# Rethinking engineering

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THE tragedy of the Concorde crash and the destruction of the Twin Towers made 2001 memorable. Both were engineering feats and landmarks in their own field. Their destruction has meant the loss of human lives.

The importance of risk and reliability analysis in engineering now appears to be growing in importance by the day.

The risk, safety and reliability methodology has come out of its childhood, it is now in its youth and has yet to mature. However, due to these recent developments the urgency to reach maturity has now hastened.

To an engineer the 'risk' associated with a hazard are a combination of a probability that that hazard will occur and the consequences of that hazard.

Consequences include injury or loss of life, reconstruction costs, loss of economic activity and environmental losses.

When explicitly addressed, a risk analysis is carried out and the result is compared with the maximum acceptable risks. These fundamental levels of safety have to be acceptable to society as a whole, for it is on their behalf that engineers make such decisions.

The UK Health & Safety Executive (HSE) has defined a maximum level of risk, which is just tolerable, and a minimal level below which further action to reduce risks may not be required.

The target probability for one year should be 1/10,000 per year per person, for 'normal cases', as this is what society nowadays seems to accept or is unavoidable anyway. For voluntary activities involving economic benefits or other profits, a higher value may be considered as acceptable.

However, if somebody is involuntarily put at an unnatural risk from which he has no benefits at all, such as those living close to a nuclear plant or near a transport route of dangerous materials, the target must be lower – at 1/100,000 per year per person.

Yet further risk reduction measures may be considered in relation to a *de minimus* annual risk levels (i.e. the levels below which risks are of no legal concern), of 1/1 million per year per person for a worker, and 1/10 million per year per person, or 1/100 million per year per person, for a member of the public.

High safety class represents situations when failure can result in large societal consequences and risks of injuries. In practice, all road bridges belong to high safety class.

Structural Eurocode1 differentiates structures in relation to risk to life, and risk of economic and social losses as in Table 2. Eurocode1 also refers to Design Working Life as referred to in Table 3.

It is to be noted that the Very High Safety Class as listed in Table 2, is not included in the partial safety factors to be adopted by structural engineers. The consequences here are regarded as extreme and a full cost-benefit analysis involving estimates of the monetary value of potential costs and benefits is necessitated.

The evaluation of economic costs and benefits is relatively straightforward, but the evaluation of monetary costs associated with risks of death is controversial as it involves assigning a monetary value to life.

Risks are acceptable if the cost of further risk reduction measures would be higher than the monetarised risk reduced by these measures. The figures in millions of euros per life saved were applied in a 'Risk-Based Regulation' project (Table 4).

These values are to be treated with reservations, as it is claimed difficult, unethical and even impossible to make a valuation of human lives. The value of life appears to be assessed differently according to geography and the social development. The integration of economic losses and human safety needs further attention with the QLI (Quality Life Index) approach appears to be promising.

Furthermore any procedure for determining a monetary value of life may be challenged from a philosophical point of view. The conclusion of this analysis might be that the structure should not be built at all.

The Twin Towers, besides being functional super high-rise office buildings were also monumental buildings, not meeting risk requirements. This placed them in the very high safety class of Table 2; thus, besides requiring higher partial coefficients for its design, it also necessitates a full cost-benefit analysis prior to proceeding with the project.

Clearly the first step is to create a language by which to assign risk – a language that can be used by designers when they are engineering a solution beyond the norm.

The World Trade Centre tragedy, although it is universally accepted that the structure performed far beyond the requirements of building codes, has changed the attitudes of many structural engineers and convinced them that fire design is as much an engineered process as wind, gravity and earthquake design.

While codified design is suitable for 'normal structures', it is apparent that for novel structures regard has to be taken of methods of probabilistic risk analysis. Together with refined statistical models of loading and material resistance a direct determination of failure probability may be the basis for decisions of the design.

For important projects it may be feasible to reduce the uncertainty by updating the assumed physical models by test programes.

The updated figures are used to estimate the structural reliability and the risk to the users. Structures for which it is not practicable to reduce risks to negligible limits include those that are exposed to significant risks of extreme loading (e.g., due to severe earthquakes, hurricanes, cyclones or landslides). Appropriate risk-acceptance criteria related to societal expectations of life protection need to be identified.

During its lifetime a project goes through a number of distinct phases. During the different phases it may have varying characteristics, with the risk varying from phase to phase.

A number of decisions will have to be made during its lifetime and different decision makers will make these. A 'log file' containing all relevant data on the history and decisions taken on the project should be readily available, as a common framework for risk and safety considerations to be taken during different project phases.

The wrong decisions taken during the Twin Towers evacuation, while still standing after the terrorists' strike, cost dearly in terms of human lives lost.

"Will we ever build high-rise buildings again?" The answer is "yes", for until we find a way to move people horizontally as efficiently as lifts can move them vertically, there will remain the need for high-rise structures, including super high rise structures, grouped together in downtown areas.

Besides the important issue of increasing structural robustness in case of extreme events, such as aircraft impact and the ensuing fire, the second issue is the rapid evacuation and saving of lives.

Clearly, trying to evacuate people through the damaged building, particularly from the floors above the impact levels is presently hopelessly inadequate. Each tall building should have a defined range of airspace around it, with automatic alarms activated for full-scale evacuation, an additional safety net also being suggested.

There should be alternative means of escape, group parachutes from various levels being suggested, together with massive helicopter rescue facilities from movable pads. Should the tall buildings be constructed as groups with interconnections at various levels for rapid evacuation, such as at the Petronas Towers in Kuala Lumpur?

With our increasing wealth, safety is an ever-increasing requirement from society. Whereas absolute safety is an illusion, tools exist for achieving a trade-off, which is an optimum with respect to the aims of the decision-maker. The techniques for risk and reliability can be applied with benefit in all phases of a project.

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**TABLE 1 – levels of risk:**

| | |
|---|---|
| Workers all occupations (upper limit) | 1/1000 per year per person (10-3) |
| Public at risk from industrial operations | 1/10,000 per year per person (10-4) |
| Public at risk from nuclear industry operations | 1/100,000 per year per person (10-5). |

**TABLE 2 – examples of reliability differentiation according to life and economic and social loss risks.**

| Degree of reliability | Potential risk to life, risk of economic and social losses | Examples of buildings and civil engineering works |
|---|---|---|
| Extremely high | Very high | Nuclear power reactors, major dams and barriers, strategic defence structures |
| Greater than normal | High | Significant bridges, grandstands, public buildings where consequences of failure are high |
| Normal | Medium | Residential and office buildings, public buildings where consequences of failure are medium |
| Less than normal | Low | Agricultural buildings where people do not normally enter, greenhouses, lightning poles |

**TABLE 4 – Giving a value to human life**

| | |
|---|---|
| Category 1: voluntary risk exposition, e.g. dangerous sports | no compensation/life saved |
| Category 2: direct individual benefit, e.g. car driving | 2.75 euros/life saved |
| Category 3: individual benefit, e.g. working conditions | 6.70 euros/life saved |
| Category 4: involuntary no direct benefit, e.g. vicinity to dangerous installations | 13.5 euros/life saved |

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**TABLE 3 – design working life examples**

| Design working life | Examples |
|---|---|
| 1-5 years | Temporary structures |
| 25 years | Replacement structural parts, e.g. handrails, small canopies, protective features (slats, caps, etc.) |
| 50 years | Buildings, footbridges and other common structures |
| 100 years | Monumental buildings and other special or important structures |
| 120 years | Highway and rail bridges |