AN OVERVIEW OF THE PROCEEDINGS

This Overview gives a flavour of two days of presentations and discussions and does not attempt to summarise the content of the papers and presentations, most of which are included in the Proceedings. Some of these presentations demonstrated how far the state of the art has progressed in computer modelling and physical modelling of impact and in displaying the complexities of structural behaviour. The challenge is to match this capability with a clarity of thought with which to direct our actions.

We start with the main conclusion: all buildings are potentially subject to accidental loadings and the only significant protection is via inbuilt 'robustness' however that may be defined. We agreed that engineers have the duty to provide robust structures but it is far from clear how this is to be achieved and to what degree. The issue is pressing since the new revision to Part A (Structure) of the Building Regulations will require 'a systematic risk assessment' of foreseeable hazards for a new - Class 3 - category of structures. This includes hospitals over 3 storeys, most other buildings over 15 storeys, public buildings over 5000 m^2 and stadiums accommodating more than 5000 spectators.

Is this a sensible list of structures to be assessed with risk analysis? What hazards should be considered? What risk is acceptable? Society's expectations are changing, and in the context of BSE a report had called for 'zero tolerable risk'. How do we define and measure robustness? Should the process be prescriptive or should it be more free thinking? These were some of the thorny issues debated. There are of course well known failures from lack of robustness, starting with Ronan Point and the progressive collapse saga. It was noted that the tie force rules we use were conceived for this particular panel system structure, but are not so relevant for most current structures. More recently, the failure of Piper's Row car park is a forcible reminder that robustness exists at a point in time and natural degradation processes superimposed on weak structures have the power to initiate sudden collapse.

In some industries, systematic approaches are made to assure capacity via the definition of basic fault or hazard loadings. The structure is then 'tested' against these. The nuclear industry is one such industry achieving high reliability via this method. But the nuclear and other industries, such as the leisure industry in designing fairground rides, additionally require a systematic examination of the all the engineering disciplines involved in the project looking for what might go wrong, learning from past failures and seeking to minimise the chances of fault and eliminating the adverse consequences when the faults cannot be avoided - summarised as Prevent, Protect, Mitigate.

Never forget the Prevent option. It is standard in modern nuclear plant never to lift heavy loads for fear of dropping them and having to design against impact. In more normal industries there may still be choice. For example it was pointed out that we are building high value structures close to waterfronts where they are inherently at risk from ship impact. Siting them just a little way back achieves significant protection. Similarly, increasing the stand off from blast loading is enormously beneficial

In bridge design, the approach to hazard and accidental loading is traditionally more prescriptive. Some of the presentations covered this area, and one made a plea that equivalent static loads should be specified with a defined duration so that designers would have the option to benefit from the resilience of their structures. One of the participants was responsible for a key standard in this area and was receptive to the idea. Hopefully there will be at least one clearly identifiable outcome from the Colloquium.

Impact loading on parapets and the risk of shipping collision for bridges over water are obvious dangers. Do they get too much attention? Taking ship impact as an example it is clear that probability and mitigation measures, as well as the costs of protection and the consequences of failure (both direct and consequential) are all matters to be weighed up and judged when deciding what the appropriate design basis should be. Bridge design also exemplifies the significant fact that economic losses to the community consequent on failure may be totally out of proportion to the costs of avoiding the loss in the first place. But what needs to be done? This is the classic dilemma of a low probability / high consequence event. In weighing up the pros and cons, the cost of business loss, the costs of life loss and the costs of asset loss all need to be weighed in the balance.

There were some participants nervous about risk based approaches because they could be time-consuming and they offered an apparent rigour which can often be deceptive. The choice of question that can be addressed is skewed by the availability of quantitative data. They are sometimes used simplistically in pass/fail systems which are administratively attractive and potentially less confrontational. There was a desire for the rigour of risk based approaches, without the constraints. Someone called for "risk assessment with imagination." The solution might lie in the presentation given on Bayesian statistical techniques because they can incorporate subjective judgements. It may be just what is needed to give value to the flood of risk assessments responding to the new Building Regulations.

While discussing numeric approaches to risk an anomaly was identified: The accepted risk of ship impact on a bridge is quoted in AASHTO and the ISO code as 10^{-4} p.a., whereas the risk usually accepted for variable loading is 10^{-6} p.a. Is this an inconsistency in structural practice, or is it a case that like is not being compared with like? Either way, it is clear that most engineers are unfamiliar with the magnitudes, and also the concepts, which underlie a numerically based risk approach.

The general mood of the Colloquium was that in high value structures especially there was real need for the exercise of professional informed judgement tempered by peer review when considering the likelihood of accidental loadings and how they should be treated. It was strongly felt that 'Regulation' should only be there in the background. In conducting any of these processes, the design team and owners must realise it is their prime duty to provide adequately safe structures and their first responsibility is to satisfy them selves rigorously that what they have done is enough. The Regulator may set the hurdles, but the team should cross them. The process should not be focussed on doing something just to satisfy the Regulator. His role should be limited to that of audit.

A comment was made on a difference between US and UK practices - characterised as US authorities emphasising the importance of the qualifications of the decision maker, and UK authorities putting more emphasis on recording the basis of the decision. Among the case histories presented to the Colloquium were two where design changes made without an understanding of the original design strategy had led to a failure and a near miss. The latter approach was favoured.

The Colloquium was reminded that experience shows we are unlikely to foresee all the demands made on the structures we design. Not least because of the increasing threat of terrorism. And even this is changing. We used to have bombs with warnings of their placement and location defined. Now we have bombers prepared to die and attacks with no warnings.

So we generally conclude that structures important to our national security and economic well being will be subject to accidental loading of some kind; some of these will be reasonably foreseeable, many ill defined but there is a fair expectation that over a long life our structures will be called upon to withstand loading as yet unimagined - genetically modified exploding squirrels were mentioned! The obligation is to provide a general measure of robustness. Codes can go someway to assisting in this but robustness is a more imaginative quality to be built in by experienced engineers: it is to do with structural form and a multitude of other attributes. There was a hope across the Colloquium to be able to measure or quantify robustness in some way. Formal concepts of "unzipping" and "clustering" were presented, but these are at an early stage. In the meantime the group felt there were various tests that could be made all pointing towards this elusive quality.

The presentations were diverse, but many common themes emerged. In dealing with many buildings, bridges and high profile facilities the loads and conditions to be sustained are necessarily vague. In nuclear structures, it is common to schedule out various hazards and extremes events which are described in the Design Basis, but beyond this there is a need to reflect on the actual structure, and how it will respond to the undefined hazards that might affect its safety. The nuclear industry also wrestles with the complex legacy of older structures beyond their design life, and yet still required to function. Engineers face the challenge of assessing the risks they pose and deciding what to do about them and their contents. It is accepted that many hazards may not be definable.

The subject of robustness arose in all our discussions. The following is an attempt to indicate the view of the Colloquium.

Robustness is a mixture of:

- Understanding as much as we can about the hazards
- Providing an appropriate structural form
- Detailing rules
- Construction quality.

The degree of attention we give to hazards needs to be proportional to the building use. EN 1991 and the new revision to the Building Regulations provide a framework for this. the latter requiring, for Class 3 structures, a 'systematic risk assessment' of foreseeable hazards. The nuclear industry has a list of 44 hazards, but for most buildings it was suggested that the hazards were not knowable, and the undefined hazards could be 'enveloped' by three standard events:

- An internal gas explosion
- An external blast
- An impact.

These would provide a specific, quantitative test for robustness.

More generally, robustness of the structural form can be tested by posing certain qualitative questions:

- Is the structure redundant?
- Are there alternative load paths?

- Are the load paths diverse?

- Is the structure insensitive to minor deviations in material strength? Or in member position?

- Do we understand the mode of failure? Is it slow or sudden?

- Is the mode of failure ductile and energy absorbing?

- Is the failure stress or displacement controlled (the latter is far more conducive to robustness)

Some of these can be tested mathematically. The technique of 'push over analysis' used in seismic design will give insights into the collapse system and the ductility demand made on joints, and should identify the 'weak link'. Other techniques are being developed. Many experiences in blast resistance plus observations after earthquakes reaffirm the crucial role of joints in providing a frame with robustness. All joints need to be capable of carrying normal loads and be capable of sustaining imposed distortion without fracture. One of the presentations showed a simple design method for steel frames which put the strength in the connections, with considerable savings in the beams when compared to limit state design.

Another analysis technique to identify the mode of collapse, and the weak link, is to carry out a cliff edge assessment as adopted for nuclear structures. The performance of the structure under overload is examined to assess the closeness of the 'cliff edge'. Primarily there should not be one, certainly not one close. Rather the objective is to avoid sudden failure and to seek a progressive mode of ever increasing displacement.

We learn much by experience, and younger engineers need instruction in the mistakes of the past. We also learn from those structures that have been subjected to significant accidental loading yet have not collapsed. As a generality, the Colloquium felt that any 'innovative' structure would score minus points on the robustness scale simply because its behaviour may contain actions which are overlooked. There are plenty of examples of novel structures failing, as was demonstrated in one of the case histories presented.

Finally and collectively we conclude there is much to ponder, much to learn and much to do.