through its centre. The tie rod supporting the lower 2nd floor walkway is still in place (look for the nut at the top of the box beam). Ironically it transpired that during the building phase of the project the north section of the atrium ceiling had collapsed with no injuries. GCI ordered a series of inspections to be carried out and construction flaws were corrected. Unfortunately, the walkway fixings were not included in this inspection, but if they had been then it is almost certainly the case that the poor design proposed by HSC would have been corrected.

Changes to the construction regulations in the US followed and the Hyatt Skywalk Collapse has become a popular case study for engineering ethics around the world. After the accident, the atrium was reconstructed with only one crossing at the 2nd floor level supported by columns underneath. Apparently, it’s a nice hotel.

Jack D. Gillum was the chief engineer and accountable for the disaster. Recognising this he accepted full responsibility, but in his defence he claimed that there had been a communication problem between HSC and his company. Basically, he believed that HSC would only propose a modification to the original plans that were structurally sound and that they were competent enough to have adequately checked it. This wasn’t the case; in fact no one even did a “back of the envelope” calculation to determine if the design met legal requirements. With hindsight it seems obvious that the modification doubles the load on the 4th floor tie rod, but at the time everyone thought someone else had checked it. That’s why it’s good to have an independent person look at the problem, as someone seeing it for the first time will not take decisions for granted.

There were other criticisms of the box beam design. For example, the fact that both the original JGA and HSC designs placed the retaining nuts directly between welded joints in the C-channels that formed the box beam introduced a serious structural weak point. It can be seen from the photograph that the C-channels first split along the weld, deformed and then allowed the bolts to slip through. Calculations have since shown that the structural integrity of the original design achieved only 60% of the required load bearing capacity as instructed by Kansas City building regulations.

Discussion questions on ethical issues introduced by this case study

1. Gillum signed and sealed the revised plans for the walkway construction. In your opinion does that make him the only person responsible for this incident? Explain your reasoning.
2. Companies and professional have liability insurance that will pay out millions of dollars in fines. Discuss whether or not this allows engineers to take more risks, or even discourages accountability. What is meant by the term “accountability” in this context?
3. HSC may have received a rough sketch of an idea by Gillum. Perhaps this was just a starting point which he wanted to get down on paper as quickly as possible. He hadn’t reviewed it, and so was unaware of the intrinsic flaws. HSC for some reason believed this to be the final version and produced their building plans from it. Does this imply that it was a careless error and that nobody was really responsible?
4. Blueprints and build plans are different things. At the end of a construction project a final set of plans are drawn up showing exactly how the building was made and with what materials. Do you think the build plans should be analysed by an independent body for every large structure? Write a few lines explaining how your conclusion is argued.

Further reading (WebPages accessed on 28th July 2009)

1. Hyatt Regency walkway collapse, Wikipedia entry
2. Walkway Collapse, Engineering.com.
   http://www.engineering.com/Library/ArticlesPage/tabid/85/articleType/ArticleView/articleId/175/Walkway-Collapse.aspx
3. "Hyatt Regency Walkway Collapse".
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   http://www.eng.uab.edu/cee/faculty/ndelatte/case_studies_project/Hyatt Regency/hyatt.htm
4. The Pulitzer Prizes for 1982, Pulitzer.org
   http://www.pulitzer.org/cyear/1982w.html

End of Hyatt Regency Walkway collapse Case Study

Bribes and when it's OK to accept gifts

Most people don't see anything wrong with a director of an engineering firm taking a client out to an all expenses paid lunch. After all, this is likely to cement relationships between the firm and the client. What if spouses come along too and it's dinner rather than lunch? Would it be OK for the director to take the client on an expenses paid golf trip, for example? In some cultures and circles it is customary to offer a small gift as a token of sincerity, but it can be a rather grey area determining when a gift becomes a bribe.

In Fledderman's book he puts it this way: "By definition, a bribe is something, such as money or a favour, offered or given to someone in a position of trust in order to induce him (or her) to act dishonestly". Acting dishonestly means unethically and corrupt engineering practices will inevitably harm the public. It is not in the public's favour, for example, for a particular engineering firm to discount its services in an attempt to unfairly win contracts. This is because competition between firms in a fair process of competitive bidding ensures that the customers are getting the best deal at the right price. Offering an unfair discount is similar to a bribe. Small talented start-up companies can never compete against heavily discounted tendering despite the other benefits of a free-market economy.

Small inexpensive gifts are OK and these can easily be declared within the normal rules adopted by the company you work for. At business lunches it is probably safer to share the costs. Try to be aware of the intentions of the person offering the gift. Is there an expectation that their firm will win your contract, or you will purchase their products? The issues to consider are: is there something suspicious about the timing of the gift, what is its value, what is the intended purpose of the gift, are you happy for your actions to be published in a newspaper, etc. If you suspect that the gift is closer to a bribe then you are required by law to reject and report it; a corruption charge is a very serious offence and UK legislation allows both the giver and receiver of a bribe to be prosecuted. Laws in the US (especially) and UK are sensitive to bribery used to secure foreign business deals. Several companies have been caught by this issue when it comes to securing lucrative deals in countries where it is perceived that gifts are a necessary part of any business transaction.

A recent article in the Law Society Gazette (see for example: www.lawgazette.co.uk/features/bribery-bill-and-corruption-clampdown, accessed 29th July 2009) refers to a tightening up of the UK laws on anti-bribery and corruption. It notes that the previous laws were perceived as inadequate in dealing with the bribery allegations made against BAE Systems Plc after it won a £43 billion defence contract with the Saudi Government to supply Tornado and Hawk jets, weapon systems, training and maintenance. In May of 2008 the Telegraph newspaper reported a rumour that "BAE set up a £60 million slush fund to bribe the Saudi princes" (the original story was broken in the Guardian a year earlier). The Law Society Gazette article goes on to highlight a case establishing precedence where a managing director of a UK security firm had been successfully prosecuted for "paying £83,000 in bribes in 2007/08 to two Ugandan officials in relation to a £210,000 contract", receiving a 5 month jail sentence.

When in Rome dilemma

You are an engineer working for an international aerospace company and you have been trying to impress the boss for sometime now. Career ambitions and an expanding family mean that you are desperate to secure promotion, so you have agreed with your partner that you will work overseas for a short time if such opportunities arise: even with the additional short-term strain this creates. If you are honest with yourself, you agree this is going to be a tough challenge. Within a few months of volunteering your boss gives you a project to bid for in a developing country, let's call it AB. The scale of the project is surprisingly bold and involves equipping several of the nation's airports with air traffic control electronics and software. AB has a terrible air safety record and several years back there was a fatal collision between a passenger aeroplane and military jet. This was blamed on the AB's lack of a proper air traffic control system. They are in desperate need of more international trade and tourism; so the struggling AB government has made a commitment to get this new system up and running as soon as possible. You are surprised to discover, however, that all your interactions with AB's government will be through a single official, let's call him John. John has no engineering degree.

You go to AB with your team and prepare to make a technical presentation on your company's radar and software tracking system. There are several other international companies bidding, including the company that promotes itself as having the best technology. You work for a small outfit which subcontracts a lot of its projects, so secretly you would be surprised if you got the contract. The presentation went well and you return to the hotel intending to spend a couple of days sightseeing and relaxing before flying home (safely, you hope). In the morning, you receive an unexpected call from John asking you to meet him for lunch. He only wants to speak to you (the boss, he says) and none of the technical team are invited. You agree and have a simple lunch in a quiet restaurant in AB's capital city. John explains his government's plans for increasing international trade, industrialisation, education, healthcare reform, etc. At the end of the meal there is a long pause and he asks "so, if you get this contract what can you do for me"? Wishing to be polite and feeling a little unsure what to say next, you tell him that he should visit London, bring his family, stay for a long time and see Paris too. He shakes you by the hand and, with a broad smile, tells you that he and his wife would like that very much as they have always wanted their children to go to school in England. Then he offers you the contract. You immediately phone your boss, your partner, the members of team and by the time you get back to the hotel everyone is celebrating.

Solutions to dilemma

The issue is simple; John has interpreted your encouragement for him to pay for his own holiday in London as a substantial incentive, believing that you or your company will pay for it and perhaps as the long-term project develops there will be more of the same. Considering that there is so much at stake, you might be tempted to put the worries about bribery to the back of your mind and just see what happens. Maybe you could work out with your boss how much it would cost to pay for John's family to visit London for a short while and that would be sufficient. It would certainly be in everyone's interest if your company received the contract, and you are eager to do a brilliant job for AB. After all, it's too late now as you've shaken on the deal and everyone's celebrating. It's just the way this country operates, you have to provide some sort of incentive to make the deal – it's us, or someone else will do the same.

Answer to dilemma: Phone John now and explain that there may have been a misunderstanding. It's better to lose the contract than be a party to corruption.

Conflict of interests

According to Fleddermann's book "A conflict of interest arises when an interest, if pursued, could keep a professional from meeting one of his (or her) obligations". There are, of course, many situations that we might consider to illustrate this dilemma. For example, a conflict of interest would arise if you were a consultant acting for two firms who were in competition. How could you ensure that the information you provide to either firm was impartial? If you were a chemical engineer working on a project to dump low level toxicity waste into a local river then you could not volunteer to serve on a committee to review the impact of the waste on the natural environment. How could you remain impartial to any decisions the independent committee wish to make? Similarly, you (or even a member of your family) cannot work as a subcontractor for a company bidding to supply materials to your firm, as indirectly you may financially benefit from the transaction.

It seems that the issue at hand is whether or not you can remain impartial during the decision making process. Some people might argue that they can "wear two hats" and clearly separate one set of issues from another in their mind. However, it is safest not to do this. Guidelines exist within the various professional codes to help you avoid such conflicts. If you work in the financial investment sector for example, then the rules on such matters (insider trading) are extremely rigid and violation will lead to severe consequences. At the beginning of a new contract, if you suspect a conflict of interest to arise then you should declare it from the outset.

When examining your motives, it is helpful to view conflicts of interest as being divided into three distinct groups: actual conflict, potential conflict or the appearance of conflict.

An "actual conflict" will arise when it is clear that impartiality will be compromised as the actual situation establishes a real dilemma. A "potential conflict" is recognised when you suspect that your judgements at some stage in the project may become threatened by bias. What is perhaps surprising is that the professional codes of ethical behaviour strongly advise against even the "appearance of conflict" of interest. This is because perception matters. Although you might believe that you have a clear and unbiased distinction in your mind between conflicting obligations the rest of the world won’t see it that way; the perceived inevitable progression is from “appearance” to “potential”, to “actual”.

Confidentiality and intellectual property

We might all agree that a patient’s medical records should remain confidential; but rules on confidentiality are surprisingly broad for other professionals too. Companies, for example, have rights to exploit their own inventions for their sole commercial gain; otherwise they would not bother engaging in research and development in the first place. Laws exist to discourage companies from stealing data from a competitor in order to gain an unfair marketing advantage. The data referred to here includes: technology secrets, current research projects, details of business transactions, data on product performance, budget allocations, number of employees working on particular projects, marketing and advertising strategies, etc. Being first to market with a new product has obvious economic advantages but it is not always the case that investments in new technology are rewarded by substantial profits. Take for example the battle between two Japanese companies; it took nearly 6 years of legal battles between Nichia and Toyoda Gosei before they could agree on who actually invented the process used to make BLUE light emitting diodes.

The system of patents, copyright protection, agreements to licence and receiving royalties on inventions are instruments of the law that have been in place for many years to protect intellectual property. In fact, the first copyright agreement was signed in the UK in the year 1710, and current law is defined by the 1988 Copyright, Designs and Patents Act. This law reminds us that it is illegal (and some might say unethical) to download copyrighted music directly from peer-to-peer sites off the internet. The ethical issue here relates to income expected by the artist and the company that produced and marketed it.

When you are working for a company you must be sensitive to issues of confidentiality. It is too easy to mention to a friend that your company is developing a new product, or you have just obtained a technology breakthrough relying on a new invention, or that your company is preparing to bid for a big government project, etc. In these cases you may be breaking confidentiality rules and be subject to internal disciplinary action. As a consultant, you may often discuss projects with potential clients and be asked to sign a Non-Disclosure Agreement (NDA) before any technical details can be exchanged. This agreement is legally binding and is a necessary pre-cursor to engaging in collaborative projects. When moving between competing companies you need to be aware that rules on confidentially related to the trade secrets of your previous employer still remain operational; you cannot transfer this information to your new company without breach of confidentiality. An illustrative legal case was Avanti Corp. vs. Cadence Design Systems. Both companies produce electronic circuit design software and have development offices in Silicon Valley, CA. In 1997 eight employees moved from Cadence to its competitor Avanti and began to work on new design tools. However, criminal charges were brought against these 8 software engineers because it was ruled that they had transferred intellectual property developed at Cadence directly into the Avanti suite of software. Five out of the eight went to jail, and Cadence were determined to sue Avanti for a billion dollars, but agreed to an out of court settlement of $195 million.

The fact that confidentiality obligations persist for a long duration should not be overlooked. This especially applies to the Official Secrets Act of 1989. If you work for a company involved in a national defence project then you will be asked to sign a declaration to be bound by this act. In doing so you are legally constrained never to disclose any information, document or other article relating to the security, intelligence or defence of the nation.

Computer related and environmental ethics

The principles already introduced will naturally apply to any new technology areas and environmental issues. The current worries about nanotechnology may have parallels with initial concerns over mobile phones and brain tumours, for example, but the jury has yet to decide. However, it appears that specific attention should be paid to ethical dilemmas that apply to computing and the environment. Certainly, environmental ethics is now a topic in its own right. Operating within ethical boundaries is again made easier by reviewing the codes of ethics published by the appropriate institution to which the engineering discipline belongs, or societies that encompass all engineering activities. The scope of ethical practices relating to computing is probably easier to identify within the contexts of confidentiality, abuse of function, or design negligence.

The 1998 Data Protection Act requires anyone who handles personal information to comply with a number of important principles. It also gives individuals rights over their personal information. There is nothing particularly unique about the legal status of data held on a computer rather than on paper stored in a physical filing cabinet. Personal information should remain confidential whatever format it is stored in.

There are also specific acts of crime that could not have occurred before computers and the internet existed; at least at their current level. This includes propagation of unethical material and illegal financial transactions.

Engineering design is dominated by computer aided techniques and software; effectively allowing engineers with less skill to design complex structures. How can we be sure that a particular implementation of a finite element algorithm obtains the correct answer? It is the responsibility of the design engineer using the software to understand its limitations. Using software beyond its intended limits is simply using the wrong tool for the job at hand. Often it is sensible to validate computer analysis by using several software packages to carryout the same calculation, or even better, do some simple “back of the envelope” calculations to verify that the answers are in the right order of magnitude.

Considering the principles of engineering ethics we have looked at so far, we should note that the development of software programmes is also subject to ethical scrutiny: software can be used to steer a missile system or manage a life support system. Again, application of the ethical codes of practice are required when beginning any new software project, but as software becomes more complex there is a new area of concern relating to verification of the code against its intended practice. A real example to illustrate this issue is the case of the radiation therapy machine called Therac-25 which was responsible for giving six patients massive overdoses of radiation between 1985 and 1987; three out of the six later died. An investigation showed that the engineers had not properly checked the software that dealt with the safety critical systems of the machine, and a bug in this software led to radiation over-exposure under some operating conditions. These engineers were also heavily criticised for producing inadequate documentation for a health care instrument. Nowadays there are established software design tools for verification and ensuring that all the lines of the code have been executed under various scenarios (a process often referred to as code coverage).

Is it possible to write software code that behaves unethically? It sounds a stupid question, but more frequently computer systems are being relied upon to make decisions automatically without human intervention. The recent stock market crash (2009) was probably made worse by the use of computer algorithms automatically selling stock as the market declined in an unintentional positive feedback configuration.

Similarly, most of the issues that might be addressed under the topic of environmental engineering ethics have been covered before. It is only necessary to look to the published codes of ethics and interpret them within this context. Consider again the codes published by the American Society of Civil Engineers (ASCE) and in particular Fundamental Canon 1 and guideline “e”:

1. Engineers shall hold paramount the safety, health and welfare of the public and shall strive to comply with the principles of sustainable development in the performance of their professional duties.

e. Engineers should seek opportunities to be of constructive service in civic affairs and work for the advancement of the safety, health and well-being of their communities, and the protection of the environment through the practice of sustainable development.

The Fundamental Canon, expanded by this guideline, confirms that professional engineers have an ethical responsibility to consider the immediate and eventual environmental impacts of products and processes that they design and/or manage, inasmuch as it affects public safety, health and welfare. This obviously includes long term sustainability of engineering practice and life-cycle management of products. It is a debatable point as to whether or not protection of the environment extends to the protection of animals that share it.

Whistleblowing

Guideline "d" associated with Canon 1 of the ASCE code states:

d. Engineers who have knowledge or reason to believe that another person or firm may be in violation of any of the provisions of Canon 1 shall present such information to the proper authority in writing and shall cooperate with the proper authority in furnishing such further information or assistance as may be required.

When faced with an unethical business conduct or a legal question, the employee has a right and an obligation to seek advice and guidance as necessary to resolve the employee's concern or question. This is called WHISTLEBLOWING and takes two distinct formats.

1. Internal whistleblowing

Internal whistleblowing involves reporting your concerns about unethical behaviour to your immediate supervisor. If this doesn't prove satisfactory then it may be appropriate to take the matter to higher levels of management, but it in all cases the suspected malpractice is kept within the company.

2. External whistleblowing

Perhaps internal whistleblowing has been tried and nobody paid attention. It may then be appropriate to report your concerns to an external body. Sometimes this might be a society or institution, or a government office; but in most cases it will mean speaking to the newspapers. Evidence shows that if you offer to do this anonymously the claims are easily discredited. Frankly, if you decide to go public you have to be prepared to reveal your identity, put your job and career at risk, and expose your family to media attention. Whistleblowing is therefore not something you should do unless you have strong evidence to support your claims, you are convinced that unethical behaviour will be successfully exposed and you have the support of family and friends. It is essential to carefully balance personal risk against professional obligation, perhaps using the decision making tools we have already introduced. When whistleblowers go public, others in the company will stand accused. Once you have "blown the whistle" it is almost certain that you will be suspended from your employment and your relationship with your colleagues will never be the same. Resigning before going public is probably a sensible strategy.

Fleddermann's book offers some guidance on when it might be appropriate to blow the whistle:

1. Need. You are only obliged to whistle blow if there is a clear breach of the ethical codes of conduct, which can be interpreted as putting the public's health at risk. If there appears to be a single incident, appropriately managed by your company, then there is insufficient reason for whistleblowing.
2. Proximity. You have to be in a position to report convincingly on the facts and cannot rely on hearsay or unproven evidence. This

usually means that you have to be in a sufficiently responsible position to have firsthand knowledge.

3. Capability. If you don't have enough evidence to succeed, or you are unwilling to see the process through to a conclusion, then there is little to be gained by blowing the whistle and the personal hardship will be more than the overall benefit.
4. Last resort. Try everything else first, perhaps encouraging other colleagues to act jointly.

To protect a whistleblower (and their family) from retribution the 1998 Public Interest Disclosure Act (UK) provides a framework of legal protection for those who expose unethical practice.

If we return to the Space Shuttle Challenger disaster we might wonder why the engineers involved didn't become whistleblowers. In fact, the three engineers working under McDonald did engage in internal whistleblowing but at the time decided against going public. This was a personal decision based on many factors, and perhaps they were not in a position to prove without doubt that a fatal accident was about to occur. However, during the investigation Roger Boisjoly did agree to expose malpractice within Morton-Thiokol. By revealing the details that led up to the incident he was effectively a whistleblower after the event; but nonetheless his actions probably contributed to the improved safety of future shuttle launches.

Whistleblowing case studies tend to be rather complex, so we won't introduce one here, but I suggest you read one of the "Board of Ethical Review" studies available from the National Society of Professional Engineers website. The following deals with whistleblowing.

www.nspe.org/resources/pdfs/Ethics/EthicsResources/EthicsCaseSearch/1988/BER 88-6.pdf
(Try first: http://www.nspe.org/Ethics/EthicsResources/BER/index.html
- if the link above doesn't work.)

Barriers to Ethical Decision-Making

The ethical behaviour expected of a profession and its governing institutions can be conveniently labelled under the heading of macro-ethics. How individual engineers respond to the moral maze presented to them comes under the heading of micro-ethics. Clearly, it is easier to state the principles that should be adopted by macro-ethics, but in practice it is failure at the micro-ethics level that leads to a blameworthy situation. There may be several reasons why such failure occurs, but two examples might be:

1. Crisis-Oriented Perspective: everything is left to the last minute and the urgent tasks are completed in preference to the important ones.
2. Cost-Oriented Perspective: budget constraints and the need to make savings lead to a cultural of relaxed accountability.

But working within the codes of practice doesn't necessarily lead to the best ethical decisions being made. As described in an article by B.M. Beamon [Science and Engineering Ethics (2005) 11, 221-234] different levels of ethical responsibility are perceived.

1. Minimalist: Engineers must follow the standard operating procedures of their profession, as bound by their employment. The objective of the minimalist is to avoid blame and liability. This is the most common philosophy of engineering practice for most companies worldwide.

2. Reasonable Care: Engineers must consider those at risk of harm from any given activity. The engineer practicing reasonable care will evaluate the risk associated with a technology (or action) and provide proportional protection to society.
3. Good Works: Engineers will act “above and beyond the call of duty” – beyond what can be reasonably expected. The good works engineer will often devote his or her own time to examine potential hazards and take extraordinary steps to safeguard against those hazards.

Concluding remarks

One of the aims of this course is to establish the undeniable principle that a career in engineering comes with certain responsibilities. Put simply, as a professional engineer you will be required to make decisions that constitute an ethical dilemma. Guidance on the boundaries of ethical practice can be found in published codes of practice by various institutions and societies. Many of the issues have been introduced by case studies to help illustrate the complexities of the decision making process and to contrast this against other aspects of your engineering course that deal with unique numerical solutions. It is hoped that by practicing problem solving techniques to the case studies you will be better equipped to deal with such issues in the future. Being able to identify and deal with ethical issues at an early stage in a project will be much better than trying to patch things up at the end. Fortunately, most engineers work in teams, establishing a buffer zone whilst your skills and experience are being developed. In conclusion it is a matter of competence, accountability and moral character.

From Ethics in Engineering by Martin and Schinzinger, page 100.

A Balanced Outlook on Law

Hammurabi, as king of Babylon, was concerned with strict order in his realm, and he decided that the builders of his time should also be governed by his laws. In 1758 B.C. he decreed:

"If a builder has built a house for a man and has not made his work sound, and the house which he has built has fallen down and so caused the death of the householder, that builder shall be put to death. If it causes the death of the householder's son, they shall put that builder's son to death. If it causes the death of the householder's slave, he shall give slave for slave to the householder. If it destroys property he shall replace anything it has destroyed; and because he has not made sound the house which he has built and it has fallen down, he shall rebuild the house which has fallen down from his own property. If a builder has built a house for a man and does not make his work perfect and the wall bulges, that builder shall put that wall into sound condition at his own cost."