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Hazard loading in the Nuclear Industry
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Introduction

Structures that are important to nuclear safety need to resist hazard loads, so far as reasonably practicable. Structures that store nuclear waste can generally not be taken out of service in the event of problems, and many are now beyond their original design life. Some being designed now have service lives of 100 to 150 years. Existing buildings have had to be assessed against hazards that were not in the original design. It is very likely that further hazards will be identified during the life of these structures. In civilisation as a whole, the rate of change is increasing, not decreasing, and there is no reason to expect nuclear safety to be any different. We should expect to see more changes in nuclear safety standards in the next 100 years than we have seen in the last 100 (ie, since 1904). The "modern standard" for hazard loading changed dramatically as recently as September 2001.

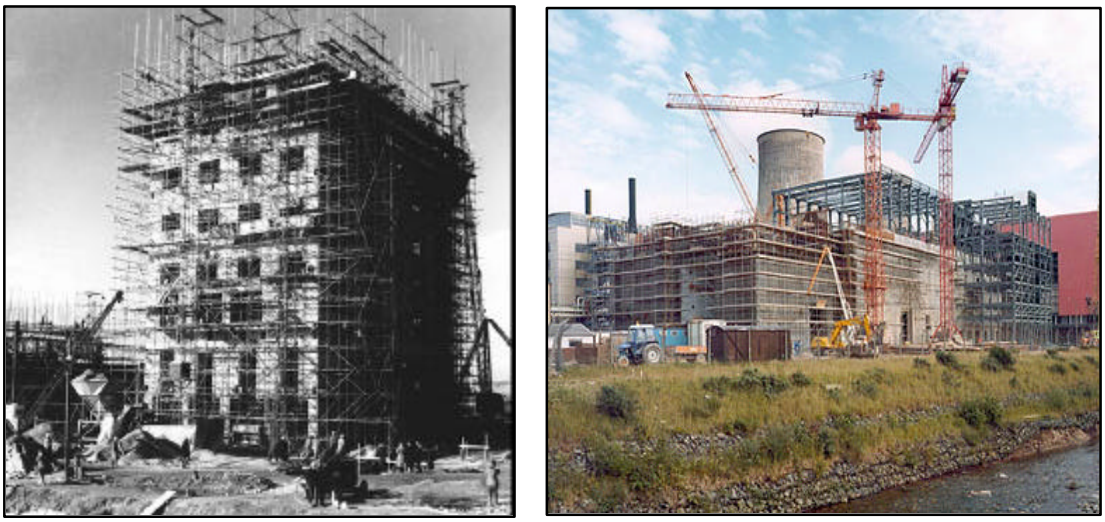

Fig 1 Typical nuclear process plant structures, 1948 and 1985

We therefore need a robust design approach for both specific hazards and overall performance. In general, when structures fail, the hazard that causes failure is not one that was designed against. In particular, hazards from terrorist action are by their very nature unpredictable. If the terrorist finds out what you have designed against, he will try something different.

We also need a pragmatic assessment approach, for new hazards acting on existing structures. We cannot afford to be too pessimistic. Modifications or premature replacement of nuclear structures will incur not only financial costs but also risks to workers. Radiation dose can be reduced but not eliminated by good working practice.

Discussion

The structural design or assessment must be closely linked to the Safety Case. The Safety Function is a useful concept. This defines the required structural performance, for safety purposes, in response to normal operational loads, faults or external hazards. In many cases, a structure can enter limit states that would traditionally constitute structural failure, while still delivering the safety function. The concept of Safety Function also requires a Safety Function Class, indicating the level of importance to safety, and implying a requirement for a corresponding level of confidence.

How do we define the level of confidence? Are probabilistic methods applicable? Probability data is scarce. The probability of failure of a light bulb can be based on the experience of millions of light bulbs. How many real structures designed to CP114 have been subjected to a UK earthquake with a zpa of 0.25g?

We have no data for the probability of terrorist attempts, only two examples of the real performance of structures deliberately struck by an airliner, and no data at all for the hazards we don't know about yet! If we tried to use traditional probabilistic methods, the bounds on the results would be so large that the results would be meaningless. Bayesian methods are worth exploring, but are not yet widely accepted.

We must therefore take a deterministic approach. Formal definitions of probabilistic and deterministic assessment are hard to find; the following are proposed:

- The objective of probabilistic assessment is to confirm that the total predicted probability of failure [however failure is defined] is less than a specified target. This requires knowledge of the probability of occurrence of each load case, and the probability of each component responding in a particular way.

- The objective of deterministic assessment is to confirm that the structure meets criteria defined in a code of practice, in which case it is deemed to have an adequate level of reliability. The partial factors in the code may have been derived by probabilistic methods, or may be based on historical adequacy.

Does a typical structural engineer understand what is implied in the calculations that show whether the structure complies with the code requirements? It may be argued that for most buildings such understanding is not necessary, but for nuclear work, where being over pessimistic may be as serious as being over optimistic, there is a need to break away from the mechanistic approach. The approach must still be justifiable, both within the nuclear site licencee and to the regulators.

Generally, current detail design methods are pessimistic, in some cases substantially so. For the design earthquake, the calculated energy in the seismic response of a typical nuclear structure at Sellafield, calculated using spectral velocity and $\frac{1}{2}mv^2$, represents about 25% of the fracture energy at the earthquake hypocentre!

Historically, we have set the partial factor on loads to unity when considering hazard loading, on the basis that the loading itself was an extreme value. This may be more difficult to justify for impact loads than for earthquakes.

When considering existing structures, it may be possible to justify using material properties, and partial factors, based on measurements rather than the original design specifications. Again, this requires a formal basis, not just a few samples.

Design codes are not necessarily suitable for assessment. The code tells you "if you design to these rules, the structure will have an acceptable level of reliability". It says nothing about structures that do not meet the rules. The only tools we have here are basic structural understanding, judgement and peer review. To permit the use of engineering judgement, peer review is essential.

Examples

Two specific internal hazards in the nuclear industry include hydrogen deflagration and impact of dropped fuel flasks. These are examined below, as examples of the issues involved.

Hydrogen deflagration

Hydrogen can be generated by breakdown of water under radiation, or by reaction of water with various metals. It is often impossible to predict whether hydrogen will be generated, or how much, and the rule is therefore to design on the expectation that hydrogen will be present. For a new plant, the ventilation design would be based on sweeping hydrogen out of places where it might accumulate.

For older plants, the existing ventilation system may not have been designed for this, and radiation may make modifications difficult. To ensure that the plant is safe, the structure or vessel should thus be capable of taking the pressure resulting from a hydrogen deflagration. Again, the safety function is crucial; what condition is acceptable after the event? What precautions are required to prevent the deflagration triggering others? If a structure is not adequate, should it be strengthened or replaced?

Alternatively, the cost of remedial work might be so large that taking into account the consequences of failure and the best estimate of the "real" risk of hydrogen it is not reasonably practicable to do other than accept the risk, provided this is tolerable.

Flask drop impact

Nuclear materials often require substantial shielding, resulting in transport flasks weighing over 100Te. The assumption in the safety case is that the crane may fail, and the flask would impact the floor below. Consider here the effect of damage to the flask, although the damage to the floor may also be unacceptable. If the flask bursts, or the lid is dislodged, the radioactivity is released to the local environment.

Fig 2 - Nuclear Fuel Flask (80Te)

The ideal solution is to avoid the risk at source, ie, design the plant so that it is not necessary to lift the flask. The next most ideal is to design the crane to a sufficiently high reliability that a dropped load can be ruled out. Usually, this is not possible; the generally accepted cut-off risk is 10^{-7} per year, and a crane includes too many moving parts and electrical components. The next choice is to ensure that the flask will tolerate any conceivable impact (which is one reason why flasks are so heavy).

For an existing plant, not designed to current standards, it is necessary to understand how the crane and flask compare with the ideal. It is then necessary to see whether the risk is acceptable. This can involve a lot of work, and may not advance safety. The best approach may be to find the weakest link in the safety case, and see how it can be improved.

Conclusions

The nuclear industry works with long timescales and unusual hazards. The presence of radiation limits the opportunity to modify structures to keep up to date with modern standards and perceived threats, and it is necessary to minimise pessimism in assessment. This requires a fundamentalist approach, reliant on understanding more than computer models and design codes. At the same time, assessments must be both pragmatic and transparent and must use "best practice". It is particularly important to understand how structural performance fits into the overall context of the safety case.