11 Upper Belgrave Street
London SW1X 8BH

Chairman: KATE PRIESTLEY MBA CQSW HFIHEEM FRSA
Secretary: JOHN CARPENTER CENG FICE FISTRUCTE FIOSH

SC/06/28

(Derived from a paper for the BRE Workshop on Robustness held in December 05)

SCOSS welcomes comments on this paper

A RISK MANAGED FRAMEWORK FOR ENSURING ROBUSTNESS

Key words: competence, people, process, product, robustness

Abstract
This paper describes an holistic approach to the process of ensuring robustness, utilising appropriate people, processes and products. It emphasises the need for a team approach having regard to all the stages in the structures life, and all the parties involved. It is placed on the SCOSS website for information and discussion. It does not deal with the technical detail or options to assuring robustness.

Introduction
The Standing Committee on Structural Safety (SCOSS) is concerned with the identification of trends or practices, including gross errors, which might give rise to a diminution of the anticipated margin against failure.

The Committee has been in existence for 29 years and over that time it has been able to initiate debate and action on a number of important topics. The extent of its deliberations may be seen by reviewing the 15 biennial reports and other publications which are all available on the website [1].

The subject of robustness has been a longstanding item on the Committee's agenda [see for example references 2 and 3].The concern has extended beyond interest in just the physical means of achieving adequate robustness- ductility, alternative load transfer paths and robust fire protection as examples- to include the process of identifying the need in the first instance, and the somewhat unsatisfactory framework (regulatory and contractual) within which these deliberations and subsequent decisions take place in the UK.

The Committee has in particular emphasised the desirability of risk based approaches to ensuring robustness, as a means of encouraging a broader appreciation of the influencing factors, and avoiding the trap of limiting the design process to a mechanistic use of design codes.

Background
This paper does not attempt to deal with the technical preferences or efficacies of various physical measures to ensure robustness, nor to enter the debate regarding performance versus prescriptive approaches, except in so far as these debates allow and encourage a proper appreciation of risk. It is instead designed to promote discussion regarding a risk based holistic approach to the consideration of robustness which will have a reasonable chance of identifying all the significant influences over the entire lifespan of the structure.

Approach to Robustness

The Standing Committee on Structural Safety is an independent body supported by the Institutions of Civil and Structural Engineers and the Health & Safety Executive to maintain a continuing review of building and civil engineering matters affecting the safety of structures.

Tel.: +44 (0) 20 7235 4535 Fax: +44 (0) 20 7 235 4294/201 9165
Email: scoss@istructe.org.uk Website: www.scoss.org.uk

To achieve robustness we need to ensure that all the influencing stages and activities are included in the considerations, and that they are accomplished competently. The issues needing to be considered to ensure provision of adequate robustness may be considered under a number of heads as shown in Table 1.

	Stage of project:	Issues to be considered at this stage:
1	Analysis and Design	• ensuring that those involved are competent in this field. • identification of hazards and resultant risks affecting robustness in Stages 2-5. • quantification of significant residual risks. • choosing appropriate design details. • advising constructors and future owners of assumptions associated with the design detail adopted (via the drawings and health and safety file[1]). • the need for an independent review of design (supplementary to numerical checks). • having an overall point of responsibility.
2	Procurement	• competency of those organisations procured. • 'best value' tendering • clear lines of responsibility and authority. • clear reporting protocols. • adequate information for planning and pricing construction phase. • adequate specification. • inclusion of adequate monitoring procedures (avoidance of self-certification approaches)
3	Construction	• ensuring that those involved are competent in this field. • understanding the stated objectives and purpose of the design. • identification of hazards and resultant risks having regard to temporary conditions. • implementing the strategy outlined in the health and safety plan or elsewhere. • ensuring contractor-design is co-ordinated. • ensuring adequate monitoring, reporting and action where required.
4	Operation	• ensuring that those involved are competent in this field. • implementing the strategy and requirements outlined in the health and safety file. • ascertaining and managing the effects of changes/refurbishment. • ensuring adequate maintenance of critical items. • ensuring that those involved are competent in this field
5	De-commissioning	• identification of hazards and resultant risks, specifically those outlined in the health and safety file. • having regard to temporary conditions.

Table 1: Stages to consider

Note that 'design' can occur anywhere within Stages 1 and 3. Although ultimately contractors have the responsibility for managing risk (and hence adequacy of robustness) during Stage 3, this should be assisted by relevant and appropriate information from designers. 'Designer' is intended as a functional term and does not necessarily relate to the organisation.

[1] A legal document arising from the UK Construction (Design and Management) Regulations 1994, which in turn arose from EC Directive 1992/57.

The degree to which designers need to anticipate risks arising from their design and which might affect contractors is a subject of debate. This matter is complicated by modern procurement routes where detailed design is often completed by sub-contractors (steelwork connections for example), and some key elements are designed by manufacturers through test rather than calculation. Ensuring the appropriate interface is achieved between these items can be important in terms of ensuring robustness. This requires clarity of responsibility at both physical and contractual interfaces.

The needs of the operational phase, in the light of the World Trade Center (WTC) attack, have received very detailed attention and remain in a period of new development and consideration [4,5]. The industry has been urged [4,5] to implement necessary measures ahead of the revision to codes of practice and other requirements.

This topic should not be considered as one for large or high risk structures alone. SCOSS has received submissions from the profession which indicate that some building submissions for minor structures feature gross deficiencies which would lead to poor robustness.

The Legislative Requirements

UK building legislation generally concentrates on design rules[2] designed to ensure the robustness of the completed structure, but does not set standards or explicit obligations for the maintenance of the structure once built.[3] The UK's building codes, delivering the requirements of the Building Acts[4], have explicitly addressed the need for adequate robustness for some years and specifically since the collapse of the Ronan Point flats in 1968. Robustness is generally dealt with in design codes by:

- Ensuring systems exist to tie elements together, and distribute loads in the event of an exceptional event.
- Designing certain key elements to have enhanced resistance
- Ensuring resistance to fire

The Building Regulations in England and Wales have recently been revised (December 04) to bring most buildings within their remit in respect of structural robustness.[5] Importantly also, buildings that fall into the highest category (Class 3) are now to be designed against disproportionate collapse using a risk assessment approach instead of the more prescriptive rules applying to Classes 1 and 2. As the Class 3 category lacks any prescriptive requirements, there is a need for formal guidance to ensure that there is uniformity of approach and rigour of analysis, and that an accepted minimum standard applies (Reference 6 gives some general guidance). A Class 3 structure would normally be expected to satisfy Class 2B requirements as a minimum.

Occupational health and safety legislation (Health and Safety at Work etc Act and subordinate regulations) creates obligations on specific parties to ensure safety at all times during construction and decommissioning, and for those periods in its operational life that a structure (building) is a 'workplace' or part of the undertaking –these requirements are set out in terms of risk management i.e. they are performance led rather than being prescriptive. The

[2] although designers are able to use alternative approaches if they are justified

[3] an exception is where a building is in a dangerous state and action is taken by the local building authority.

[4] These differ to varying degrees between Scotland, England and Wales and Northern Ireland

[5] prior to this they applied only to buildings over 4 storeys in height.

Workplace (Health, Safety and Welfare) Regulations require workplaces to have 'solidity and stability' although the Health and Safety Executive has not yet offered any guidance on this requirement. The Author would argue however that this legislation is a blunt tool for ensuring that robustness is built-in, as opposed to identifying fault or deficiency after an adverse event. SCOSS has addressed shortcomings in legislation in a Topic Paper [7].

A major concern in ensuring the continuance of robustness is that subsequent maintenance, alteration or refurbishment works have the potential for disturbing key robustness measures e.g. fire stopping or fire protection to steel members, without any formal inspection or 'sign off' of critical work. Some have called for the licensing of buildings as a means of regulating work (often undertaken by other disciplines e.g. M&E contractors) that may have a detrimental effect upon the structural integrity of the structure.

The Construction (Design and Management) Regulations 1994 (CDM) require a 'health and safety file' to be created. Although this has to contain details of significant risks that may arise during the life of the structure, it is slanted towards personal risk, rather than risk to the structure itself. Anecdotal evidence suggests that the contents of the file are often poor, and its very existence is often not assured despite its legal status. The provision of a building 'log book' has been suggested but this currently has no legal status or universal acceptance and hence lacks an adequate 'driver'.

Recent Developments

The collapse of the WTC has undoubtedly brought the subject of robustness, and disproportionate collapse in particular, to the fore, and, whilst the event was exceptional both in likelihood and severity, it has nonetheless raised a number of issues which are pertinent to lesser buildings. This emphasises the essence of a risk managed approach. SCOSS made this point in the 14th Biennial Report in relation to the IStructE report on *Tall Buildings and Other Structures* [5]. An extract from Chapter 2 of the Biennial Report reads:

> 2.10 Although the (*IStructE*) report concentrated on tall buildings, or those with large occupancy, it was notable that, as indicated above, many of the recommendations were equally applicable to structures of all sizes, i.e.:
>
> i) there may be buildings not considered to be above the trigger points of large and tall, but which are nonetheless susceptible to extreme events by virtue of use, occupancy, or proximity to other structures of larger size,
> ii) other 'structures' may be equally susceptible to extreme events particularly those with minimal redundancy e.g. grandstands.
> iii) many of the principles that the report outlines in terms of robustness, means of escape etc make good engineering sense for any building, even in the absence of extreme events, and hence there is merit, and opportunity, to encourage decision makers on all buildings, to assess the consequences of their design through a structured risk management process.
>
> 2.11 As is the case with risk management, the particular circumstances would determine the relevant events to be assessed and for many structures the list of risks would rapidly reduce to 'commonplace' eventualities. The key message is that the need to consider risk holistically applies to all structures, and that this exercise will bring general benefit to facility owners and operators, as well as enhanced safety.

The USA NIST[6] report [4], recently released for public comment, supports many of the IStructE report recommendations. It is usefully summarised in reference 8. It emphasises that improved resistance does not just come from enhanced structural form; improved

---

[6] National Institute of Standards and Technology

management, protected lifts and more careful positioning of plant can all contribute to the overall robustness of the building, i.e. it requires an holistic inter-disciplinary risk based approach.

Recommended approach

SCOSS considers that such an inclusive approach is the appropriate way forward. In this respect it is suggested that robustness is best assured by considering the process having regard to the following:

People: In order to ensure robustness as indicated in Table 1 it is necessary that those involved in the conceptual decisions, the design, the procurement and construction and subsequent management of the building are competent to undertake the allocated task. These competencies should include those of the experienced engineer who is able to stand back and take a project overview.

Currently few of the construction institutions actively validate the on-going competence of their members once formally qualified, although all members have an individual responsibility to maintain their skill base and not to undertake work for which they lack competence. The concept of certified engineers, whose competence is evaluated periodically, has its attractions.

It is considered that a number of the skills associated with assessing robustness, in the holistic manner outlined, should be acquired in the first instance at university during the education phase; this was strongly advocated in the 15th Biennial report [12]. The concept that there is no exact answer to a structural engineering problem and that the analysis and chosen solution may be affected by a range of unknowns and uncertainties is an important aspect to engineering competent solutions. Much of this skill can only come with experience, but the underlying philosophy- that of managing risk- is one that requires early establishment.

Process: The process of achieving robustness has a number of facets which have the potential for allowing a weakness or serious fault to occur e.g.:

Element	Comment
Analysis Model	Does the model of the structure replicate actual behaviour with sufficient accuracy? Has the model been validated and are the results verified? Does the analysis allow for temporary conditions?
Actions	Have all foreseeable events been included (or knowingly omitted)? Are dynamic actions likely?
Structural Details	Do they meet current thinking in respect of robustness measures e.g. do they have sufficient ductility? Is there likely to be a misunderstanding/omission of data between different designers (e.g. engineer/architect) or where design responsibility is often passed on to others e.g. steel detailing, reinforced concrete slab design? Are the details practicable (i.e. buildability and maintainability issues)?
Use of Codes	Does the structural concept lie within the boundaries of code assumptions?

Element	Comment
Best practice	Does the design make use of best practice and contemporary data (design codes do not necessarily reflect current thinking or knowledge)?
Inter-discipline co-ordination	Are the measures taken overall, complementary and co-ordinated? Is there a party with overall responsibility?
Information	Has sufficient quality information regarding the design philosophy and details adopted been conveyed to the constructors and those who will maintain the facility?
Implementation	Is the form of contract, the means of procurement, and the degree of control/supervision appropriate? Is there an appropriate 'design change' control protocol?

Table 2: Process checks

The items scheduled in Table 2 were also outlined and discussed in reference 9.

It is important that the assessment of robustness is a team approach, involving the structural engineer (structural frame and foundations), architect (envelope) and services engineer (M&E plant and systems) as a minimum, and is one that avoids the dangers of mechanistic risk assessment. These can lead to an automatic routine which runs the risk of missing a project specific issue. The use of a competent facilitator to lead discussions on hazard elimination and risk mitigation will often be money well spent.

It can be seen from the above that quality communication is a vital component in obtaining and maintaining robustness. Risk thrives at interfaces, both physical and contractual, and the typical construction project frequently has more interfaces than is wise, or required.

SCOSS is preparing a background paper on the adoption of independent reviews for innovative, complex or unusual structures [introduced as a category in reference 10], as a means of ensuring that robustness, and other key attributes, have been properly assured. The concept of such a review is to:

- Validate the design philosophy,
- Identify the major hazards and ascertain if they have been dealt with[7]
- (Qualitatively) validate and verify the analysis model
- Question the design assumptions in respect of construction, use and maintenance.

All public UK highway structures are subjected to one of three levels of independent check; the level depends upon the size, cost and complexity of the structure. The highest level is a fully independent check of the design intent without sight of the calculations.

[7] see for instance the reference to 'abnormal hazards reasonably foreseeable' in Approved Document A para 5.1e

SCOSS has previously stated that '*for safety critical aspects of the design and construction of structures whose failure would have high consequences, third party certification is needed to give adequate assurance of structural safety*.'[11]

Product: Generally the choice and use of products will not be an issue as they are well controlled, quality assured and understood. Nonetheless, there are examples where specific care is required e.g. the occurrence of liquid metal assisted cracking (LMAC)- reported as being rare, but a serious event when it does occur- the tenacity of fire proofing material (according to NIST a major influence in the case of WTC), the performance of materials and whole components in real fires. The supervision of the installation of products is also important. The 15th Biennial Report [13] described some concerning practices regarding the installation of structural fixings.

In addition, the use of CE markings and associated EU terminology and procedures (for example ETAGs, ETAs) also introduce an area of possible confusion to practising engineers who have been educated and trained in traditional UK (or other) systems. This could be of serious consequence if related to items concerning robustness e.g. fire proofing materials or products. SCOSS has recommended [13] that some clear guidance be produced in a format suited to project related applications.

Summary

This paper has attempted to demonstrate that the provision of structural robustness consists of more than just the use of the correct technical detail and appropriate design code. It requires an appreciation of the wider issues (technical and managerial), and a whole life approach. The whole team should contribute in order to arrive at an integrated solution.

This paper should not be seen as an argument against innovation; carefully considered innovation can, in some circumstances, be a way to reduce risk and enhance robustness [14].

The philosophy of this approach should be imparted to aspiring engineers during the education phase and then progressively developed through experience.

References

1 Standing Committee on Structural Safety
www.scoss.org.uk

2 Ibid
14th Biennial Report Section 2.3

3 Ibid
13th Biennial Report Section 2

4 Final Report on the Collapses of the World Trade Center Towers (Draft)
http://www.nist.gov/public_affairs/releases/wtc_briefing_june2305.htm
National Institute of Standards and Technology

5 Safety in Tall Buildings and other buildings with large occupancy
Institution of Structural Engineers July 2002.
ISBN 0 901297 24 0

6 New approach to disproportionate collapse
S Alexander
The Structural Engineer Vol 82 No 23/24 7 December 2004 p14-18

7 Assessment and Inspection of buildings and other structures
SCOSS Topic Paper
www.scoss.org.uk/publications.asp

8 NIST report: issues for the future
F Wainwright
The Structural Engineer Vol 83 No 14 19 July 2005 p12-13.

9 Reflections on structural safety
J Carpenter
The Structural Engineer Vol 80 No 8 16 April 2002

10 Forensic investigation: The true calibrator for design limit states
J G M Wood
Proceedings of the 3rd International Conference on Forensic Engineering: Diagnosing Failures and Solving Problems
Thomas Telford 2005 ISBN 0 415 39524 0

11 Reference 1
13th Biennial Report Section 2.6

12 Ibid
15th Biennial Report section 4.1

13 Ibid
15th Biennial Report section 4.3

14 The observational method-learning from projects
Alan Powderham
Proceedings of the Institution of Civil Engineers: Geotechnical Engineering 155 January 2002 Issue 1 pp59-69

01.03.06