Structural Safety 1997–99: Review and recommendations

Twelfth Report of SCOSS
The Standing Committee on Structural Safety

February 1999

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11 Upper Belgrave Street
London SW1X 8BH

SCOSS Constitution 1997–99

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Foreword

May I preface my remarks by saying how delighted I was to be asked to take over the Chairmanship of the Standing Committee in May 1998 from Professor Anthony Kelly. I should like to take this opportunity of acknowledging the excellent work of my predecessor. Professor Kelly served as Chairman for a period of ten years and established a pattern of interaction between Government Departments and Learned Bodies that allowed for an independent committee approach that is so important in any assessment of problems associated with safety. His relaxed but effective way of dealing with complex problems of major public interest and concern will make him a very difficult chairman to follow.

The Committee has continued to work hard to monitor the current practices and trends that involve structural safety and in particular to give warning where unacceptable risks are believed to exist. This Twelfth Report summarises the work and findings of the Committee in the period January 1997 to January 1999. During the course of the work the Committee has been grateful for the continuing help received from the Institutions of Civil and of Structural Engineers, the Health and Safety Executive and other government departments and bodies and from many individual engineers in both public and private sectors. Their ready cooperation and assistance has enabled the gathering of a wide range of information, experience and views on many topics thus facilitating the development of the Committee's independent conclusions and recommendations.

More effort has been put into publicising the findings of the Committee. A very effective approach to this is in the publishing and distribution of the SCOSS bulletin. Bulletin 2 was published in January 1998 and provided information and news on topics relating to structural safety, including progress in the implementation of the recommendations of the Eleventh SCOSS Report. Bulletin 3 is published with this Twelfth Report to promote its recommendations. A wider promotion of the findings of SCOSS is planned for the future, including through the SCOSS world wide web site.

During 1997, the funding arrangements for SCOSS were reviewed by its sponsors, the Institution of Civil Engineers, the Institution of Structural Engineers and the Health and Safety Executive. I was particularly pleased to find, on taking over the Chair, that the arrangements had been renewed and the Business Plan for the 1998-99 period was updated to broaden and deepen the field of assessment over the coming two years.

The Lord Lewis of Newnham
Chairman

Feedback Invitation

Engineers and others are invited to express concerns about situations, incidents or trends adverse to structural safety, on a confidential basis if they so wish, to SCOSS. Feedback on experiences where structural failure has occurred or where it has been averted, i.e. 'near-misses', is especially valuable.

SCOSS invites comment on this Report.

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Abbreviations used in the Report

API	American Petroleum Institute
ASCE	American Society of Civil Engineers
BCA	British Cement Association
BRD	Building Regulations Division (of DETR)
BRE	Building Research Establishment
CDM	Construction (Design and Management) Regulations 1994
BSI	British Standards Institution
CAC	Calcium aluminate cement
CEB	Comité Euro-Internationale du Béton*
CEN	European Committee for Standardisation
CIRIA	Construction Industry Research and Information Association
CROSS	Confidential Reporting on Structural Safety
CWCT	Centre for Window and Cladding Technology
DETR	Department of the Environment, Transport and the Regions
ECCS	European Convention for Constructional Steelwork
FIP	Fédération Internationale de la Precontrainte*
HAC	High alumina cement
HMRI	Her Majesty’s Railway Inspectorate (a part of HSE)
HSE	Health & Safety Executive
IABSE	International Association for Bridge and Structural Engineering
ICE	Institution of Civil Engineers
IStructE	Institution of Structural Engineers
LUL	London Underground Limited
MHSW	Management of Health and Safety at Work Regulations 1992
RAAC	Reinforced autoclaved aerated concrete
SEWC	Structural Engineers World Congress, July 1998
SCI	Steel Construction Institute
SCOSS	Standing Committee on Structural Safety
TCFE	Technical Council on Forensic Engineering of ASCE
UK	United Kingdom

* FIP and CEB merged in 1998 to form FIB, the International Federation for Structural Concrete.

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Executive summary

The Standing Committee on Structural Safety (SCOSS) has become increasingly concerned over recent years by the growing background hazards to the achievement of acceptable structural safety arising from a number of pervasive trends and changes. These concerns are reflected particularly, but not exhaustively, in the recommendations on general principles given in this Twelfth Report.

There is potential in all building and civil engineering structures for unsafe situations to arise. Gravity is unrelenting. Extreme climatic and man-made events may occur. The deterioration of materials and structure eventually over time is inevitable. However, the number of structures that have become unsafe in the United Kingdom (UK) and in many other parts of the developed world in recent times has been quite small due largely to the skill and dedication of professional civil and structural engineers in averting recurrences. There is a strong tendency amongst those in government and others who are responsible for structural maintenance and procurement resources, to make the comfortable assumption that all is well and will continue to be well even if resource is reduced. A good structural safety record will not be sustained in the future unless adequate resources are provided to enable vigilance and effort in the maintenance of safety standards.

Continuous vigilance and effort is required to offset the potentially adverse effects on structural safety of several pervasive trends and changes:

- Partly as a result of legal trends, organisations and individuals have become more intent on specifically defining the boundaries of their responsibilities and denying any role in areas they believe to be outside those boundaries. One result of this trend is that the concept of collective responsibility for safety amongst groups of organisations is now largely in the 'back of the mind'. It has therefore become increasingly difficult to achieve collective agreement on action and strategy in areas where many organisations all have an interest in safety, eg. the development of codes and standards for structural design.
- For the ageing infrastructure in the UK and elsewhere, the climate of increasing commercial competition and drive for efficiency may lead to reduced emphasis on safety requirements. Owners of structures seek ways of making them 'work harder'. Consequently professional engineers are under pressure to identify and quantify existing margins of safety and to reduce them. Whilst such approaches may be reasonable, it is important to proceed with great care. Bridge assessment is one area where such pressures exist.
- There is a natural but not inevitable tendency amongst engineers towards collective amnesia concerning previous structural failures and the lessons to be learned from them. This process occurs as older engineers retire and their places are taken by younger ones. It falls largely to educators, continuing professional development, and feedback mechanisms such as that provided by SCOSS and the technical press, to offset this natural tendency.

The recommendations on general principles given below indicate some steps that should be taken to offset the adverse effects of these trends on structural safety. The recommendations on specific topics, also given below, refer to particular issues where action is needed to maintain adequate structural safety.

RECOMMENDATIONS ON GENERAL PRINCIPLES

Codes of practice for structural design

[Section 2.1]

1. The Institutions of Civil Engineers and of Structural Engineers and the British Standards Institution should review the whole production and writing process of codes, including the Structural Eurocodes, and define and vigorously implement a strong policy, agreed and actively supported by industry and government, addressing the following issues:

- The growing portfolio of codes of practice in structural engineering and the inadequacies and confusions within them.
- The need to converge as far as possible to a single set of codes that clearly distinguishes between performance requirements, principles and rules.
- The need to keep codes reasonably in line with technological advance and to withdraw codes that are obsolete.
- The need for positive strategic management of the process of code development for the UK.

Control of risk through design [Section 2.2]

2. The Institutions of Civil and of Structural Engineers should prepare guidance on procedures for assessment of hazards and risks affecting structural safety that should be followed as part of an explicit risk management process starting at the design stage of projects. The procedures should include the definition and prioritisation of critical situations relating to hazards to the structure during its life, and the determination of the need for, and adequacy of, safeguarding measures.

3. The regulatory requirements for risk management should be clarified by the relevant government departments.

Quality management systems and design [Section 3.8]

4. Managers of quality assurance systems relating to structural design should ensure that they are explicitly based on a direct response to the specification clauses of ISO 9001. In particular design management controls for verification and review should be based on ISO 9001 Clause 4.4.

Use of computers [Section 3.7]

5. Those responsible in universities, professional engineering institutions and government for the education of engineers and their continuing professional development should provide more guidance on understanding structural behaviour and its modelling for computer analysis, and on avoiding uncritical reliance on computer-generated results.

Resistance to disproportionate collapse [Section 2.3]

6. The Department of the Environment, Transport and the Regions should continue consideration of the SCOSS recommendation that resistance to disproportionate damage (robustness) should be required by regulation for all structures, especially those where large numbers of people may congregate.

7. The Department of the Environment, Transport and the Regions should issue Approved Document guidance on the design of structures for robustness and provision against accidental actions including advice on identification of hazards and analysis of critical situations.

Periodic structural inspection [Section 2.4]

8. Owners and operators of buildings and other structures should arrange for periodic inspections and structural appraisals to ensure that their safety is adequate as they continue in use; this process is particularly important for structures where large numbers of people may congregate.

Continuing structural safety - the regulatory regime [Section 2.4]

9. The review in progress by the Department of the Environment, Transport and the Regions and the Health and Safety Executive of the respective roles and responsibilities of the Health and Safety Executive and Building Control Authorities for the continuing safety of permanent and short-life structures should be completed to determine an adequate regulatory and enforcement regime.

RECOMMENDATIONS ON SPECIFIC TOPICS

Safety management of bridges [Section 2.5]

10. Responsibilities for enforcement of the requirement for safety of highway bridges should be independent and completely separated from those for maintenance, operation and use.

11. The owners of rail underbridges should consider adopting a safety file approach as a framework for managing the safety of each bridge.

Multi-storey car parks and edge barriers - technical issues [Section 3.1]

12. The Institution of Structural Engineers should expedite the preparation of up-to-date guidance on the structural design and assessment of multi-storey car parks including edge barriers.

Stadia structures [Section 3.2]

13. Owners of stadia should arrange a detailed structural inspection and appraisal of the structures periodically by a competent person to ensure their safety is adequate in the light of current circumstances and use.

Periodic inspection of cladding [Section 3.3]

14. Owners of buildings should arrange for periodic inspection of claddings to check safety. The requirement for checking should be defined in the CDM health and safety file.

Bridge strikes [Section 3.4]

15. The Bridge Strikes Prevention Group, regulatory authorities and industry should more vigorously seek and implement measures for the prevention and mitigation of bridge strikes and their effects.

Reinforced autoclaved aerated concrete [Section 3.5]

16. Owners of both school and non-school buildings that have pre-1980 RAAC plank roofs should arrange for these roofs to be inspected if this has not been done since 1994, although generally the deterioration of RAAC planks may not jeopardise structural safety.

Lighting columns [Section 3.6]

17. Owners of existing lighting columns should arrange for them to be inspected periodically giving greatest priority to those that are likely to be most vulnerable due to position, age, environment, detailing and quality.

OTHER TOPICS CONSIDERED

Additional topics covered in the Report include scour, slab/column reinforcement in concrete flat slabs, thaumasite sulphate attack on concrete and calcium aluminate cements in construction.

1 Introduction

1.1 Complacency

There is potential in all building and civil engineering structures for unsafe situations to arise. Gravity is unrelenting. Extreme climatic and man-made events may occur. The deterioration of materials and structures over time is inevitable.

Relatively few incidents of loss of structural safety have arisen in the United Kingdom (UK) and many other parts of the developed world in recent years. It is tempting and comforting to consider these incidents, eg. the collapse of the Ramsgate walkway in 1994 (1) and of part of the Piper's Row car park, Wolverhampton, in March 1997 (2), to be isolated events. Superficially this may appear to be the case. However, the record of structural safety over recent decades in the United Kingdom and more widely over a longer time shows that structural collapses arise regularly although fortunately infrequently. Their causes revealed in subsequent investigations are sometimes unsuspected and surprising. In recent times the implications of such events have been substantial, mainly because the deficiencies that come to light in the investigations may be present in a large population of structures built using similar modern technology and methods. The collapse may well be 'the tip of the iceberg' created by trends and changes in the requirements of clients, materials and construction technology and/or the processes of design, construction, maintenance and use.

Although the number of structures that become unsafe has been quite small in recent times, the potential for safety loss to become widespread is substantial. The fact that the number is small is due largely to the skill and dedication of professional civil and structural engineers in averting recurrences. There is a strong tendency amongst those in government and others who are responsible for structural maintenance and procurement resources to make the comfortable assumption that all is well and will continue to be well even if resource is reduced.

Complacency can preclude recognition of increasing risks to structural safety. It can lead to statements such as 'you will appreciate the general level of risk, both to employees and members of the public, from unsound structures is very low'. The good record of structural safety may not be sustained in the future without adequate resources to maintain safety standards. Continuous vigilance and effort is needed to identify and offset pervasive trends and changes that may have an adverse effect on structural safety levels.

1.2 Pervasive trends and changes

Current levels of safety of building and civil engineering structures may be argued to be broadly adequate and acceptable. Some particular areas are identified by SCOSS in later sections of this report where this is believed not to be the case and recommendations are made for restoring safety levels. However, there are several pervasive trends and changes that pose a threat to the achievement of acceptable structural safety.

Roles, responsibilities and duties

Changes have taken place in perceptions in society of roles and responsibilities relating to safety. Society has become more litigious and the law has evolved to emphasize personal and specific duties. One result is that organizations and individuals have become more intent on specifically defining the boundaries of their responsibilities and denying any role in areas they believe to be outside those boundaries. The concept of collective responsibility for safety amongst organizations is now largely in the 'back of the mind' of many organizations and, in some cases, is not accepted at all. Consequently it has become increasingly difficult to achieve collective agreements on action and strategy in areas relating to structural safety where different organizations and groups all have an interest. The development of codes and standards for structural design, discussed in 2.1, is an example of this type of difficulty, which, if not overcome, will have an adverse effect on structural safety.

Commercial pressures

The ageing infrastructure in the United Kingdom and elsewhere is required to continue providing service in a climate of increasing commercial competition and pressure for efficiency. Such pressure may lead to reduced emphasis on safety requirements. Complacency can tend to govern. Engineers have a difficult task in making cases for repair/strengthening/replacement of existing structures in the face of the resource manager's question: 'Since the structure has stood and served its purpose for the past *x* years, what makes you think it will not perform and be safe for next year, or even the next five years, if we don't spend money on it?'

Understandably owners of structures wish to get the most out of their assets. To that end they seek ways of making them 'work harder'. Professional engineers are therefore increasingly trying to identify and quantify existing margins of safety with a view to determining whether they are more than adequate and can be reduced without reducing safety below an acceptable level. Whilst such approaches are perfectly reasonable, it is important to proceed with great care. Techniques for making such assessments are developing which, together with use of judgement, enable priorities to be more rationally determined. Bridge assessment, discussed in 2.5, is one area where such pressures exist.

Collective amnesia

There is a natural but not inevitable tendency amongst engineers towards collective amnesia concerning structural failures of the previous generation and the lessons to be learned from them. This process occurs as older engineers retire from practice and their places are taken by younger ones. Petroski (3) based on research by Sibly & Walker (4), has described an apparent 30-year cycle of over-confidence amongst bridge engineers in the last 150 years. He emphasized the benefit of the philosophical approach to design that realises the need to know and respect the lessons from failures. Kletz(5) in relation to the process industries, identified a cycle of corporate forgetfulness allowing errors and oversight previously identified to creep back in less than 10 years. He pointed to the phenomenon that memory is personal and experiences are not easily passed from one generation to the next.

Many younger engineers today have little knowledge of the structural failures which occurred in the 1960s and 1970s, eg. Ferrybridge, Ronan Point, box girder bridges at Milford Haven and Yarra, Camden, Stepney and Rock Ferry school roofs. Consequently they may not be aware of the lessons learned(6).They may not therefore recognise the danger when a similar potential failure situation arises within their own experience. Overconfidence in more powerful design tools and over-optimistic extrapolation are constant temptations militating against caution.

It falls largely to educators, continuing professional development and feedback mechanisms, such as that provided by SCOSS and the technical press, to offset the natural tendency towards collective amnesia.

1.3 The widening perspectives of SCOSS

The Interim Committee on Structural Safety, set up in 1973 to advise on whether a permanent Standing Committee on Structural Safety should be established, included Sir Alfred Pugsley amongst its members. Modern engineers owe a great debt to him for communicating with such clarity the basic rules of structural safety (7). His books and papers on structural safety remain relevant today and a valuable source for learning (8-10). Through his experience and study of engineering failures, eg. the R101 airship disaster, Tacoma Narrows bridge collapse, and the Comet aircraft crashes, he explained that structural safety is not just a technical matter but also depends on prevailing political, financial, scientific, professional and industrial conditions. His work led to these factors becoming much better recognized today, although control of the complex interactions between them can still be elusive, leading occasionally to catastrophic structural collapses.

When SCOSS was formed in 1976 it was seen mainly as a body for considering particular technical issues relating to structural safety, examples being resin-bonded steel plates, brittle fracture, and cavity wall ties. Sir Alfred Pugsley's insight into the importance of pervasive non-technical matters to structural safety was not recognized. This was perhaps because action on SCOSS recommendations on particular technical issues is generally relatively easy and it has often been within the interest and control of those directly concerned to take the action recommended. Several topics of this nature feature in later Sections of this Report, eg. lighting columns. Over time however, SCOSS has also become concerned about wider topics involving organizational or regulatory aspects of structural safety. These issues relate to more pervasive trends and changes and include more difficult and nebulous matters such as attitudes, culture and responsibilities. The implications and solutions are complex and less clear-cut, eg. resistance to disproportionate collapse, or structural safety of multiple use buildings. To address SCOSS recommendations in such cases can require wide consultation and discussion amongst the engineering profession, industry and government, and may not therefore be capable of rapid implementation. The potential benefits for structural safety of implementation are, however, generally more widespread and profound. Examples of such topics which are discussed later in this Report include codes and standards for structural design and hazard identification and risk assessment in design.

1.4 The Twelfth Report

SCOSS has been pleased to note the developments that have taken place following the recommendations in the Eleventh Report, see Appendix A.

This Twelfth Report gives particular attention to the influences of pervasive trends and changes on structural safety. The Report may appear to concentrate overly on structural failures, collapses and safety 'near-misses' that have been reported. This focus on losses of safety may give the impression that such losses are numerous. This impression would, of course, be erroneous as already indicated. However, close examination of the relatively few failures and collapses that have occurred may indicate features which may jeopardise safety more generally. Such examinations provide a most pertinent basis of learning to avoid losses of safety in the future, see 5.2.

References, Section 1.4

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2.1 Topics of greatest concern

2.1 Codes and standards for structural design

SCOSS Reports have on several occasions made recommendations to the British Standards Institution (BSI) for revision, review or withdrawal of specific British Standard (BS) codes of practice relating to structural engineering. Most recently, the recommendations have expressed concerns about wider issues relating to the growing portfolio of structural engineering codes and standards, including those developed on a European basis, compatibility between them and their maintenance in an up-to-date user-friendly form (Table 1). Whatever the reasons for them, the inadequacies and confusions in codes identified by SCOSS are considered to constitute a background hazard to safety.

These concerns are supported by coverage in the technical press. For example, letters from practising engineers are published regularly in *The Structural Engineer* and *New Civil Engineer* drawing attention to inconsistencies in new and amended codes and standards. A continuing complaint is that codes and standards are now published in many parts, so that the cost of the whole document is very much greater than that of the single volume version of previous editions. Further, these parts are then amended and revised in such a way that it is very difficult for the user to keep up to date. (1)

Another issue that has prompted extensive correspondence in the technical press over the past two years is the increasing complexity of structural codes. This has applied particularly to the wind loading code (BS6399: Part 2), the earth retaining structures codes (BS8002), and the possible variation in factors of safety between the codes for concrete and steel structures.(2-5) The very nature and purpose of codes are increasingly being questioned.

Modern codes of practice for structural design first appeared in the 1930s but it was not until the 1960s and 1970s that BS codes for design in the major structural materials became a comprehensive technical basis for practice, eg. BS153, BS449, CP114, CP115 and CP116. Originally these codes were prepared under the aegis of the Institution of Structural Engineers. The work was transferred to the British Standards Institution in the 1960s. Since that time the portfolio of BS structural codes has grown and become more comprehensive through successive development and revision. A major change in the philosophy and basis of the codes began in the 1960s with the introduction of concepts of limit state design. Increasing international acceptance of this approach led to the first code being introduced on this basis in the UK in 1972, ie. CP110: 1972. Subsequently the former permissible stress basis for structural design has gradually been replaced until, today, the permissible stress approach has been almost entirely superseded. However, some permissible stress codes have been retained even after a limit state code is in use because of pressure from some users, leading to a further layer of complexity and possible confusion.

Whilst the development of BS codes has continued over the past three decades or so, the technology of structural engineering has become increasingly international with the growth of vigorous technical–scientific bodies devoted to advancing structural engineering, eg. CEB, FIP, ECCS. These peer-group bodies have done much to encourage a unified limit state approach to structural design and to refine the techniques using reliability-based methods. The creation of the European Economic Community provided a natural forum for their work to be the springboard for the development of the Structural Eurocodes.(6) This international set of ten European codes for structural design in almost 60 separate parts, now in an advanced stage of development, was conceived as a means of facilitating a single market in structural engineering. It is intended that the Structural Eurocodes will replace existing BS codes (and national codes in the other member countries of the European Committee for Standardisation (CEN)), in due course.

At the same time as CEN has continued to develop the Eurocodes, other codes and standards for specific areas of structural engineering have been prepared by the International Standards Organisation (ISO). The worldwide international character of the offshore oil industry has led to the main focus for structural engineering codes for offshore structures being within the industry (7) and, more recently, in ISO.(8) In other cases, ISO codes exist, or are in preparation, covering the same or similar scope to CEN and BSI codes. The development of the three ‘streams’, ie. ISO, CEN and BSI, is a complex process. BSI provides the UK input into the process. Clearly it faces a substantial task in seeking to obtain codes as outputs from the process that are up-to-date, concise, comprehensive and user-friendly for use by the structural engineering industry.

The development and use in the UK of non-BS codes on structural engineering is another significant trend over the past, say, 20 years. Whilst the technical content and complexity of BS codes has grown, they have evolved largely without the inclusion of clear and comprehensive statements of general principle crucial to clients. Major owners of structures, eg. Highways Agency, British Rail (now Railtrack plc), and London Underground Limited (LUL), have developed their own codes, particularly in areas where BS codes do not exist, are inadequate, or need variation to meet their requirements, eg. codes for structural assessment of existing bridges. These codes make reference to BS codes in many cases but their content tends increasingly to be generated by the initiating organisation using in-house expertise, consultants and peer-group advice.

Other guidance on structural engineering is produced by the Institutions of Civil Engineers and of Structural Engineers, and by industry bodies such as the Steel Construction Institute (SCI), British Cement Association (BCA), the Construction Industry Research and Information Association (CIRIA), the Transport Research Laboratory (TRL) and the Building Research Establishment (BRE). The Institution of Structural Engineers has, for example, successfully published a series of Manuals which are, in effect, simplified versions of the main BS structural codes.(9) These documents often become widely used and, in effect, codes of practice. There appears to have been a trend towards the preparation of such documents by industry possibly because the BSI process is slow, time-consuming and difficult to focus and control.

At an international level, other industries have taken ownership of the preparation of design standards in a way that has enabled substantial flexibility and responsiveness. For instance, the first edition of the American Petroleum Institute design standard for fixed offshore structures (API RP 2A) was published in 1969, and 20 editions have been published since then.

There are therefore several routes by which codes and standards for structural design are prepared. Whilst the principal route uses a committee made up of representatives of the interested parties from the industry, the professions and government, other routes are also used. The overall costs of developing and maintaining codes for structural design are very high. The complex task of drafting is usually undertaken either by the committee members, who often undertake the work on a voluntary basis, or sometimes by use of a consultant to prepare a first draft under contract. The direct financial costs of full and active participation in international code committees is considerable. Engineers are often inhibited from volunteering to contribute for this reason. Once the codes have been established, they must be maintained and updated. A continuing commitment to this process is needed.

The difficulties of managing and motivating a team of volunteers within a commercial framework is of course not unique to the task of code development. However, it may be that this process can no longer be considered to be operating effectively within reasonable time scales for drafting and revision of national codes of practice for structural engineering. Input from individual construction professionals is now very much less than in earlier times. There are two main reasons for this lesser input. There is a shortage of professional engineers with the necessary knowledge and ability to prepare codes and those that do exist are not made available to BSI Committees because of the cost to their own business.

These organisational factors together with the trends towards international CEN and ISO codes and non-BSI codes have led over time to a dilution and diffusion of effort in code development. As a result the traditional system of producing codes is not meeting the requirements of professional engineers and their clients.

At the same time the position of BSI as the UK focus for the development of CEN and ISO codes for structural engineering is a key one. These codes as well as the national BS codes are, in effect, jointly ‘owned’ by the engineering profession, industry and government. Strong leadership and collective action by these interests is needed now to remove the background hazard to safety by overcoming the problems identified above in the preparation and management of codes and standards for structural design.

A way forward may be to remove performance requirements and principles, including loading, into specifications prepared with government support. Codes of practice prepared by industry would then give advice on developing designs that conform to the specified requirements and principles. The division of conventional codes along these lines has been foreshadowed in the Structural Eurocodes.

Recommendation:
The Institutions of Civil Engineers and of Structural Engineers and the British Standards Institution should review the whole production and writing process of codes, including the Structural Eurocodes, and define and vigorously implement a strong policy, agreed and actively supported by industry and government, addressing the following issues:

- **The growing portfolio of codes of practice in structural engineering and the inadequacies and confusions within them.**
- **The need to converge as far as possible to a single set of codes that clearly distinguishes between performance requirements, principles and rules.**
- **The need to keep codes reasonably in line with technological advance and to withdraw codes that are obsolete.**
- **The need for positive strategic management of the process of code development for the UK.**

Table 1: SCOSS recommendations relating to codes of practice for structural design

Ninth SCOSS Report, 1992 (1) Cranes: BS2573: Part 1 should be reviewed (2) Air-supported structures: BS6661 should be withdrawn
Tenth SCOSS Report, 1994 (3) Air-supported structures: BS6661 should be withdrawn (4) Internal masonry walls: BS5628 should be reviewed with regard to internal walls with large openings in three-storey houses.....
Eleventh SCOSS Report, 1997 (5) Pin connections: The Steel Construction Institute in collaboration with the British Standards Institution should review the guidance on the design, inspection and maintenance of pin connections in bridges and buildings (6) Fatigue in steel structures: The Institutions of Civil and of Structural Engineers, and the British Standards Institution should undertake a strategic review, from a safety standpoint, of standards and codes of practice relating to design against fatigue in steel structures as a basis for achieving convergence towards a compatible set of fatigue rules taking into account the commitment to the development of the CEN Structural Eurocodes. (7) Codes of practice, standards and guidance documents: Practising engineers would be assisted substantially in ensuring structural safety if more positive action was taken by the Institutions of Civil and of Structural Engineers, the British Standards Institution and appropriate Government Departments at an early date to amend or replace codes of practice and other guidance documents in line with technological change and new guidance which becomes operational in Europe. (8) Structural codes of practice: The British Standards Institution should give publicity to an overall policy for the development of codes of practice relating to structural design and should aim to achieve a single set of codes through positive coordination and support of their development. (9) Air-supported structures: The British Standards Institution should withdraw BS 6661: 1986

References, Section 2.1

1. Cost of codes and publishing policy. *New Civil Engineer,* 10 April 1997; *The Structural Engineer*, 15 July 1997, 21 October 1997, 9 December 1997.
2. Complexity of codes of practice: wind loading. *The Structural Engineer,* 18 February 1997, 15 April 1997, 15 July 1997.
3. Complexity of codes of practice: BS8002: Earth retaining structures. *The Structural Engineer*, *Verulam*, 19 August 1997.
4. Complexity of codes of practice: inconsistency between tables and formulae. *The Structural Engineer*, 19 August 1997.
5. Safety margins in codes. *The Structural Engineer*, 15 October 1996, 21 January 1997, 20 May 1997, 19

August 1997, 18 September 1997, 9 December 1997.

6. Menzies J. B. and Smith B. W. The Structural Eurocodes. *Paper P320-4, Structural Engineering World Wide* 1998. Elsevier. *ISBN 0 08 04 2845 2.7*.
7. American Petroleum Institute. *Recommended practice for planning, designing and constructing fixed offshore platforms*. API RP 2A-WSD (with supplement 1) 1996
8. International Standards Organisation: ISO 3819- 2. *Fixed steel offshore structures.* ISO/TC67/SC7, draft ‘C’ August 1997.
9. Manual for the design of reinforced concrete building Institution of Structural Engineers structures, 1985: Manual for the design of plain masonry building structures, 1997: Manual for the design of steelwork building structures, 1991, Recommendations for the permissible stress design of reinforced concrete building structures, 1991*, SETO, London.*

2.2 Assessment of safety and risk at the design stage

In its Eleventh Report, SCOSS recommended that:

> *“Starting at the design stage of projects, designers should apply an explicit risk management process, including the identification of hazards and assessment of risks, with the effort expended and sophistication of the assessment being directly related to the nature, size and importance of the structure.”*

The need to implement the recommendation was emphasised by the trial relating to the collapse of the Ramsgate walkway (1,2). Following the collapse in 1994, HSE brought criminal proceedings against several organisations including the port authority client under the Health and Safety at Work etc Act 1974. One of the points to emerge at the trial was that the client had a statutory duty to carry out risk assessments relating to the "conduct of its undertaking", and such a risk assessment carried out at the design stage should have identified that the safety of the walkway was dependent on the integrity or performance of a single precarious element. It was suggested at the trial that the need for special measures such as the incorporation of fail-safe features, would have been picked up if a proper risk assessment had been carried out, and that the risks to life would have been reduced.

The Judge, Mr Justice Clarke, quoted from the prosecution evidence in his summing up:

> *”The client is required to make an assessment of risks – that follows directly from the Health and Safety at Work Act – and is required to identify the risks and make sure that those risks are properly managed.”*

The duty is more fully described in the Management of Health and Safety at Work Regulations1992,(3) made under the Act. MHSW Regulation 3(1) provides, so far as it affects risks to the public, that:

> *"Every employer shall make a suitable and sufficient assessment of…the risks to the health and safety of persons not in his employment arising out of or in connection with the conduct of his undertaking, for the purpose of identifying the measures he needs to take to comply with the requirements and prohibitions imposed upon him by or under relevant statutory provisions"*

The judge's summing up in the Ramsgate case leaves some doubt as to whether a client may discharge this duty by appointing an independent person or organisation to carry out the risk assessment. Risk assessment relating to structural safety could advantageously be combined with the risk assessment relating to safety during construction under Regulation 14(a) of the Construction (Design and Management) Regulations 1994.(4) The position could be made clearer by amendment to the CDM and/or MHSW Regulations or through a related Approved Code of Practice. One possibility would be to extend the role of the planning supervisor to ensure that the combined assessment process is carried out.

In structural engineering generally the procedures used by designers to achieve structural safety in the face of the wide range of hazards that may arise remain largely implicit and are somewhat piecemeal. For example, the needs for inspection in service are not always defined in the design process and traditionally are determined subsequently. Measures to protect structures from hazards are generally determined largely on the basis of experience rather than by use of systematic identification and analysis of critical situations that may arise during the lifetime of the structure.

Codes of practice for structural design have traditionally left such considerations and the determination of the overall structural concept to the skill and experience of the engineer. Rather they have concentrated on defining methods for verifying the design of individual elements of the structure. In contrast, a range of hazard identification and risk management techniques, eg. Failure Mode and Effect Analysis (FMEA) and Hazard and Operability Studies (HAZOP), are used in the chemical process and nuclear industries. They have not been adopted generally in civil and structural engineering but a trend towards systematic identification of hazards and critical design situations may be found in some modern codes or draft codes, eg. the Eurocodes.(5)which include more specific advice on identification of hazards and critical design situations.

The process of risk management is actually closely related to that of fundamental design. Both entail the identification of possible modes and causes of failure, and ensuring that the likelihood of occurrence is avoided, combated or reduced to an acceptable level. Risk management at design stage should deal with much more than just the possible need for fail-safe measures.

Recommendations:
The Institutions of Civil and of Structural Engineers should prepare guidance on procedures for assessment of hazards and risks affecting structural safety that should be followed as part of an explicit risk management process starting at the design stage of projects. The procedures should include the definition and prioritisation of critical situations relating to hazards to the structure during its life, and the determination of the need for and adequacy of safeguarding measures.

The regulatory requirements for risk management should be clarified by the relevant government departments.

References, Section 2.2

1. Chapman J. C. Collapse of the Ramsgate Walkway. *The Structural Engineer.* Vol. 76, No. 1, 6 January 1998. pp 1–10.
2. Barber, J. *Ramsgate Walkway collapse: legal ramifications.* Forensic Engineering: A professional approach to investigation. Conference, Institution of Civil Engineers, September 1998.
3. Management of Health and Safety at Work Regulations 1992, London, HMSO.
4. Construction (Design and Management) Regulations 1994. London, HMSO.
5. Menzies J. B. and Smith B. W. The Structural Eurocodes*. Paper P320-4. Structural Engineering World Wide,* Elsevier, *ISBN 0 08 042845 2* , 1998.

2.3 Resistance to disproportionate collapse

The long-standing dialogue between SCOSS and the Building Regulations Division of the Department of the Environment, Transport and the Regions (DETR) on this topic has continued.

SCOSS continues to encourage adoption of the recommendation in its Tenth Report that both fundamental performance requirements relating to structural safety, ie. safety in normal use and resistance to disproportionate damage in the event of accident, misuse or exceptional circumstances, should be recognised in the Building Regulations for all building structures. The recommendation refers not only to buildings of normal frame construction, eg. offices and shopping complexes, but also especially to multi-storey car park structures - see 3.1 - and stadia - see 3.2 - which tend to have greater vulnerability to progressive collapse. The continuing concern of SCOSS is the greater in this context because large numbers of people tend to congregate within many of these structures and a sudden progressive collapse would be a disaster if crowds were present at the time.

The Eleventh SCOSS Report recommended that guidance on structural concepts and forms that have a low sensitivity to damage and an appropriate capacity to resist disproportionate collapse should be prepared. SCOSS was pleased to note that DETR is reviewing Part A of the Building Regulations and commissioned work during 1998 on ‘Guidance on robustness and provision against accidental actions’. In considering alternatives to the existing Building Regulation requirements relating to disproportionate collapse, the study is taking into account the Eurocode on accidental actions due to impact and explosions.(1) SCOSS welcomes this forward-looking approach and awaits with interest the resulting consultation on proposals for revision of the Building Regulations and Approved Document guidance. The nature of the subject suggests that such guidance should include the systematic identification of hazards and the analysis of critical situations, see 2.2.

Explosion within or external to buildings or other structures is one circumstance in which resistance to disproportionate damage is essential. Discussion of this topic in the Eleventh SCOSS Report concluded that, whilst attempting to protect buildings fully from damage by massive explosions is not realistic, aiming to achieve robust structures, ie. structures resistant to disproportionate collapse, generally also gives some degree of explosion resistance. Robustness, or structural integrity as it is often termed in North America, has become a topic of great importance there since the bomb attacks on the New York World Trade Centre and in Oklahoma City. (2,3) The detailed report on the Oklahoma City bomb discussed the vital importance of structural detailing in achieving robust structures. Structures in

Structural Robustness: aftermath of a bridge strike by a road vehicle and its load on a railway underbridge (Photo: A3 Gross Moor Iron Bridge – Cornwall County Council)

seismically active regions are routinely designed and constructed with details specifically designed to withstand severe/extreme loading, eg. top steel in reinforced concrete beams and slabs and additional continuity steel at beam–column junctions. Such features add only a small cost but may increase the robustness of a structure substantially.

In North America and elsewhere, trends in the use of computers in structural engineering suggest there is the possibility of an adverse influence on the robustness of building structures of sophisticated structural analyses. Modern computer-based analyses enable increasingly realistic structural modelling, more complex and refined calculations and more design options to be routinely examined. As a result engineers are now able to take redundancy and secondary effects into account quantitatively and directly. The ability to undertake complex structural calculations has increased confidence in and dependence on the validity of calculation. There may be a trend, as a result, for designers to provide structures with less redundancy than previously. For any given structure there is no established basis for determining how much redundancy is required to maintain the risks of unserviceability or collapse in service at an acceptably low level. Hence the engineer may be tempted to reduce redundancy in pursuit of economy of construction by using refined and detailed calculations to validate the design, see also 3.7. The resulting structures tend to have lower redundancy and less tying between components. There is also a trend towards more prefabrication and rapid assembly of structures arising from commercial pressures for greater productivity in construction. These considerations add weight to the SCOSS recommendation in the Tenth Report. It is an especially important recommendation for building structures, such as assembly halls, shopping complexes and stadia, where large numbers of people may congregate.

Recommendation:
The Department of the Environment, Transport and the Regions should continue consideration of the SCOSS recommendation that resistance to disproportionate damage (robustness) should be required by regulation for all building structures, especially those where large numbers of people may congregate.

The Department of the Environment, Transport

and the Regions should issue Approved Document guidance on the design of structures for robustness and provision against accidental actions and including advice on identification of hazards and analysis of critical situations.

References, Section 2.3

1. ENV 1991:2:7: *Eurocode 1 : Accidental actions due to impact and explosions.* CEN, 1997.
2. Carper, K. L. Current structural safety topics in North America. *The Structural Engineer*, 16 June 1998, pp 233-9.
3. Federal Emergency Management Agency. *The Oklahoma City Bombing: improving building performance through multi-hazard mitigation.* ASCE, 1996. FEMA 277.

2.4 Continuing safety of existing structures - the regulatory regime

Levels of structural safety in existing structures may become unacceptable due to:

- degradation or fatigue of materials in use
- changes in loading (which may be due to changes in use or user characteristics)
- shortcomings in the original design or construction that become apparent over time.

Perceptions of safety may also change over time due to developments in understanding of the behaviour of structures, materials, equipment or people.

For existing multi-storey car parks SCOSS recommended in the Eleventh Report that they should be

- inspected and assessed periodically for structural adequacy and safety, and that improvements and remedial measures identified as necessary should be implemented.
- inspected and assessed for the adequacy of edge barriers as regards moving vehicles and the safety of children, and that improvements and strengthening identified as necessary should be implemented.

The response to the SCOSS recommendations by owners and operators of multi-storey car parks

Partial collapse of the multi-storey car park in use at Pipers Row, Wolverhampton on 20 March 1997. (Photo: Wolverhampton Express and Star)

revealed a reluctance by some to undertake periodic inspection and assessment, or to implement measures identified as necessary, in the absence of any perceived regulatory requirement to do so or any authority undertaking enforcement. For example, operators took a different approach to manned car parks, where it was perceived that the requirement of the Workplace (Health, Safety and Welfare) Regulations 1992 to maintain a workplace in an efficient state and in good repair applied. These Regulations are enforced by local authority inspectors, environmental health officers and HSE inspectors. Unmanned car parks were perceived as requiring no attention to ensure continuing structural safety unless they were patently dangerous. The Automobile Association has recently added its support to the SCOSS recommendation for periodic structural inspection of multi-storey car parks by calling for such inspections to be made compulsory (1).

The lack of a perceived regulatory requirement to take measures to ensure continuing structural safety arises due to a traditional division of responsibility between two government departments (and related local authority departments). For many years Building Control Authorities have been responsible for the structural safety of new buildings (though not some civil engineering structures), but the responsibility is seen to be discharged on completion of the building. It may be revived if the building is to be altered. Under the Building Act 1984, Building Control Authority becomes involved again if information is received indicating the building may be dangerous. Hence the duties of these Authorities do not entail looking for dangers that are not apparent. Section 2 of the Building Act 1984 introduced a new provision for the imposition of ongoing requirements through Building Regulations, and this is a possible vehicle for addressing the problem, but no Regulations have yet been made under this Section. The alternative approach is under the Health and Safety at Work Act 1974, with enforcement by HSE inspectors. Due to the traditional demarcation of responsibility, the possible application of the Health and Safety at Work etc Act 1974 to structural safety has largely not been developed. Its potential significance in this context was demonstrated by the HSE prosecution in 1997 in relation to the Ramsgate walkway failure (2). The defendants in that case were all prosecuted for breach of Section 3(1) of the Act, which states:

> *"It shall be a duty of every employer to conduct his undertaking in such a way as to ensure, so far as is reasonably practicable, that persons not in his employment who may be affected thereby are not thereby exposed to risks to their health and safety."*

The duty of a building owner or operator arises by virtue of being an employer, that is having employees. It does not necessarily have anything to do with the employment. Section 40 of the Act makes the duty an affirmative one to do as much as is reasonably practicable to satisfy the duty. What became apparent from the Ramsgate prosecution was that, in the view of HSE - and the view was upheld by the trial judge - the duty under Section 3(1) imposes a duty on the owners and operators of structures, as 'employers' to ensure the adequacy of structures used by the public so that there is no unreasonable risk to their health and safety.

In principle, this should apply equally to a multi-storey car park that could be liable to collapse, or where the edge barriers could be inadequate to restrain moving vehicles or provide a safe environment for children.

It would be reasonable, for the purposes of Section 3(1), to expect the owner or operator of a multi-storey car park, in the light of the warnings in the Tenth and Eleventh SCOSS Reports, to appoint consultants to carry out inspections and assessments, both of the structure and the edge barriers.

General powers are available to HSE inspectors to take action to enforce the duties under Sections 2, 3 and 4 of the Health and Safety at Work etc. Act 1974.

The Act itself puts the matter quite strongly. Section 18 states explicitly that:

"It shall be the duty of the Executive to make adequate arrangements for the enforcement of the relevant statutory provisions except to the extent that some other authority or class of authorities is… made responsible for their enforcement."

The way appears to be open to HSE, within its powers under the Act, to draw the attention of such owners and operators to their duties, to ask for copies of appropriate certificates from suitably qualified consultants, and to issue Improvement Notices if the owners fail to appoint consultants within a reasonable time.

If such inspections and assessments reveal the need for improvement or remedial measures, then SCOSS recommends that the responsibility for checking the design and the implementation should be the responsibility of Building Control Authorities, but responsibility for ensuring that measures were taken would rest with HSE.

The need for clarification of roles and duties under existing law or for an amended regulatory regime to ensure the continuing safety of existing structures is not limited to multi-storey car parks. It is relevant to structures more generally, particularly those where larger numbers of people may congregate, eg. assembly halls and stadia (see also 3.2), or where the nature of the construction is such that deterioration may not be immediately apparent without close inspection. Public safety may be jeopardised by loss of structural safety of permanent structures in use. Likewise short-life structures, such as chimneys that are designed for a life of 10 or 20 years, also may become unsafe, especially if they are retained in use after their design life has expired. Regular inspection of short-life structures is essential to ensure their safety in use.

SCOSS drew the attention of the Department of the Environment, Transport and the Regions in July 1998 to these issues. Various approaches to ensuring the continuing safety of structures are now being considered by the relevant government departments.

Recommendations:
Owners and operators of buildings and other structures should arrange for periodic inspections and structural appraisals to ensure that their safety is adequate as they continue in use: this process is particularly important for structures where large numbers of people may congregate.

The review in progress by the Department of the Environment, Transport and the Regions and the Health and Safety Executive of the respective roles and responsibilities of the Health and Safety Executive and Building Control Authorities for the continuing safety of permanent and short-life structures should be completed to determine an adequate regulatory and enforcement regime.

References, Section 2.4

1. *Automobile Association,* AA calls for concrete assurances. Press release, November 1998.
2. Barber, J. Ramsgate walkway collapse : legal ramifications. *Forensic Engineering: A professional approach to investigation.* Conference. Institution of Civil Engineer, September 1998.

2.5 Bridge assessment

Highway bridges

The UK's stock of about 150,000 bridges is owned and managed by relatively few organisations, principally central government, county and other local authorities, Railtrack Plc, London Underground Limited and British Waterways. Considerable expertise and resources are needed to assess the condition, load-carrying capacity and maintenance requirements of these bridges in view of their diversity of ages, forms of construction, materials, and loading. Maximum permitted weights of heavy lorries are due to be increased in 1999 but the substantial programme of highway bridge assessment and strengthening to accommodate the increased loading has fallen behind schedule. Concern has been expressed in many quarters about this, not least in the House of Commons Transport Committee enquiry into the Road and Bridge Maintenance Programme that reported in February 1997.(1) SCOSS submitted evidence to that enquiry.

SCOSS discussed the issues during 1997 with the Highways Agency, which is responsible for about 11,500 motorway and trunk road bridges and about 4,000 other structures, and was pleased to note actions being taken by the Agency in response to recommendations in the Eleventh SCOSS Report.

Some of the delay in the highway bridge assessment programme has been the result of the need for some assessments to be more detailed than originally envisaged and of uncertainty about the actions required during the assessment process. SCOSS has noted the recently-issued Advice Note (2) on the management of sub-standard highway structures. This advice provides guidance on maintaining safety whilst actions are decided and carried out on a bridge that is suspected or known to have inadequate load-carrying capacity relative to current requirements. A key feature of the advice is the recognition of the contribution that monitoring can make to the assurance of safety of particular types of bridge, termed 'monitoring-appropriate bridges'. The guidance includes description of the process of structural assessment, of classes of monitoring, and of the factors to be considered in choosing an appropriate monitoring regime. Overall it should assist in the complex task of maintaining the safety of sub-standard highway bridges during assessment and the subsequent period before replacement or strengthening.

Guidelines for supplementary load testing of bridges have recently been issued by the National Steering Committee for Load Testing of Bridges and discussed at a conference at the Institution of Civil Engineers.(3) The guidelines have been developed as an aid to the assessment of load carrying capacity. The levels of test loading are defined as sufficient to obtain satisfactory measurable response from the structure but insufficient to cause any permanent structural damage. Supplementary load tests are envisaged as a part of the whole assessment process. The guidelines recommend that supplementary load testing for assessing the load distribution behaviour of existing bridge structures be adopted with caution and undertaken by those with appropriate expertise. SCOSS concurs with this recommendation.

Railway bridges

Railtrack Plc is responsible for over 40,000 bridges. About 20,000 of these bridges carry railway traffic over water and highways and are owned by Railtrack Plc. These underbridges range in size from the massive Forth Bridge, through plate girder bridges spanning urban back streets and brick arches over country lanes, down to small pedestrian subways and culverts. Masonry (brick or stone) arches are the most common type making up about 50% of the total. Wrought iron accounts for a further 12%.

Most masonry arch bridges are the original structures dating from when the railways were first built. Comparatively few of the original metal or timber superstructures remain since many were reconstructed toward the end of the last century or the beginning of this, some more recently. Most Railtrack underbridges were therefore designed and built before the advent of modern bridge design standards.

London Underground Limited (LUL), which is responsible for some 2000 bridges, is also an important owner of railway underbridges. Its underbridge stock consists of approximately 450 underbridges. The stock includes a few large bridges. Many larger bridges were rebuilt between 1880 and 1960 to accommodate track widening or route extension.

The Health and Safety Executive (HSE) is publishing a report on the structural assessment of railway bridges. (4) The report was commissioned following identification by HM Railway Inspectorate (HMRI), a part of the HSE, of a need for review and examination of current practice in the structural assessment of UK railway underbridges (bridges under a railway line) and overbridges (bridges over a railway line). The report included review of a number of foreign standards for assessment of the structural safety and condition of existing railway bridges. Its conclusions included comment on the organisational arrangements for conducting structural assessments and the standards used in the context of trends in traffic loads and in structural assessment practice in other areas, eg. offshore structures and overseas.

Attention was drawn in the report to a requirement in Swiss Standard SIA 462 that a group of independent experts has to be established to assist assessment where high risks to people and the environment have to be accepted, high costs will arise for maintenance and repair, or safety can only be evaluated qualitatively. SCOSS suggests this approach could be valuable in relation to assessment of particular bridges in the UK.

A strategic long-term approach to the technical support provided to the structural assessment of railway bridges including maintenance of up-to-date in-house knowledge and continuing professional development and training for engineers engaged in assessment was recommended in the report. Recommendations for improvements to industry standards and codes of practice for assessment were also given. SCOSS supports the recommendations and, in addition, recommends that the industry should consider the use of a safety file approach, including a life prediction, as a framework for managing the safety of each bridge.

General

For both highway and railway bridges, SCOSS examination of structural assessment of bridges has revealed rapid development of practice as owners seek to make their bridges ‘work harder’. The heavy financial and commercial pressures that are now present and the imprecise nature of the judgements required in the assessment of mature structures suggest that responsibilities for enforcement of safety requirements should be separated from those for maintenance, operation and use. Currently for highway bridges, these responsibilities are carried by the Highways Agency split between its technical approval and its project and operating directorates.

Recommendations:
Responsibilities for enforcement of the requirement for safety of highway bridges should be independent and completely separated from those for maintenance, operation and use.

The owners of rail underbridges should consider adopting a safety file approach as a framework for managing the safety of each bridge.

References, Section 2.5

1. *The Road and Bridge Maintenance Programme*. First Report. House of Commons Paper 105-1. The Stationery Office, February 1997.
2. BA79/98: *The management of sub-standard highway structures*. Highways Agency, 1998.
3. *Guidelines for the supplementary load testing of bridges*. Institution of Civil Engineers, National Steering Committee for Load Testing of Bridges, Thomas Telford, London, 1998.
4. *Structural assessment of railway bridges: standards and practice*. Contract Research Report (in press), Health and Safety Executive, 1999.

3 Other topics of concern

3.1 Multi-storey car parks including edge barriers - technical issues

SCOSS has been concerned about structural safety of multi-storey car parks for some years, and published recommendations about periodic inspection and structural appraisal, edge barriers and updating of current guidance in its Tenth and Eleventh Reports. The concerns were highlighted by incidents involving edge barriers at a car park in Canterbury in January 1996 and February 1998, and by the partial collapse of the top deck of the Piper's Row car park in Wolverhampton in March 1997.

Over the past two years SCOSS has communicated its concerns on technical issues widely to government, car park owners and operators and the structural engineering profession. Actions taken have included:

- A British Cement Association/SCOSS conference 'Concrete car parks: design and maintenance issues' on 29 September 1997. The papers have since been published by the British Cement Association (1) and a shortened version of the keynote paper by the SCOSS Secretary was published in *Parking Review* in October 1997.(2)
- One-day conferences on concrete car parks at Aston University, Department of Civil Engineering, on 25 March and 23 September 1998.
- A short paper 'Multi-storey car parks – current safety issues' published in *Concrete*, April 1998.
- SCOSS Bulletin 2 included a main feature entitled: 'Structural appraisals of multi-storey car parks – have yours been done yet?'. The Bulletin was distributed widely during 1998 to local authorities and other car park owners and operators.

SCOSS has continued to encourage the Institution of Structural Engineers to expedite revision of the 1984 recommendations for multi-storey car parks (3), and to widen their scope to cover the design of edge barriers and the structural appraisal of existing car park structures and edge barriers. Unfortunately a case for financial support for this work made to DETR was not successful and industrial support was not sufficient for the work to start until 1999. Consequently publication of the revised guidance is unlikely before 2002. In view of the delay, SCOSS proposes the Institution of Civil Engineers or the Institution of Structural Engineers organise a seminar to enable structural engineers and others involved in barrier design and testing to share experience, and to discuss the needs of clients, consultants and testing specialists. The seminar would provide a valuable input to a review of barrier design and assessment. An appropriate focus for conducting the review might be the BSI Committee responsible for BS6180,(4) which has been made aware of the concerns for safety in this area. This Committee is currently considering revision of barrier requirements in view of the need to safeguard children.

Multi-storey car parks should have adequate resistance to disproportionate damage in the event of accident, misuse or exceptional circumstances, see 2.3. In this context, SCOSS questioned the provisions in BS8110 for continuity reinforcement through columns in flat slab structures. It is understood that an amendment to BS8110 is being considered to make explicit the need for appropriate continuity, see 4.2.

SCOSS has continued to receive enquiries from consultants, local authorities, test houses and barrier manufacturers about procedures, equipment and criteria for performance of edge barriers, indicating a widespread need for information. A barrier accident took place at Watling Street Car Park, Canterbury on 9 February 1998. A car broke through a barrier at the end of a long exit ramp which had been newly installed during the past year. The car park where the accident took place is the same one where a car broke through a fourth floor barrier in January 1996. This latest incident emphasises the need for an in-depth review of barrier design and of criteria and methods for assessing existing barriers. Some research and development work is in progress in industry and universities. In particular the University of Southampton has a test rig which simulates vehicle impact on barriers. The University has proposed a research project using the rig to test a wide range of barrier designs with a view to preparing more general specification, design and assessment recommendations. An application for financial support for this project is under consideration by DETR. In industry, a dynamic test method for barriers has been developed.(5)

The continuing enquiries received by SCOSS from consultants, local authorities and test houses have served to emphasise the importance of the recommendations in the Eleventh Report and especially the need for better guidance. For example, the incidental discovery of failed ties between an external brick cladding and a car park structural frame revealed an unsafe situation which should have been found earlier by structural inspection and appraisal. In relation to structural durability, a wide range of surfacing materials are offered for use on car park decks and no standard exists for these materials – only some of them provide long-term crack bridging and protection of the structure against ingress of water and salt.

Recommendations:
The Institution of Structural Engineers should expedite the preparation of up-to-date guidance on the structural design and assessment of multi-storey car parks including edge barriers.

References, Section 3.1

1. British Cement Association. *Concrete car parks – design and maintenance issues*. Conference Report M21. Crowthorne, 1998.
2. *Parking Review.* October 1997
3. Institution of Structural Engineers and Institution of Highways and Transportation: *Design recommendations for multi-storey and underground car parks.* London, 2nd edition 1984. 60 pp.
4. BS6180: 1995. *Code of practice for barriers in and about buildings.* British Standards Institution, London.
5. Williams, H. Testing concrete car park edge barriers. *Concrete.* April 1998.

3.2 Safety of sports stadia structures

During 1998, SCOSS received expressions of concern that many large sports structures may not be receiving adequate structural inspections and appraisal of their safety as they continue in use. Their major structural elements are often exposed to the weather and thus are vulnerable to corrosion or other degradation processes. Some stadia structures have extremely large elements spanning stands that seat thousands of people. Trusses more than 100 m long and cantilevers having projections greater than 50 m have been used in some recent structures. Such large elements are usually critical, but their size and configuration makes them difficult to inspect unless the design included suitable access facilities. Whilst it can be expected that new stadia may include such facilities, older stadia, particularly those used by smaller or less wealthy clubs, may be less easy to inspect.

Some general guidance on this topic is included in the “The Green Guide”.(1) However it is brief and essentially the Guide provides guidance on safety and the number of spectators that can be safely accommodated within a sports ground. It has undoubtedly improved safety in that respect, but it does not comprehensively address safety issues relating to primary structures such as long-span roofs. There is no other authoritative guidance that relates directly to this topic although there is general guidance in the Institution of Structural Engineers' report '*Appraisal of Existing Structures'* .(2)

All sports grounds designated under the Safety of Sports Grounds Act 1975 are required to have a safety certificate which is reviewed annually by the Certifying Authority. It is a condition of the safety certificate that every 12 months ground management must submit a report from a competent person that the structural elements have been inspected and found to be adequate. This process is sound provided an acceptable level of competence by virtue of appropriate experience and training can be defined. A structural engineer with no experience in long span structures would possibly not be able to identify the critical elements that may suffer from fatigue or other 'hidden' effects.

SCOSS believes that large stadia structures (and other significant structures) should receive a detailed inspection and structural appraisal periodically to check that their structural safety is adequate in the light of current circumstances and use. The period between structural appraisals could perhaps be related to the type of structure, number and condition of critical components and potential susceptibility to disproportionate collapse. A period of 6-10 years is likely to be appropriate for most large stadia structures. Risk assessment should be an integral part of the appraisal process with structures being categorised according to complexity and risk and the more complex being subjected to independent checking. Structural appraisal criteria should be established taking into account load factors used in the original design, the degree of redundancy present, the risk of disproportionate collapse and the consequences of failure. The acceptability of the current condition of the structure should be determined on the basis of inspection (and testing where necessary) and analysis. If the condition is found to be unacceptable, work to remedy the situation should be specified and undertaken.

Maintenance manuals should be drawn up for existing as well as new stadia structures. An appropriate structural safety management regime over the longer term should be defined for this purpose. There should be a clear managerial chain by which responsibility for adequacy of the overall sports ground and of the parts is clearly articulated.

Another concern is that most stadia are now procured on a design and build basis, with contractors being responsible for the design element. When this is obtained by engaging a consulting firm with the designers being 'paid off' when the initial design is complete, there is concern over the method by which design related issues not previously identified can be properly addressed. Because stadia often pose challenging structural problems, contractors who undertake the design work themselves should ensure that the necessary level of expertise is available to them. Procurement by a design and build method and the fact that Building Control officers generally only have one major stadium in their area, can mean that there are no experienced stadia designers or appraisers involved in the project. In addition, the Football Licensing Authority (FLA) does not employ or commission checks from stadia engineers.

Given the potentially severe consequences of a structural collapse in an occupied stadia structure, SCOSS believes the above scenario is somewhat 'loose'. Consideration should be given to adopting independent checking procedures for the design of structures used to accommodate large assemblies of people akin to the procedures adopted for checking large bridges or dams.

Recommendation:
Owners of stadia should arrange a detailed structural inspection and appraisal of the structures periodically by a competent person to ensure their safety is adequate in the light of current circumstances and use.

References, Section 3.2

1. Department of National Heritage, The Scottish Office. *Guide to Safety at Sports Grounds.* Fourth Edition, 1997.
2. Institution of Structural Engineers. *Appraisal of existing structures.* London, SETO, Second Edition, 1996.

3.3 Cladding on buildings

Stone Cladding

SCOSS attention was drawn in 1998 to concerns about the performance of thin stone cladding on buildings in relation to possible failure due to fatigue of the stone and its fixings.

Failures of stone cladding have been known for many years. A considerable number occurred in the early 1980s as this form of cladding increased in popularity. The most well-known failure was perhaps that of the marble cladding to the 82-storey Amoco Tower in Chicago which was completely reclad in granite in 1990 (1).

The increased use of thin stone cladding gives rise to a greater potential for failure as the range of applications and designs grows. In-service performance is influenced not only by the environment surrounding the cladding but also by the design of the cladding system and the properties and behaviour of the stone. Structural movement, thermal and wind effects may over a period of years weaken panels and fixings which may also suffer higher stressing due to variations in properties and the dimensions of the cut stone. Properties are variable within any given stone and from stone to stone. Different types of stone vary in the accuracy with which they can be cut. The performance of stone cladding panels may also be influenced adversely by surface finishes. These factors and the interactions between them are complex. As a result, successful design and specification of stone cladding is a complex process. The uncertainties involved are increased by the current trend to use larger and thinner stone panels. Fortunately the early adverse experiences have led to the preparation of helpful guidance to assist designers and specifiers.

The Institution of Structural Engineers published in 1995 a general guide on the design and erection of cladding (2) in response to a recommendation in the Eighth SCOSS Report

British Standard BS8298 provides guidelines specifically for design and installation of natural stone cladding (3). The Building Research Establishment published an Information Paper in 1997 (4) referring to changes in BS8298 and problems relating to distortion, surface finishes and fatigue. Most recently, the Centre for Window and Cladding Technology has developed guidelines for stone selection, testing and design that gives advice on allowing articulation to avoid stress concentrations (5). Overall the available guidance to assist design and specification of stone cladding appears now to be much improved.

Use of glass

Glass is used in buildings essentially in two ways. Firstly, there are uses in which the glass only supports its own weight and transmits loads incident

Inspection and material sampling of cladding by rope access (Photo: Messrs Sandberg)

on it to a frame through a structural connection. The connection may consist of a structural silicone adhesive or of mechanical devices, usually bolted proprietary connections, which support the individual panels of glass on the frame. Secondly there are true structural uses of glass in which the glass is used as a structural element to transfer load within a structural system. Examples are the use of glass fins to transmit loads and suspended glass assemblies in which a sheet of glass is hung from the one above. These two forms of construction present different risks, and risks of different magnitude.

Failures of such glass constructions have occurred. The principal causes of glass failure appear to be poor design and workmanship. Stress concentrations arising from lack of fit, edge damage during construction, incorrect installation of fixing and seals, and lack of allowance for in-service movement or temperature change may each lead to glass failure, often at an early age. Failures sometimes arise due to manufacturing defects in the glass itself.

Techniques have been developed for identifying stress concentrations. Interpretation, however, is not straightforward requiring consideration of loading, temperature and building movement in order to identify prestress arising from toughening, and stresses due to load, temperature movement and other causes.

A SCOSS concern is that designers should ensure that they fully understand the behaviour of structural glazing systems before using them in innovative applications. Another concern is that glass constructions and glazing systems including fixings, should be inspected carefully at the time of construction and subsequently during the lifetime of the building.

Existing regulations do not provide an obvious means of ensuring that inspections in service are carried out. One SCOSS suggestion is that the requirement for inspection should be stated in the health and safety file required by the CDM Regulations. The approved Code of Practice states that this may include “maintenance procedures and requirements for the structure”. An alternative, perhaps less attractive suggestion, is that the requirement should be stated in Building Regulations made under Section 2 of the Building Act 1984, which enables Building Regulations to impose continuing requirements on owners and occupiers of buildings. For a fuller discussion of responsibilities for continuing structural safety see 2.4.

The Institution of Structural Engineers has prepared a guide on structural glazing in response to a recommendation in the Tenth SCOSS Report. This guide will provide a valuable basis for confident design of glass in buildings (6). A guide to good practices for overhead glass has recently been published by the Centre for Window and Cladding Technology. (7)

General

Overall there has been substantial innovation and development in cladding and wall systems over recent decades, and especially in the use of stone and glass. Innovative applications have been used for walling and roofing on modern buildings providing new and adventurous architectural forms. Both stone and glass are brittle materials and essentially cannot redistribute load. The design and specification of cladding and wall systems is a complex process requiring much careful analysis and thought, together with care and control during construction, to achieve a successful result. There have been some cases of stone and concrete panels, whole windows and glass panels falling from buildings.

The Eleventh SCOSS Report drew attention to the requirements in some other countries for design, installation, alteration and periodic inspection of exterior walls of buildings above a certain height. There are statutory requirements for the periodic inspection of cladding on high-rise buildings in, for example, New York and Singapore. In view especially of the innovative nature of much cladding on modern buildings, periodic inspection during use is necessary. Clearly potential hazards to safety are greatest for cladding on tall buildings. The introduction of a requirement for periodic checking of the safety of cladding at height, along the lines adopted in some other countries, is therefore a desirable and prudent step that should be taken in the UK and more widely.

Recommendation:
Owners of buildings should arrange for periodic inspection of claddings to check safety. The requirement for checking should be defined in the CDM health and safety file.

References, Section 3.3

1. Ridout, G. *Thin stone cladding defects*. Technical Forum, Building - Technical File, Number 26, July 1989.
2. Institution of Structural Engineers*. Aspects of cladding*. SETO, London, August 1995, 72pp.
3. BS8298:1994. *Code of practice for design and installation of natural stone cladding and lining*. London, BSI, 1994.
4. Yates, TJS and Chakrabarte, B*. External cladding using thin stone*. Information Paper IP6/97, Building Research Establishment, April 1997.
5. Centre for Window and Cladding Technology. *Guide to the selection and testing of stone panels for external use*. 1998. ISBN 1 874003092.
6. Institution of Structural Engineers*. The structural use of glass in building* (in press).
7. Centre for Window Cladding Technology. *Slope glazing: standard and test methods*. 1999. ISBN 1 874003 56 4.

3.4 Bridge strikes

SCOSS has noted the continuing incidences of bridges strikes. This topic has been discussed in SCOSS Reports on eight previous occasions since 1977. There are over 1000 incidents each year of large vehicles, including buses and coaches, passing under and colliding particularly with railway bridges. Such accidents lead to fatalities and injuries as well as causing delays on the road and rail networks. A railway bridge strike could also result in the derailment of a train with disastrous consequences. The cost of repairing the bridges is estimated to be about £4.5 m per year. The costs of disruption to road and rail traffic are even greater.

The incidence of strikes by road vehicles is increasing mostly due to the increasing number of vehicles using the road network, but also possibly due to a greater proportion of strikes being reported. This increase is occurring despite much good work done by the members of the Bridge Strike Prevention Group to reduce the risks. Over the past two years the main actions taken to strengthen prevention of strikes have been:

- A revision of the Road Vehicles (Construction and Use) Regulations came into force on 1 October 1997 (1). The regulations require vehicles over 3 m high to display the height of the vehicle in the cab or the driver must carry suitable information about the height of overhead structures along the route. They also require vehicles with power-operated equipment over 3 m high to be fitted with visible warning devices to alert the driver if the equipment exceeds the height limit. Buses on regular local journeys are exempt. There is some concern that if these buses are hired, they might be driven on other routes and so be at risk of bridge strikes. The Department of Transport issued a guide to the new Regulations in 1997 (2).
- The Highways Agency has published a design standard for collision protection beams (3) that provides details of legal requirements, general principles, loading and design.
- A new edition of the Truckers Atlas (4) was published in 1998 that includes information on low bridges on main routes but not on minor roads. The DETR is considering whether a database of all low bridges could be compiled.
- The Bridge Strike Prevention Group is considering whether notes about low bridges, bridge strikes and the new ‘Construction and Use’ Regulations may be included in the Highway Code, the publication ‘Know your traffic signs for commercial drivers’ and in various industry publications. Other ways of increasing awareness amongst heavy goods and public service vehicle drivers are being sought.
- Trials are continuing of warning devices, mainly infra-red systems but use of other systems, eg. low-frequency radar or laser radar devices, is being examined and a study of driver visibility is in progress.

SCOSS is concerned about the continuing high incidence of railway bridge strikes. An average of three strikes per day suggests an unacceptable risk to public safety. Since changing traffic conditions and increasing lorry traffic and weights may increase risks in the future, there is a strong case for ongoing monitoring of strike incidents to obtain warning of changing accident rates and indications of the effectiveness of preventive measures.

Recommendation:
The Bridge Strike Prevention Group, regulatory authorities and industry should more vigorously seek and implement measures for the prevention and mitigation of bridge strikes and their effects.

References, Section 3.4

1. Road vehicles (Construction and Use) Regulations. 1998.
2. Guide to 'Bridge Bashing' Regulations. Department of Transport., 1997.
3. BD65/97 *Design criteria for collision protection beams.* DMRB Volume 2.2 Stationery Office, February 1997.
4. Automobile Association. Trucker's Atlas, 1998.

3.5 Reinforced autoclaved aerated concrete

Reinforced autoclaved aerated concrete (RAAC) has been used for at least 25 years in the UK in the form of planks for roofing, and also panels for walls, floors and internal partitions. These units were manufactured and widely used in the UK until 1982, when production was discontinued for commercial reasons. A limited amount (around 1 million cubic metres) is imported from other countries in Europe and used in a small number of new developments. This compares with continuing widespread use in many other parts of the world. For example, approximately 2000 million cubic metres per year are manufactured in Germany. The material is extensively used in Japan as walling units in steel framed structures because of its good behaviour in seismic conditions.

Currently produced roofing planks are designed with a lower span/depth ratio than that used in the 1970s. There is not thought to be any likelihood of UK manufacture starting again because of the high costs of setting up a suitable manufacturing plant.

In 1995, concern was expressed in the Verulam column in *The Structural Engineer* about the structural performance of this form of construction following inspections of cracked units in school roofs (1). Although BS8110: Part 2: Section 6 (2) has rules for designing RAAC, investigations reported by the BRE (3) had concluded that RAAC planks could not be expected to have a useful life of much more than 30 years. Subsequently a proposal was made for the removal of the reference to RAAC in BS8110 on the basis that its inclusion gives this form of construction 'an unjustified respectability', 'the impression that it can be used for permanent structures' and that safety is in question. This concern was brought to the attention of SCOSS.

Autoclaved aerated concrete is a relatively weak material compared to normal dense concrete and, in particular, has a low capacity for developing bond with embedded reinforcement. In addition, the material provides little protection to reinforcement against corrosion. The reinforcement is therefore given a protective coating (a form of latex was used up to about 1980; more recently a bitumen coating has been used) during manufacturing to enhance durability. Such coatings, however, tend to reduce bond. To assist in safeguarding against bond failure, reinforcement cages are welded and incorporate transverse bars. Overall the result is that RAAC planks tend to creep – deflecting over time and cracks may occur on soffits, and the reinforcement may corrode.

In 1994, the then Department of Education asked BRE to inspect a number of school roofs in Essex. The results were reported in BRE Information Paper IP10/96.(3) This report, which was limited to RAAC planks designed before 1980, concluded that 'there is no evidence so far to suggest that RAAC planks pose a safety hazard to building users'. The Department of Education sent a warning to all schools referencing the Information Paper, and advising inspection and assessment of roofs incorporating RAAC planks. As a result Essex County Council is known to be inspecting some 60 school buildings. The BRE investigation did not therefore suggest a need for SCOSS to examine the topic at that time.

BRE has subsequently conducted loading tests on RAAC planks of recent manufacture using bitumen-coated reinforcement in top and bottom mats that are linked together. In some tests failure was sudden at very low deflection. These tests on imported planks raised questions on the draft European Standard prEN 12602 (4) which is at an advanced stage of preparation. The DETR has therefore commissioned design studies to examine the issues and to provide a basis for comments on the prEN. DETR has also had discussions with the Belgian manufacturers. BSI Committee B/525/2, which is responsible for BS8110, was contacted by SCOSS to ask if consideration is being given to amending or withdrawing BS8110: Part 2: Section 6.

The main issues relate to:

- whether the assumptions made in design concerning bond, modulus of elasticity and resistance to corrosion are sufficiently conservative in view of observed deflections, cracking and bond slip.
- the mechanism of failure over time, eg. whether moisture movement may adversely affect structural performance.

- whether excessive deflections and/or corrosion may lead to an unsafe condition and failures without warning, particularly in modern imported planks.
- the suitability of RAAC planks for use in 'permanent' construction.

BRE has concluded that pre-1980 RAAC planks in roofs do not appear generally to present a safety hazard as they gradually deteriorate over time. SCOSS concurs with this conclusion. Inspections of existing roofs of this type have been recommended. The recommendation has been drawn to the attention of schools.

The adequacy of the current structural design of RAAC planks has recently been examined by DETR and subsequently amendments to BS8110 and prEN 12602 have been agreed that remove references to RAAC in these standards.

Recommendation:
Owners of both school and non-school buildings that have pre - 1980 RAAC plank roofs should arrange for these roofs to be inspected if this has not been done since 1994, although generally the deterioration of RAAC planks does not jeopardise structural safety.

References, Section 3.5

1. Verulam. *The Structural Engineer*, 21 February 1995.
2. BS 8110. *Structural use of concrete.* Part 2: 1985. *Code of practice for special circumstances.* London, BSI, 1985.
3. *Reinforced autoclaved aerated concrete planks designed before 1980*. BRE Information Paper IP 10/96.
4. prEN 12602, *Prefabricated reinforced components of autoclaved aerated concrete*, London, BSI.

3.6 Lighting columns

There are about 6.5 million lighting columns in the UK of which over 25 per cent are more than 30 years old. The main types currently in use are made of cast iron, reinforced or prestressed concrete, tubular steel (with shoulder), tapered tubular steel, folded sheet steel, aluminium alloy, stainless steel or composite materials. Some three-quarters of the total are up to 6 m in height. The remainder are 8 m or 10–20 m in height. Some 10 per cent of the total stock is reported to be in urgent need of replacement. Resources available for column replacement have not always been sufficient over recent years. Consequently the average age of the stock and the number of defective columns is increasing, bringing greater risks to the safety of the public.

Lighting columns are cantilever structures. Their structural safety is therefore directly dependent on avoiding failure of the cantilever cross-section from causes, such as material deterioration, fatigue, or overload due to wind action.

The commonest cause of failure of steel columns is internal or below-ground corrosion or fatigue failure initiated at swage joints of sections of different sizes or at square-cornered access openings exacerbated by corrosion.

Reinforced concrete columns deteriorate due to corrosion of the reinforcement/tendons causing cracking and spalling of the concrete. Visible degradation is generally observed leading to the replacement of the column before it becomes structurally unsafe. Corrosion and fatigue may also occur at the junction between the steel cantilever arm and concrete post.

Failures of columns, in particular following corrosion of steel, are quite common due to the age of the lighting stock. Members of the public are rarely involved. The risk of injury due to column failure is low but increasing as the age of the stock increases. One death resulted from the collapse of a 35 year old tubular steel column in Gateshead in 1995 and a pedestrian was seriously injured when a steel column fell in Westminster in January 1998. Most road accidents associated with lighting columns occur on built-up roads and very few on motorways. For accidents involving single vehicles colliding with objects off the carriageway, only about 3 to 5% are associated with lighting columns.

The Westminster column that failed in 1998 was one of the types with a cast iron decorative 'collar' over the lower part. Corrosion of the part of the column within the 'collar' is hidden and difficult to inspect. The failure was due to corrosion. In view of the difficulty of visually inspecting for corrosion, a simple test method that consists of applying a lateral load to the column about 2m above ground is now in use in some areas to measure the integrity of columns and their foundations

Collisions of road vehicles with lighting columns also result in loss of life and injury, most commonly where impact involves the heavier types of column. This annual toll would be less if the risks of collision and damage could be reduced by careful siting and column design.

Failure of the fixings of lanterns to the columns is a common occurrence. Generally these failures are detected by annual inspections of lighting columns before the lanterns become detached and fall to the ground.

A gale in January 1993 lasting for about two days caused structural failure of a number of steel lighting columns on trunk roads and motorways in Northern England and Southern Scotland. Amongst a total of some 650 columns, 4 collapsed and over 50 were found to be cracked. The failures arose from fatigue that resulted from in-line oscillation caused by the wind which blew relatively constantly for many hours at about half the design wind speed of the columns.

Fatigue fracture of a steel lighting column (Photo: Flint & Neill)

The Highways Agency commissioned investigations of the failures, which led to the development of fatigue design rules. The rules were incorporated into Departmental Standard BD26/94 (1) and also into BS5649 (2). Previously no rules existed for the design of columns against fatigue. Euronorm EN40 (3) prepared by CEN/TC50 now provides a method, adopted from BS5649, for taking fatigue effects in steel columns into account in design if required by the customer.

In January 1998 further wind-induced failures of lighting columns occurred. The failures were of columns on the M62 motorway and arose from a different failure mechanism to that experienced in 1993. The Highway Agency commissioned an investigation that has now been completed and, as a result, a revision of BD26/94 is under consideration.

Several investigations of the various recently-observed types of failure of lighting columns are therefore in hand with a view to overcoming the shortfalls in structural safety. SCOSS believes these actions and the accumulated experience of columns in use can provide a sound basis for determining appropriate inspection and appraisal techniques for existing lighting columns and for considering improvement to the standards for existing lighting columns. Events such as seminars and conferences to provide opportunities for exchange of experience amongst those responsible for lighting columns would assist prevention of failures in the future.

SCOSS is concerned that resources being made available for inspection and replacement of defective columns are inadequate to maintain an acceptable level of safety. Relevant questions to be considered include:

- Inspection and appraisal of existing lighting columns. Are all engineers who are responsible for the structural safety of lighting columns alerted to the situation? Two one-day conferences were arranged by Aston University during 1998 which assisted exchanges of information and experience amongst engineers responsible for such structures (4). Are suitable techniques available for assessing present condition and future life? Is an appropriate framework for inspection/appraisal in place, particularly where columns are explicitly designed for a certain design life?
- Standards for new columns. Are current standards for design, materials, manufacture and installation satisfactory in relation to long-term structural safety with respect to wind forces, fatigue and accidental actions arising from vehicle collisions?
- Are resources adequate for inspections of existing columns and replacement of deteriorated columns before they became unsafe?

Recommendation:
Owners of existing lighting columns should arrange for them to be inspected periodically giving greatest priority to those that are likely to be most vulnerable due to position, age, environment, detailing and quality.

References, Section 3.6

1. *Design of lighting columns,* Departmental Standard BD26/94. Design Manual for Roads and Bridges, Volume 2 Section 2, Part 1, The Stationery Office, September 1994.
2. BS5649. *Lighting columns*, Parts 2-9, London, BSI.

3. BSEN40, *Lighting columns*, Parts 1-9, London, BSI.
4. Aston University, Department of Civil Engineering. One-day conferences on lighting columns, 10 June and 3 November 1998.

3.7 Use of computers

In response to a recommendation in the Tenth SCOSS Report, the Institution of Structural Engineers set up a task group to prepare concise guidelines aimed at both large and small engineering practices. SCOSS is pleased to note that the guidelines are due to be completed in 1999 (1) and hopes that they will be widely promulgated.

When using computer software engineers have a duty to appreciate its basis and limitations and to guard against the uncritical acceptance of results. SCOSS continues to be concerned about potential shortfalls in safety arising from inappropriate use of computers. The problem is one that is being recognised in other parts of the world, for example the Forensic Engineering Congress organised by the American Society of Civil Engineers in October 1997 included two sessions on computer misuse.(2) At the Structural Engineers World Congress in July 1998, a session on computer use also revealed substantial concerns that structural safety is at risk through computer use. The issue is complex. Some relevant factors appear to be:

- Inappropriate modelling of structures for analysis. The modelling of structures for analysis using standard software is generally not taught in university courses. This skill is acquired largely during an engineer's practical career and is therefore not subject to proper development, rigour and correction of misunderstandings. Some guidance has recently been published (3).
- The inability of engineers to use approximate design methods efficiently (4) possibly because simple approaches to analysing problems are not provided during the engineer's education (5).
- The placing of too much trust in computer outputs and the distancing and thus the loss of practical engineering thinking on the problems being addressed (6).

It is hoped the Institution of Structural Engineers Informal Study Group on the qualitative behaviour of structures may be able to make a positive contribution to encouraging and developing appropriate approaches in undergraduate education.

Recommendation:
Those responsible in universities, professional engineering institutions and government for the education of engineers and their continuing professional development should provide more guidance on understanding structural behaviour and its modelling for computer analysis, and on avoiding uncritical reliance on computer-generated results.

References, Section 3.7

1. Institution of Structural Engineers**.** *(Report in preparation),* London, 1999.
2. *Forensic engineering.* Ed. Kevin L. Rens. Proceedings of the First Congress. ASCE, 1997. ISBN 0 7844 0277 9. 342 pp.
3. Brown, D. *Modelling of steel structures for analysis.* Publication P148, Steel Construction Institute, 1995.
4. Sandberg, H. R. Computer programs overused and overvalued*. Paper P331-1 Structural Engineering World Wide 1998,* Elsevier. ISBN 0 08 042845 2.
5. More, W. P. Computing simulation as a substitute for physical testing. *Paper P331-2, Structural Engineering World Wide,* 1998, Elsevier. ISBN 0 08 042845 2.
6. Emkin, L. Z. Misuse of computers by structural engineers - a clear and present danger*. Paper P331-3, Structural Engineering World Wide* 1998, Elsevier. ISBN 0 08 042845 2.

3.8 Quality management systems and design

In the trial relating to the Ramsgate walkway failure, one of the main criticisms of the port authority client was its failure to stipulate in the contractual arrangements adequate requirements for quality assurance. The criticisms revealed, however, a degree of uncertainty as to what requirements should have been imposed and whether they would have been effective to prevent the failure (1).

The fundamental shortcoming in relation to safety and function at Ramsgate was that the structural concept of the design was seriously flawed because the assumptions regarding the structural behaviour of the structure were incorrect. Although calculations had been done to verify the behaviour of the structure, they were misleading - a particular form of structural behaviour under load appears to have been assumed based on an inadequate model of the applied loads. The flawed concept did not come to light because the approach to checking adopted by the certification body did not pick up the conceptual error.

In addition, other quality problems that were overlooked were identified at the trial:

- Fatigue: there was a failure to allow for fatigue, having regard to the repetitive movement in service.

- Welding: there was a failure to ensure the skill of the operatives, and to ensure that critical welds were examined during preparation and after completion.
- Moving parts: inadequate provision was made for lubrication and maintenance.

Where quality management systems are made a contractual requirement, it is usual to stipulate the requirement by reference to the ISO 9000 series of quality system standards. These Standards were, however, developed mainly for manufacturing. Some interpretation is needed to make them applicable to the design and construction of structures. For example, in manufacturing, a single organisation usually has overall responsibility for design and production. ISO 9001 entitled 'Model for quality assurance in design, development, production, installation and servicing' (2), is intended for use by such organisations. However, as the only model specification referring to design, ISO 9001 is also applied in design-only organisations such as structural designers.

The design element is covered by Clause 4.4 of ISO 9001, which specifies powerful procedures for design control. These include:

- 4.4.6 Design Review
- 4.4.7 Design Verification
- 4.4.8 Design Validation
- 4.4.9 Design Changes.

A letter in Verulam(3) rightly pointed out that "a system that addresses both verification and review would result…by adopting design management controls based on Clause 4.4 of BS EN ISO 9001: 1994".

There is a problem, however, in that the application of Clause 4.4 depends on sub-clause 4.4.1which states:

> *"The supplier shall establish and maintain documented procedures to control and verify the design of the product in order to ensure that the specified requirements are met".*

Understood in the context of a Standard written for organisations that are responsible for all stages, it will be appreciated that the word 'product' is used as an all-embracing term. However, some design-only organisations fail to appreciate this and apply a narrow interpretation of the word 'product' in 4.4.1. Consequently, they do not apply Clause 4.4 to all their design activities and therefore miss out appropriate procedures. To give proper sense to the Standard in the context of design and construction of structures, the word 'product' must be interpreted, where necessary, as referring to the ultimate product, ie. the building as a structure and as a functioning entity, as well as the more immediate product of drawings and specifications. Clause 4.4 is the only element within ISO 9001 which provides procedures capable of picking up the flaws in conceptual understanding of the behaviour of a structure.

It was also observed in the extracts from quality procedures submitted in response to SCOSS enquiries that the style in which some quality system procedures are written is obscure and hard to understand. Their effectiveness is therefore likely to be reduced. Quality system procedures should be as clear and concise as possible.

Recommendation:
Managers of quality assurance systems relating to structural design should ensure they are explicitly based on a direct response to the specification clauses of ISO 9001. In particular design management controls for verification and review should be based on ISO 9001 Clause 4.4.

References, Section 3.8

1. Barber, J. *Ramsgate Walkway Collapse: legal ramifications* Forensic Engineering: A professional approach to investigation. Conference. Institution of Civil Engineers, September 1998.
2. BS EN ISO 9001: 1994. Quality systems. *Model for quality assurance in design, development, production, installation and servicing*. London, BSI, 1994.
3. Letter from Verulam. *The Structural Engineer.* April, 1997.

4 Other topics considered during 1997-99

4.1 Scour

SCOSS has discussed the safety implications of scour and flood damage to bridges in three previous Reports. The preparation of Advice by the Highways Agency on the management of bridges subjected to scour, mentioned in the Eleventh SCOSS Report, continues (1).

The draft advice defines a two-stage assessment process. The first stage involves a site inspection following the collection of data on the bridge, its foundations and, if possible, any information on the bridge's history and any problems experienced. The main aim is to determine whether the bridge could suffer from scour damage at all. If a significant risk of scour endangering the bridge is found, then the assessment proceeds to the second stage. This stage involves calculation of potential scour depths and an assessment of a priority rating for the bridge. The rating gives an indication not only of the relative potential for scour damage but also of the importance of the bridge and hence the need for further consideration and possible action.

The advice is intended for use by bridge inspection staff as a means of assessing the potential for scour to damage a bridge. The subject is complex and hence the advice is rather lengthy since those who use it are not expected to have expert knowledge of hydraulics and hydrology. SCOSS believes the advice, which is currently the subject of application trials, does provide a helpful framework and basis for engineers to control the risks of damage and collapse of bridges due to scour.

The risks of scour and flooding adversely affecting the safety of bridges is well recognised in the railway industry. Railtrack Plc uses a Railway Group Standard (2) which sets out minimum requirements for managing the risk to structures from scour and hydraulic action under flood conditions. The risk is required to be assessed and control measures implemented to achieve an ‘As-Low-As-Reasonably-Practicable (ALARP) risk to railway operations. Requirements are defined for initial assessment of susceptibility to scour and/or flood and for procedures to receive and act on flood warnings. London Underground Limited has a specification that sets down the standards for the inspection of bridges which contains advice on high risk structures including bridges with risk of scour.

SCOSS notes that three bodies, the Highways Agency, Railtrack Plc and London Underground Limited, now have documents setting standards for the management of the risk of scour to bridges. It is suggested that these bodies give consideration to the benefits of amalgamating the advice into one standard.

References, Section 4.1

1. *Assessment of scour at highway bridges.* Highways Agency Draft Advice Note: Revision D: June 1998.
2. *Scour and flooding - managing the risk.* Railway Group Standard GC/RT5143, Railtrack, Plc, November 1995.

4.2 Slab/column reinforcement in concrete flat-slab framed structures

SCOSS examination of the structural safety of concrete frames used as multi-storey car parks revealed doubt concerning continuity reinforcement through columns in flat-slab structures. Neither BS8110 (1) nor Eurocode 2 (2) require continuity steel with the result that punching shear may be resisted by a plain concrete section alone. However, both codes require reinforcement to be placed in strips close to the column. It was reported that the steel reinforcement adjacent to the column induces compression into the column-slab interface giving resistance to punching shear.

Despite this explanation, SCOSS was concerned that this form of construction may not be adequately robust, particularly if all slab/column connections are similarly detailed and slabs are thin. With current detailing methods there is little reserve of strength following the unlikely event of a local structural failure. The concern therefore relates to whether any additional measure, such as providing some bottom steel passing through the column, should be included in such structures to give robustness against progressive collapse. Such measures would clearly be desirable, for example, for structures where risk of accidental actions is high, see 2.3.

The concern has been referred to the BSI Committee B525/2, which is responsible for the two codes, for consideration of the need for amendment to the relevant clauses.

References, Section 4.2

1. BS8110 : Part 1 : 1997 *Structural use of concrete : Code of Practice for design and construction.* London, BS1, 1997.
2. ENV1992-1*: Design and rules for buildings of concrete structures. Part 1: General principles*. London, BSI, 1994.

4.3 Demolition and structural alteration

Instances of unplanned collapses during alteration and demolition work continue to occur from time to time. Demolition and structural alterations are much easier, safer and less costly if accurate structural records and drawings are available. SCOSS has been pleased to note that some of those commissioning works appear to be recognising their responsibilities for providing accurate information as a requirement of the CDM Regulations. In due course, CDM health and safety files should form a good basis for developing operational manuals including detailed structural information.

Valuable practical guidance, such as the NFDC Guidance for deconstruction of tower blocks over ten storeys (1) is becoming more widely available. The new edition of the BS Code of practice for demolition should also help (2).

References, Section 4.3

1. *Guidance for deconstruction of tower blocks over ten storeys.* National Federation of Demolition Contractors, Staines, September 1997.
2. BS6187: 1999 *Code of practice for demolition* London, BSI (in press).

4.4 Thaumasite sulphate attack in structural concrete

The presence of thaumasite sulphate attack in concrete in the foundations of some bridges over the M5 motorway became known in early 1998. This phenomenon had not been previously identified in major structures in the UK although it was known to cement technologists over 25 years ago. The Building Research Establishment published its first reports into thaumasite sulphate attack on buried concrete in 1993. The recently-identified cases of attack occurred even though in some cases sulphate resisting cement had been used to make the affected concrete. The exact combination of conditions which leads to this form of attack in practice is not entirely clear although it appears to be limited to concrete buried in the ground, eg. piles and other forms of foundation, in some parts of the UK. The attack rates appear to be relatively slow and not likely to jeopardise structural safety.

Investigations by the Building Research Establishment and by consultants working for the Highways Agency have provided input to the work of the expert group chaired by Professor L. A. Clark of the University of Birmingham. Construction Minister Nick Raynsford announced the setting up of the group in early April 1998. The report produced by the group has recently been published (1). A paper summarising the main findings of the report is also available (2). Investigations on a limited number of highway and building structures provided the main basis for assessing the risk of attack. The report concluded that the risk of thaumasite sulphate attack is small for most existing buildings and structures. Areas of the United Kingdom where structures are likely to be most at risk were identified. Clients, designers and specifiers were advised to review structures under construction. New guidance was given on ground assessment and changes to concrete mixes for sub-soil structures were recommended.

Although thaumasite sulphate attack does not appear to pose a threat to structural safety, further investigation of its incidence is desirable in view of the limited number of structures examined so far.

References, Section 4.4

1. *The thaumasite form of sulphate attack: Risks, diagnosis, remedial works and guidance on new construction.* Report. DETR, January 1999.
2. *Thaumasite form of sulphate attack*. Concrete, February, 1999.

4.5 Calcium aluminate cements in construction

In 1997, the Concrete Society published Technical Report 46 re-assessing the use of calcium aluminate cements in construction (1). These materials are a family of cements of which high alumina cement cement (HAC) is the best-known type in the UK. CAC materials have an established market in specialised products such as grouts, mortars and screeds, in chemically - resistance pipe and flue liners, in rapid repair mortars and concretes and in sprayed concrete accelerators.

HAC concrete was used structurally in the form of precast prestressed beams in the construction of many buildings, particularly in the 1960s and 1970s, until three collapses occurred in 1973 and 1974.

Following extensive investigations of the causes of the collapses, the use of high alumina cement concrete for structural use in construction was prohibited. A factor contributing to the collapses was a loss of strength of the HAC concrete due to a chemical process known as conversion.

The Concrete Society report cites new evidence of an improved understanding of the mechanism and consequences of conversion in HAC concrete. It suggests that the strength of HAC concrete after conversion is predictable and that, when properly used in structural calculations, should lead to safe estimates of strength. However the Concrete Society report does not advocate the use of prestressed CAC concrete elements for mainstream construction. The material is significantly more expensive than Portland cement and, as a result, its widespread adoption for precast or in-situ concrete structures is unlikely. Rather the report seeks to encourage a climate in which cautious acceptance based on careful appreciation of the situation of each proposed application, and backed up by further research, becomes the norm. Its main recommendation is that specifiers, users and clients should be encouraged to consider applications where the special properties of calcium aluminate cements would bring technical and commercial benefits either in conventional concrete form or as specialist proprietary products. Two of the four recommendations ask for additional study of particular issues.

In considering the protection of steel reinforcement against corrosion in CAC concrete, the report refers to BRE Digest 392 (2) which commented that field evidence shows no quantifiable difference between the susceptibility to corrosion of reinforcement in HAC concrete and OPC concrete. The report also draws attention to the differences in the reactions relating to carbonation in HAC and OPC concretes and to the limited knowledge of the interaction between HAC concrete and embedded reinforcement. This is one area where understanding is incomplete. Further research is clearly needed to determine the long term performance of reinforced calcium aluminate cement concrete in environments that arise in practice.

Points of view have been published suggesting that the report is too optimistic in assessing the data and experience in the use of calcium aluminate cements and concrete (3). Further information on experience of the use of HAC concrete and debate on the content of the report may be expected (4). New research evidence is needed to achieve real progress in developing a better understanding of CAC concretes and of their performance in practical applications.

Overall the cautious approach advocated in the report does not overstate the case for the use of CAC concretes. The information and experience available in the light of past events and the further knowledge gained in the past 20 years have been evaluated. The report recognises there are still gaps in knowledge. It seeks to describe the properties and performance of CAC concretes so that designers, clients and others might be better informed. Clearly it is only in situations where the engineer is confident that he properly understands every aspect of the proposed application should he consider the use of calcium aluminate cement concrete.

References, Section 4.5

1. The Concrete Society. *Calcium aluminate concrete in construction : A re-assessment.* Technical Report 46, Slough, The Society, 1997.
2. Building Research Establishment. Assessment of *existing alumina cement concrete construction in the UK*. BRE Digest 392, 1994.
3. Neville, Adam. *A 'New' Look at High Aluminia Cement.* Concrete International, August 1998.
4. Rogerson, Richard and Price, Bill. *High-alumina cement concrete in buildings,* Concrete, February 1999.

4.6 Adjudication and the Housing Grants Etc Act

The Housing Grants, Construction and Regeneration Act 1996 (1), sometimes known as the 'Construction Act', has been brought into force so as to apply to construction contracts entered into after 1 May 1998. The Act responds to the recommendations of Sir Michael Latham concerning the need to promote prompt and regular payment, and overcome the practice of withholding of monies due on the basis of unjustified assertions of set-off. Insofar as inadequate and unreliability of funding can hamper an organisation's ability or willingness to devote adequate resources to safety matters in design or construction, the Act should be a positive contribution to safety.

The Act does, however, introduce two major changes in the legal framework which both have direct practical impact and could affect safety. First, Section 108 of the Act provides a right to require any dispute under a construction contract to be referred for immediate, speedy adjudication. An adjudicator's decision is stated to be binding, at least on an interim basis. This represents a dramatic change from conventional litigation or arbitration, since the decision of an adjudicator may be reached while the project is still live. The adjudicator's decision could therefore affect what is actually constructed or the construction methods to be used. The adjudicator is only allowed 28 days to reach a decision after the dispute has been referred. Many potential adjudicators are lawyers and quantity surveyors, rather than engineers.

Second, Section 112 provides a right to a contractor, designer or supervisor to suspend performance of obligations in the event of non-payment of a "sum due". This is completely new as a matter of law. Formerly, if a party to a contract suspended performance of its own obligations on the grounds of late payment by the other party, it risked severe contractual repercussions, and the other party could immediately step in to take over. Suspension could introduce risks to structural safety, eg. if a tunnelling contractor suddenly stops a drive in soft ground.

SCOSS is concerned that the Act, and the related Scheme for Construction Contracts (2) made under the Act, do not address the potential safety implications of these changes. As regards adjudication, there is no requirement to have regard to competence or resources in selecting an adjudicator (unlike a designer or contractor), no provision to enable the time allowed for a decision to be extended on safety grounds if the party referring the dispute does not consent, and no requirement on the adjudicator to have regard to safety in the decision. As regards suspension, there is no requirement to have regard to safety in exercising the right to suspend performance. It has been suggested that overriding powers and duties exist, to have regard to safety. If that is correct, then there is a need to ensure that the powers and duties are widely understood. Otherwise, there is a need to review the adequacy of the statutory and regulatory framework.

References, Section 4.6

1. Housing Grants, Construction and Regeneration Act 1996.
2. The Scheme for Construction Contracts. (England and Wales) Regulations 1998 (SI1998/549).

4.7 Structural use of adhesives

SCOSS is pleased to note that the Institution of Structural Engineers has published a guide on the structural use of adhesives (1). It gives basic information on the materials and techniques involved, outlines the range of applications for structural adhesives and indicates how simple joints may be designed. It was prepared by a Task Group set up by the Institution in response to a recommendation in the Tenth SCOSS Report.

References, Section 4.7

1. Institution of Structural Engineers. *Best practice: Structural Use of Adhesives.* SETO, London, 1999.

5 Other matters

5.1 Confidential Reporting on Structural Safety (CROSS)

The Eleventh SCOSS Report discussed the important role in achieving structural safety that communication processes play. In particular, feedback of information from experience, both good and bad, and its wide dissemination amongst engineers and others, is a powerful means of alerting them to adverse trends and of increasing awareness of hazards and risks to structural safety.

Attention was drawn to the confidential feedback systems which operate beneficially in other industries, eg. aviation. Whilst SCOSS aims to increase the feedback that it provides, it does not fulfil a major role as a confidential feedback route for information on individual experience. SCOSS concluded that such systems relevant to the maintenance of structural safety are not as well developed in the construction industry as in some other industries. A recent seminar organised by the Health Directorate of the Health and Safety Executive revealed increasing use and recognition of the value of such systems in improving safety (1). There was also a substantial consensus on the features essential to their success.

The discussion of this topic in the Eleventh Report raised interest in the Institutions of Civil Engineers and of Structural Engineers and attention was drawn to it in the technical press. A press campaign to sound out views in industry on a scheme for Confidential Reporting on Structural Safety was undertaken by New Civil Engineer. (3,4)

The Institution of Structural Engineers set up a small working party involving representatives of the two Institutions, SCOSS and New Civil Engineer to consider the requirements for such a scheme. The working party has recently reported to the two Institutions.

Stronger feedback systems in the construction industry would be a positive influence towards improved safety and performance of structures. SCOSS hopes the working party will be able to define a system that will supplement its work and bring benefits of improved practice, and also lead to improvements in the education and training of professional engineers relating to hazards to structural safety.

References, Section 5.1

1. Health and Safety Executive. *Confidential human factors incident and near miss reporting programmes.* Seminar papers, December 1998.
2. Speaking out for safety. *New Civil Engineer.* 9/16 April 1998.
3. *New Civil Engineer,* 2 July 1998.

5.2 Some relevant publications relating to structural safety

In addition to the references noted elsewhere in this Report, SCOSS has noted several other publications and major lectures of interest, in particular:

- *Construction Failure*. J Feld and K L Carper, John Wiley, 1997. ISBN 0471 57477 5.
  The second edition of Jacob Feld's classic work contains much new information and case studies of structural collapse and failure around the world. The book discusses technical and procedural failures of many types of structure, supplemented with new case studies. Expanded coverage is provided of natural hazards, the main structural materials, responsibility and contractual issues, and construction safety issues.

- Current structural safety topics in North America. Carper K. L. *The Structural Engineer*, Vol. 76, No. 12, 16 June 1998, pp. 233–9.
  The paper, which contains extensive references, identifies ten structural safety topics currently under study in North America: topics related to seismic performance of structures, wind hazards, safety during the construction phase, redundancy, structural integrity and 'robustness', facades and curtain walls, infrastructure maintenance, repair and replacement, management and procedural issues, integration of current research into practice, misuse of computer software, and inclusion of failure-related information in professional education. These topics are remarkably similar to those examined by SCOSS over recent years illustrating the value of learning from experience on a worldwide basis. An introduction to the ASCE Technical

Council on Forensic Engineering is also given in the paper together with a failure classification system that can be used to explore the underlying and often interrelated causes of failure.

- *Engineering for hazard reduction: a regulator's perspective.* Jenny Bacon. Hazards Forum 1997 Michael Leonard Lecture, 27 October 1997.
  The Director General of the Health & Safety Executive considered the benefits of engineering solutions to health and safety problems and drew on a wide range of applications to illustrate this – noisy machinery, offshore health and safety, explosives and explosions, processing of hazardous materials, crowd pressures, among others. She discussed the important part played by engineering judgement in deriving engineering solutions and the problems of communicating clearly the basis of such judgements. The importance of the human factor was emphasised.

- *Failures in civil engineering: structural, foundation and geo-environmental case studies.* Prepared by the Education Committee of the Technical Council on Forensic Engineering. ASCE, 1996. 104 pp.
  Over 40 case studies are presented in this concise book, each summarising the failure event, the lessons learned and listing references for further study.

- *Forensic Engineering* Ed: K. Rens (ASCE)
  This book contains the papers presented at the First Forensic Engineering Congress, held in conjunction with the ASCE National Convention in October 1997. The main topics covered include the engineer as expert witness, multi-hazard mitigation, lift slab construction, the Northridge earthquake, and computer misuse.

- *Forensic engineering: a professional approach to investigation.* Conference, September 1998, Institution of Civil Engineers. Thomas Telford (in press).
  The conference discussed the role of the expert witness, reviewed the Ramsgate walkway collapse and approaches to technical investigation of failure incidents. Papers were also presented on insurance, legal aspects and lessons to be learned for the application of computer technology and for management and design.

- *Introduction to Safety and Reliability of Structures.* Jörg Schneider, IABSE, Zurich, 1997. ISBN 3 85748 093 6.
  This book, in English, is a much-needed text on a subject with which many practising engineers are not yet familiar. Intended for both students and practising engineers, it explains concepts and procedures by simple examples. It includes an approach for dealing with hazards through the use of hazard scenarios and a safety plan. The approach is akin to the process for assessment of safety and risk advocated in the Eleventh SCOSS Report and in 2.2 of this Report.

- *Learning from failures: the systems approach.* Joyce Fortune and Geoff Peters, John Wiley & Sons, 1995. ISBN 0 471 94420 3.
  This accessible textbook derives from Open University research over many years into understanding organisations and failures within them. It makes extensive use of case studies to illustrate the use of the 'systems failure method', and various qualitative techniques for viewing past and potential failures. The studies include the 1985 fire on board a plane at Manchester airport, Bhopal, a large-scale IT project, and the Channel Tunnel.

- *Management of concrete structures for long-term serviceability*. Eds: E. A. Byars and T. McNulty. Thomas Telford, London, 1997. ISBN 0 7277 2654 4. 144 pp.
  This book contains ten papers presented to an international seminar held at the University of Sheffield. The themes covered were design, construction, prediction, inspection and strategies for maintenance and serviceability.

- *Man-made disasters*. Turner B. A. and Pidgeon N. Butterworth-Heinemann, second edition, 1997.
  The first edition of this book became established as an important guide to the role of human factors in disasters. It has been revised and updated to produce this new edition.

- *Offshore safety – where are we going?* P O'Ferrall. Symonds Group Safety Lecture. 28 April 1998.
  The lecture shows how the offshore industry has progressed from reacting to accidents to pro-actively identifying hazards before they occur, and putting in place measures to control risk from the outset, using the ALARP principle. The hazard management approach is described, with illustrations from other industries and countries.

- *The Oklahoma City Bombing: improving building performance through multi-hazard mitigation*. Federal Emergency Management Agency Mitigation Directorate/ASCE. August 1996. FEMA 277, 114 pp.
  This report reviews the damage caused by the explosion in April 1995, with the purpose of determining the failure mechanism for the building. It makes recommendations for reducing such damage to new and existing buildings in the future.

- *Safety by design – an engineer's responsibility for safety.* Hazards Forum, London, 1997. ISBN 0 9525 1031 6.
  This series of six lectures has been prepared by the Hazards Forum for engineering graduates and young professionals. The impetus for the publication came from discussions within the Forum about technical, legal and human factors relating to safety, and support from the member institutions that greater emphasis should be given to safety in the engineering profession, particularly during the education and training of professional engineers.

- *Safety of bridges* Ed: P. Das. Thomas Telford, London, 1997. ISBN 0 7277 2591 2. 256 pp.
  Based on the papers presented at a symposium sponsored by ICE and the Highways Agency, this book outlines the safety concepts that form the basis of modern design and assessment codes for bridges. The main themes are: safety concepts and codes, bridge-specific loading, options and economics, whole-life assessment, general risk assessment.

- *Critical review of the SMRF connections in new hi-rise buildings.* N. Youssef and K. Lee. Paper T114-4. Structural Engineering WorldWide. 1998, Elsevier. ISBN 0 08 042845 2. This paper describes developments in California in the design and construction of steel building structures following the widespread failures of welded connections in the Northridge earthquake in 1994.

- *On the collapse of the Las Vegas Hilton's spectacular sign.* F. A. Charney et al. Paper T114-6. Structural Engineering WorldWide. 1998, Elsevier. ISBN 0 080 42845 2. This paper reports on the numerous shortcomings in the design and construction process that contributed to the inadequacy of the structure.

- *Forensic engineering in safety enforcement - some UK experiences.* B. S. Neale. Paper T202-2. Structural Engineering worldwide, 1998, Elsevier. ISBN 0 08 042845 2

- *Structural Engineering World Wide 1998.* Proceedings of the SEWC. Abstracts volume ISBN 0 08 042845 2. 1998, Elsevier. 1004pp. The full papers of this major congress are available on CD-ROM.

5.3 International links

There is much similarity worldwide in trends and developments that influence structural safety. For this reason SCOSS is keen to build links with structural engineering organisations in other countries. SCOSS interactions with structural and civil engineers overseas have grown steadily in recent years. *Structural Engineering International* and *Civil Engineer International* included summaries of the Eleventh SCOSS Report in 1997, bringing SCOSS findings to a world-wide audience.

Three SCOSS members outlined our work at international meetings: Professor David Nethercot to the Hong Kong Branch of the Institution of Structural Engineers in September 1997 and to the Institution of Engineers in Singapore in November 1998; Brian Neale to the ASCE Technical Council on Forensic Engineering (TCFE) in October 1997; and Brian Simpson to the Structural Engineering Society of the Institution of Professional Engineers New Zealand in March 1998.

Exchanges with TCFE have been greatly helped by the enthusiasm of Professor Kenneth L. Carper of Washington State University, a former TCFE chairman. TCFE, a close analogue to SCOSS, develops practices and procedures to reduce failures in engineered facilities; disseminates information on failures; provides guidelines on their investigation; and encourages ethical conduct in forensic engineering. SCOSS members Brian Neale and Gordon Millington attended the First Forensic Engineering Congress (mentioned earlier), held in conjunction with the ASCE 1997 National Convention in Minneapolis. The Eleventh SCOSS Report was reviewed in the August 1997 issue of the *ASCE Journal of Performance of Constructed Facilities*. This journal provides valuable reports of experience and is a feature of the considerable activity within ASCE on forensic engineering. Special issues of the Journal in 1998 have been devoted to the structural engineering issues raised by the Northridge earthquake and the L'Ambience Plaza collapse of a lift slab structure in 1987.

SCOSS was pleased to meet Professor Carper in

July 1998 at the time the presentation of his paper to the Institution of Structural Engineers, see 5.2.

5.4 SCOSS web site

A SCOSS web site has been established. It includes the recommendations contained in this Report and other recent Reports and information about the background and terms of reference of the Standing Committee. It provides an opportunity for SCOSS to disseminate findings of its discussions as they arise, without necessarily waiting until the publication of its biennial Reports. It makes the work of SCOSS more readily accessible to engineers and students throughout the world, and, it is hoped, provides a very effective additional means of communicating the findings and recommendations.

6 Future SCOSS programme

The SCOSS 1998/99 business plan identifies the following key items of work and new initiatives:

Output

- Publish Twelfth Report and Bulletin 3 summarising 1997–99 findings and recommendations.
- Publish other papers relating to topics in Twelfth Report as appropriate.

Other output

- Seek further to increase awareness among practising engineers and others of current topics of concern through issue of Bulletins and other means. eg. lectures.
- Maintain regular liaison with the Institutions of Civil and of Structural Engineers, HSE, DETR, Highways Agency and industry.

Information gathering and analysis

- maintain up-to-date information on areas and topics already examined (Appendix C) and newly identified, including:
- biological attack on concrete
- bridge strikes cladding and fixings
- effects of climate change
- stability of terraced housing
- education and training
- fatigue in steel structures
- multi-storey car park structures and edge barriers
- positive/adverse effects of regulations on structural safety
- resistance to disproportionate damage safety of sports stadia
- scour and flood damage to bridges
- solidity and stability of structures
- standards and codes of practice
- structural assessment of railway and highway bridges
- use of computers
- management of structural engineering records in the construction industry

Topics arising at short notice

- Respond to reported concerns and structural failures/collapses appropriately as they occur.

New initiatives

- consider setting up a database of SCOSS information.
- establish more international contacts to obtain better information on structural safety events worldwide.
- promote SCOSS recommendations especially in other parts of Europe.

Appendix A – Developments following the Eleventh SCOSS Report

Recommendations made in the Eleventh Report are given below together with developments that have taken place since the Report was published in January 1997.

INSPECTION AND APPRAISAL OF EXISTING MULTI-STOREY CAR PARKS

Recommendation

Owners and operators of existing multi-storey car parks should commission periodic inspections and structural appraisals on the condition of their structures. Such inspections and appraisals should be made by engineers with appropriate experience following the principles adopted by bridge owners. Appraisal should extend beyond any areas of conspicuous deterioration, particularly where water with road salts may have penetrated, and should include a review of resistance to progressive collapse.

ADEQUACY OF EDGE BARRIERS IN MULTI-STOREY CAR PARKS

Recommendation

Owners and operators of existing multi-storey car parks should:

- establish whether the strength of edge barriers is adequate to restrain vehicles,
- establish whether the height and design of edge barriers are appropriate to safeguard small children,
- modify, strengthen or replace inadequate edge barriers.

GUIDANCE ON ASSESSMENT OF BARRIERS IN MULTI-STOREY CAR PARKS

Recommendation

The Institutions of Civil and of Structural Engineers should urgently prepare guidance on assessment and strengthening of existing edge barriers in multi-storey car parks.

Developments

- BSI made aware of SCOSS concern about barriers in July 1997.
- Wide publicity given to SCOSS recommendations following incidents in Wolverhampton and Canterbury.
- Association for Structural Engineers of London Boroughs (ASELB) intends to issue a technical bulletin on inspection and appraisal in 1999.
- BCA Conference held on 29 September 1997 with SCOSS support and involvement.
- Aston University held conference February 1998.
- BS Committee responsible for BS8110 intend to amend code to deal with horizontal ties through columns.
- IStructE plan to prepare new edition of joint IStructE/IHT 1984 guide.

PIN CONNECTIONS IN BRIDGES AND BUILDINGS – REVIEW OF GUIDANCE

Recommendation

The Steel Construction Institute in collaboration with the British Standards Institution should review the guidance on the design, inspection and maintenance of pin connections in bridges and buildings.

PIN CONNECTIONS IN BRIDGES AND BUILDINGS – DESIGN

Recommendation

The design of pin connections should be overseen by suitably experienced engineers who are responsible for design, detailing, installation, inspection and maintenance.

Developments

- Discussions held with SCI to pursue recommendations.
- BSI has attempted to address the issue, but the topic is covered in a number of committees, and difficulties of co-ordination remain.
- ICE is encouraging BSI to prepare Part 8 of BS6349 maritime structures code on link span structures. DETR declined to support.
- CIRIA is preparing guidance on procurement and management of link span structures.

FATIGUE IN STEEL STRUCTURES

Recommendation

The Institutions of Civil and of Structural Engineers, and the British Standards Institution should undertake a strategic review, from a safety standpoint, of standards and codes of practice relating to design against fatigue in steel structures as a basis for achieving convergence towards a compatible set of fatigue rules, taking into account the commitment to the development of the CEN Structural Eurocodes**.**

Developments

- Discussions between Institutions and BSI initiated.
- Discussed at liaison meeting of SCOSS and BSI in July 1997. Suggestion made that a workshop of invited experts, perhaps one from each of the relevant committees, should be arranged to address the problem.
- B/525 has discussed and asked BSI staff to investigate topic, including overlap with WEE committees.

DISPROPORTIONATE COLLAPSE

Recommendation

The Institutions of Civil and of Structural Engineers should prepare design guidance for engineers on structural concepts and forms which have a low sensitivity to damage and an appropriate capacity to resist disproportionate collapse.

Developments

- ICE Seminar on 5 March 1997 attended by over 60 delegates.
- Robustness Committee set up by DETR Building Regulations Division - outcome awaited.
- DETR review of Part A of the Building Regulations and commissioning of the preparation of guidance on ‘robustness and provision against accidental actions’ with the intention of proposing revision to Requirement A3 of the Building Regulations.
- IStructE plan to set up task group in 1999 to prepare guidance.

FLOOD DAMAGE TO BRIDGES

Recommendation

A continuing collaboration between highway authorities, Railtrack and other owners of bridges over water, possibly under the aegis of the Institution of Civil Engineers, should be established to keep flood damage to bridges under review and to develop consistent best practice.

Developments

- Highways Agency preparing Advice Note on assessment of scour at highway bridges.

HAZARD IDENTIFICATION AND RISK ASSESSMENT IN DESIGN

Recommendation

Starting at the design stage of projects, designers should apply an explicit risk management process, including the identification of hazards and assessment of risks, with the effort expended and sophistication of the assessment being directly related to the nature, size and importance of the structure.

Developments

- Technical notes to be commissioned from IStructE members for publication in The Structural Engineer.

DESIGN AND BUILD: CLIENT-SUPPLIED DATA

Recommendation

Bodies responsible for standard forms of contract for design and build should review their conditions of contract to ensure that the responsibility of the designer for investigation, checking and evaluating ground and other site conditions is clearly stated, and that there is protection against unjustified reliance on or over-optimistic interpretation of client-supplied data.

Developments

Comments received from the Conditions of Contract Standing Joint Committee and the ICE New Engineering Contract Panel.

STRUCTURAL CODES OF PRACTICE

Recommendation

The British Standards Institution should give publicity to an overall policy for the development of codes of practice relating to structural design and should aim to achieve a single set of codes through positive co-ordination and support of their development.

Developments

- Discussions with BSI initiated.
- BSI Committee B/525 re-formed with T A Rochester as Chairman. SCOSS represented by the Secretary.
- Discussion with T Rochester and D Lazenby, BSI Director of Standards, at SCOSS meeting July 1998.

AIR-SUPPORTED STRUCTURES – WITHDRAWAL OF BRITISH STANDARD

Recommendation

The British Standards Institution should withdraw BS 6661: 1986 *Guide for the design, construction and maintenance of single-skin air-supported structures*.

GUIDANCE ON AIR-SUPPORTED AND FABRIC STRUCTURES

Recommendation

The Institutions of Civil and of Structural Engineers in collaboration with the industry should prepare guidance on the design, specification, construction and use of air-supported and fabric structures.

Developments

- BSI reviewed information provided by SCOSS and issued notice of intention to withdraw this standard.
- IStructE Informal Study Group on Space Structures to consider the recommendation.
- Preparatory discussions under way between researchers and practising engineers on sources of funding for preparation of guidance.

FEEDBACK OF EXPERIENCE

Comment

Systems for the feedback of experience relevant to the maintenance of structural safety are not as well developed in the construction industry as in some other industries.

Developments

- Press campaign by *New Civil Engineer* to sound out industry views on confidential reporting on structural safety (CROSS)
- Working party set up by Institution of Structural Engineers to consider the requirements for a CROSS system for the construction industry has reported.

Appendix B – SCOSS: origin, role and terms of reference

SCOSS – the Standing Committee on Structural Safety – is an independent body established by the Institutions of Civil and of Structural Engineers and others in 1976 to maintain a continuing review of building and civil engineering matters affecting the safety of structures.

The prime function of SCOSS is to identify in advance those trends and developments which might contribute to an increasing risk to structural safety. To that end, SCOSS interacts with the professions, industry and government on all matters concerned with design, construction and use of building and civil engineering structures.

SCOSS reports directly to the Presidents of the Institutions and liaises with the Directors of Engineering of the two Institutions. Its Reports are published biennially. The Reports are available from both Institutions and are sent to key representatives of organisations with responsibility to contribute to structural safety. Papers and bulletins are also published from time to time to draw attention to SCOSS's recommendations and to encourage the collection and dissemination of experiences likely to foster the avoidance of structural failures and a greater measure of structural reliability.

Whilst concentrating on matters relating to the United Kingdom, SCOSS maintains an awareness and contact with construction events worldwide. In so far as its resources enable it to do so, it seeks to obtain information from overseas experience by appropriate contacts with the International Association for Bridge and Structural Engineering and other international associations.

Topics for consideration by SCOSS arise from many sources, relying upon information derived mainly from the experience of others. SCOSS seeks information on how structures actually perform in practice. It identifies where risks are thought likely to be unacceptable and then seeks changes of practice which will maintain safety. It is itself a feedback mechanism and encourages other, more comprehensive, modes. Feedback is received through the day-to-day interaction of SCOSS members with the professions, industry and government. Feedback on topics which are considered particularly relevant is actively sought by the Secretary and Technical Officer. SCOSS receives presentations on specific topics from relevant experts. More than a hundred topics have been closely studied at some time in the last 20 years, see Appendix C. Many of these topics are, by their nature, fundamental and ongoing and of a general nature. Others are relatively detailed and result from incidents reported to SCOSS as potential problems. Not all topics drawn to the attention of SCOSS are necessarily pursued. Once a topic has been addressed, SCOSS aims to leave the matter unless it decides that there are ongoing structural safety issues which are not being adequately addressed elsewhere.

Confidentiality is an essential feature of SCOSS's procedure. This helps to encourage those who have doubts, fears or experiences of potential problems to share them with SCOSS. It also means that ideas, materials or techniques under discussion are not seen to be unnecessarily blighted by suspicions.

Administrative and secretariat support are funded by the two Institutions with additional financial assistance to these support services being provided by the Health and Safety Executive commencing in November 1995. The Institution of Structural Engineers provides the secretarial services.

Terms of reference

The terms of reference of SCOSS are to:

- Consider both current practice and likely development from the standpoint of structural safety.
- Be aware of trends and innovations in design, construction and maintenance from the standpoint of safety.
- Consider whether unacceptable risk exists or might arise in the future and, if believed so, to give warning to relevant bodies.
- Consider whether further research and development appears desirable from the standpoint of structural safety.
- Disseminate the findings of the Committee by a biennial published report and by other appropriate means.
- Avoid duplicating the work of the Health & Safety Executive, of the Institution of Civil Engineers and of the Institution of Structural Engineers.
- Report to the Presidents of the Institutions of Civil and of Structural Engineers annually and from time to time on specific issues.

Appendix C – Cumulative index to topics considered by SCOSS since 1976

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