Standing Committee on Structural Safety

Ninth report

July 1989 to June 1992

October 1992

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11 Upper Belgrave Street
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ISBN 1 874266 04 02
Published by SETO Ltd, 1992
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Foreword

The safety of structures and of the people using them has always been a requirement of civilised societies. Safety used to be achieved solely by trial and error. Nowadays we appeal to well-tried empirical and scientific methods of design and construction. A complex infrastructure of scientific, engineering and organisational techniques is used to ensure safety. The Standing Committee on Structural Safety is an important element in this complex; seeking to identify, ahead of time, aspects which may have slipped through the conventional systems for ensuring safety.

The Committee aims to assist in preventing disasters involving structural failures, to encourage application of the lessons of structural accidents and to assist safe innovation and public safety. It provides a route through which informed apprehensions concerning structural safety may be examined, on a confidential basis if required, and drawn to the attention of responsible organisations in a constructive and responsible manner.

Achieving these aims is a challenge. In meeting it the Committee receives much positive help from engineers and others in both the public and private sectors. Their cooperation and support greatly enhances and facilitates our work. I am especially grateful to them and also to the members of the Committee as well as to our Secretary and Technical Officer for their hard work.

Professor Anthony Kelly
Synopsis

The Standing Committee on Structural Safety, (SCOSS), operates as an independent committee maintained jointly by the Institutions of Civil and of Structural Engineers. This report covers the period July 1989 to June 1992. Following a review of the Committee’s role, method of working and constitution, by the Presidents during 1990, it was commissioned for a new phase of work in April 1991. The new Committee was asked to examine structural safety at a more strategic level and to extend consideration to include additional areas such as offshore structures.

In discharging its new brief the Committee re-examined the basic factors concerning structural safety. A distinction was drawn between the direct contributors to structural safety, e.g. designers and constructors, and the indirect contributors, e.g. controlling authorities, standards organisations and professional institutions. Feedback of information on structural performance was identified as a crucial element.

Feedback and trends

The Committee works to complement the existing, sometimes complex, systems for preserving structural safety both by providing a route for feedback and by the early detection of adverse trends. Experience has shown that evidence likely to assist in preventing structural failures may be found by an ongoing review of:

- structural failures
- trends in design and construction
- methods of setting safety levels
- procedures for control of design and construction
- new materials or structural forms
- inspection and maintenance
- social and economic changes

The Committee therefore recommends that research on innovation and trends in structural engineering practice and performance are a necessary extension to feedback.

The Committee aims to encourage feedback. The Fellowship of Engineering ‘Draft Guidelines for Warnings of Preventable Disasters’ were welcomed. The ‘Embryo Code of Practice on Risk Issues’ prepared on behalf of the Engineering Council was seen as a useful initiative to encourage debate amongst engineers. Feedback of information from litigation could make a valuable contribution to safety and efficiency. The Committee agreed a Practice Note with the Law Society to facilitate that process and now asks for the help of professional engineers.

Taking a more strategic view, the Committee focused its attention on modern urban developments which feature many aspects of structural engineering, such as combined shopping, office and leisure complexes (multiple-use buildings) and sports and concert stadia.

Multiple-use buildings

Structural trends and innovative characteristics in multiple-use buildings were examined from three points of view - occupancy, fire safety, structure and cladding.

Multiple-use buildings have become an increasingly important feature of urban development in the UK. They usually include many forms of retailing outlet and sometimes include hotel, office and leisure accommodation. They often have underground service yards for access by heavy goods vehicles. They frequently incorporate malls and atria and have long-span lightweight roofs forming complete envelopes to the development. The design considerations for multiple-use buildings were seen to be akin to those for indoor or covered stadia. The Committee recommends that the design of malls and atria should consider loading, fire resistance and crowd evacuation from the point of view that malls and atria are places of public assembly. Guidance on design for heavy vehicle impact on key structural elements should also be prepared particularly in relation to the possibilities for “disproportionate” collapse of the structures above. Barriers need to be designed to accept anticipated concentrations and patterns of crowd flow in the process of emergency evacuation.

The Committee recommends that there should be an appropriate level of full-time management and surveillance in multiple-use buildings which rely on active systems for fire safety. These systems should be subject to regular maintenance and performance testing, possibly by third parties, to meet appropriate inspection and certification requirements of local fire authorities. Only by developing fail-safe monitoring and controls of critical active fire precautions can "trade-off" reductions of passive structural fire resistance be justified where life safety would be at risk.

Performance of structures in fire

The Committee took note of reports of the performance of buildings in some recent fires. Several significant fire incidents have occurred highlighting different aspects of structural fire behaviour. Although structural failure in fire has generally contributed little to the loss of life, there is a need to ensure that this situation does not suddenly change through a progressive weakening of fire safety requirements. The Committee concluded that buildings...
under construction are more vulnerable to fire than was generally recognised and that claddings may not have adequate passive resistance against the upward spread of fire.

The recognition of the role of fire safety engineering in the Building Regulations 1991 was noted. For safety both passive and active fire measures need to be achievable, maintainable and enforceable. The close interrelationship between fire safety and structural safety was examined and the increasing reliance upon active systems for fire detection, suppression and smoke control was identified. The introduction of sophisticated and sometimes automated management control of active systems whose reliability is crucial to safety, especially in multiple-use buildings, in the event of fire, was considered. The Committee recommends that the overall efficacy of active systems and associated passive measures should be further researched and that the Fire Research Station be encouraged to study their performance in fires to provide feedback from practical experience.

Expertise in fire safety engineering rests with a comparatively small body of engineers. The Committee recommends that the growing use of fire safety engineering should be matched by growth in the education and training of fire safety engineers and in research. The closer cooperation of the Institute of Fire Safety and the Institution of Fire Engineers would provide a strong professional framework.

Cladding and roofing

Examination of the structure and cladding in multiple-use buildings identified unconventional features now increasingly adopted in other commercial buildings. In roofs, the use of long spans of lightweight construction involving glass and other translucent materials may create a greater sensitivity to wind and solar action. An increasing dependence upon such materials to distribute wind and snow load to structural members and also to provide lateral restraint, was noted. In cladding, for example, increasingly complex systems with innovative use of structural adhesives, suspended glazing and the rigging and tensioning of facades have been introduced. The Committee welcomes the extension of the Building Regulations to control the structural adequacy of cladding and recommends that the monitoring of the performance of cladding systems in multiple-use buildings should be undertaken.

Following reports of structurally inadequate cladding repairs placing passers-by in serious danger, the Committee recommends that major structural repairs to building cladding and overcladding should be subject to control under the Building Regulations.

Sports and concert stadia

Structural safety forms only one aspect of the wide topic of safety in stadia and stands. Social and economic changes have led to an increasing frequency of large leisure events with large crowd occupation together with high levels of crowd activity in a wider range of events. The Committee closely followed the work of the IStructE Committee and subsequently the Taylor Report and the responses evoked. It identified roof structures, retractable terraced seating and barriers and handrails as topics for its examination.

The construction of all-seater stands requires major large-span roofs and long cantilevers. Such projects which are being undertaken to comply with current legislation and to provide new standards of safety and comfort, require managerial and technical skills of a high calibre. The roof structures of stadia illustrate the particular sensitivities of long-span roofs in that they cover accommodation for many hundreds of people and the long-span structural form often incorporates statically determinate primary elements unprotected from local extreme climatic actions. These particular aspects should be recognised in design and structural appraisal. Special attention should be paid to, for example, dynamic performance, fatigue and low temperature performance of welds. The Committee emphasises the importance of the use of appropriate quality management systems in design and construction and recommends owners should commission regular structural inspection and maintenance and the keeping of permanent structural records to assure the future safety of these structures.

Retractable and demountable terraced seating

During 1991 the attention of the Committee was drawn to disturbing sway movements of high tiers of retractable seating at venues for pop concerts. The structural implications of these movements generated by the rhythmic loading from synchronous movements of the concert audience, were found to be difficult to assess. Discussions with the parties involved revealed several areas of uncertainty relating to structural safety, in particular criteria for design, factors of safety and potential for progressive collapse under dynamic crowd loading. The Committee recommends that an independent structural engineering check of the adequacy of such structures should be a requirement of licensing. It also recommends that further research should be carried out on crowd loading, and that additional technical guidance should be prepared.

Safety of temporary stands and staging structures

Certain large leisure events, such as golf tournaments and pop concerts, involve the construction of temporary stands and stages which are not required to be subjected to structural safety checking. The Committee believes structural safety may be in jeopardy in these circumstances. The tragic collapse of the temporary stand in Bastia has provided a timely reminder of the need to ensure safety of temporary stand structures.
The Committee recommends that temporary stands for public occupation and associated stage structures be required to have an independent structural check as a condition of licensing by local authorities even when they are on private property.

High-bay warehouses

Wholesalers, chain-store operators and manufacturers have for many years stored products or parts ready for assembly in bulk in large quantities in concentrated stores. Warehousing techniques have been developed involving the automatic placing of pallets in high vertical racks. More recently the racking has also been used to support the wall and roof cladding of the building. This clad-racking building principle is now well established and there appear to be no aspects detrimental to structural safety with respect to normal loads. However the vulnerability to fire of large stocks of materials and packaging and the difficulty of segregating high risk materials and of access to the seat of any fire raises special questions of structural fire safety not met with in other types of building.

The Building Regulations 1991 now make concessions to structural fire resistance and boundary distances for the provision of sprinklers in some buildings including storage structures. The Committee’s concern is whether such structures, with little fire resistance, would perform satisfactorily during fire fighting if the sprinklers fail to control a fire.

The Committee recommends that greater use should be made of sprinklers capable of operating through racks. Consideration should be give to compartmentation where sprinklers are fitted in the largest warehouses even though this might place some constraint on the flexibility of warehouse use.

There remains a concern about the inherent danger to isolated workers who, for inspection and maintenance purposes, may be within the racking area in the event of a fire developing between them and the exit. The Committee recommends designers should consider the provision of safe escape exit routes bearing in mind the obstacles inherent in such structures when mechanised.

Building alterations

Confusion can arise concerning responsibilities for the accuracy of structural information on existing and adjacent construction prior to structural alterations. The Committee continues to be concerned about the effects of alterations on adjacent structures, since plans, calculations and checking are only controlled for the property directly affected.

The Committee welcomes the recent amendments to the Building Regulations which require a building to comply with the Requirements for structure (A1 to A4) where there is a material change of use into a hotel, boarding house, institution or a public building. It recommends the preparation of better guidance relating to structural alterations and the safety responsibilities of the parties directly and indirectly affected.

Barriers and handrails

The subject of barriers and handrails was considered in relation to leisure, office and shopping complexes and sports and concert stadia and arenas. The Committee recommends that further research for the development of design recommendations should be carried out into crowd loading on barriers and handrails.

Freestanding masonry walls

An enquiry amongst Local Authorities suggested that some freestanding walls are jeopardising safety. A number of deaths involving collapse of freestanding walls were reported. The Committee recommends that consideration be given to including freestanding walls in the brief of the building surveyor when properties change hands. Failures should be monitored to assess whether improved safety results from the recent issue of guidance for owners and builders.

Air-supported structures

In its Eighth Report the Committee made recommendations for the review of the standards of design, construction and operation of air-supported structures. Following its examination of reports of failures of these structures the Committee recommends that BS6661 should be withdrawn and design guidance be developed for all types of air-supported structures. In addition, a consistent approach to control under Building Regulations should be adopted throughout the United Kingdom.

Post-tensioned grouted structures

Further consideration of the safety of buildings and bridges constructed with grouted post-tensioned steel tendons led to the recommendation that a stringent regime of inspection and appraisal of existing construction in post-tensioned concrete should be introduced. The search for an effective means of inspecting tendons should continue. For new post-tensioned structures, the Committee recommends that alternative stressing methods be investigated which avoid the need to rely upon grouting steel tendons.

Damage to bridges by ships

The Committee reiterates its recommendation for mitigating damage to bridges by ships, i.e. improvement of design features of bridges and piers and the wider use of fenders and dolphins.
Other topics

The Committee examined several other topics. These include hydrogen embrittlement of zinc-coated HT steel bars, durability of concrete in relation to use of cement additives and concrete admixtures, safety of chair lifts and cable cars, cranes, effects of rising ground water, safety of old tunnels, overcladding, void formers and safety of offshore structures.

The Committee's conclusions are given within the Report.

For the future, the Committee expects some of the topics discussed in this Report to require further consideration. Several new topics have been identified, such as appraisal of the strength of old masonry, the mis-use of computers, the influence of structural education and training on safety, and techniques of facade retention.
1 Introduction

The Standing Committee aims:

- to assist in preventing structural failures especially those which could threaten life;
- to encourage the understanding and acceptance of lessons from structural accidents;
- to promote safe construction and;
- to increase public safety.

This Ninth Report of the Committee covers its work during the period July 1989 to June 1992. It is based on the previous two annual reports to the Presidents. It is an up-to-date summary of the Committee's findings which are developed on a day-to-day basis in interactions with the professions, industry and government.

In 1990 the Presidents of the two Institutions undertook a review of the Committee's role and operation following a decision of the Property Services Agency to withdraw its financial support. As a result the Committee was reconstituted and commissioned by the two Institutions in April 1991 for a new phase of work. Its new terms of reference are given in Appendix 1. These new arrangements were made to enable the Committee to extend its consideration to, for example, offshore structures and to examine at a more strategic level the application and development of materials, technologies and practices.

The funding of the essential administrative and secretariat support since April 1991 has been granted by the two Institutions on behalf of which the Institution of Structural Engineers provides the secretarial services.

The Committee's work has been developed to ensure continuity in the examination of topics where questions were outstanding in April 1991. An alphabetical list of the topics reported by the Standing Committee since its inception in 1976 is given in Appendix 2.
2 Systems for maintaining structural safety

2.1 General
The main contributors to the systems involved in maintaining structural safety may be described as follows:

Direct contributors:
- Designers
- Manufacturers
- Constructors
- Maintainers

Indirect contributors:
- Controlling authorities
- Standards organisations
- Clients and commissioning bodies
- Professional engineering institutions and other professional bodies
- Trade associations
- Research and development organisations in government, universities and industry
- Educational and training organisations - academic, employer or trade union sponsored
- Media

In general terms, the direct contributors provide and maintain the structural safety of structural works for which they take practical responsibility against the background provided by the indirect contributors. The latter essentially set the standard of structural safety which should be observed. To determine whether the standard actually achieved is adequate and is being maintained, the indirect contributors particularly require feedback of information on performance in practice. They, to a greater or lesser extent, seek out such information and use it to bring about adjustments to the standard of structural safety which is judged to be needed.

The Committee works to complement these complex systems which in many cases are not explicitly established. Experience has shown that evidence likely to assist in preventing structural failures may be found by review of:

- The findings of investigations of structural failures and accidents
- Trends in design and construction practice
- Methods by which structural safety levels are set and maintained
- Procedures for controlling and checking design and construction
- Introduction of new or improved materials and structural forms
- Social and economic changes which may bring new hazards or demands for new types of structures
- Inspection and maintenance of existing structures

Topics examined by the Committee are invariably identified by review in one or more of these areas. Those identified during the period July 1989 to June 1992 are discussed in the later sections of this report.

The Committee is a widely experienced group, mainly of professional engineers linking both the direct and indirect contributors. It provides a route for feedback of information from experience and performance in practice. The Committee considers such feedback to be an essential element in maintaining structural safety and has recently examined two particular mechanisms which aim to encourage it. They are discussed in 2.2 and 2.3 below.

2.2 Warnings of preventable disasters
The Fellowship of Engineering published "Draft Guidelines for Warnings of Preventable Disasters" (1) in January 1991 following a conference on "Preventing Disasters" (2). The Draft Guidelines highlight the individual engineer's responsibility to draw attention to possibilities of danger. The Committee considers the Draft Guidelines are a valuable initiative which should stimulate review of existing lines of communication between government, industry and the professions.

The Committee offered comments to the Fellowship. It suggested that advice be included on the role of the Health & Safety Executive in the circumstances where the person warned makes no reasoned response to the warning. Proposals were also made for describing the possible role of the appropriate Engineering Institution in examining the implications of a hazard which may relate to several organisations and situations. In this circumstance an Institution could assist by quickly setting up a task group including as appropriate, representatives of the Health & Safety Executive and Government Departments to examine the potential wider implications. Such action can be a very efficient way of handling a hazard affecting a large industry at the stage when its extent and magnitude is not established.

The Committee has examined the 'Embryo Code of Practice on Risk Issues' produced on the behalf of the Engineering Council (3). It notes this initiative to encourage
debate on what engineers can do to mitigate risk with special regard to human safety and the environment. Risk is an emotive term depending on the perceptions of individuals, whereas safety is a state which is indicative of security from danger. Although safety may be interpreted differently according to circumstances, it is a familiar, taught and practised concept. By definition risk is never completely avoidable and the engineer's responsibility is to minimise and reduce it to an acceptable level. Risk arises from numerous causes known and unknown; it is sometimes a feature of innovation in technology and procedures but also may arise from lack of knowledge of established practice. As introduced in the 'Embryo Code', the practice of risk assessment and management may weaken the present well-defined requirements and responsibilities for safe practice. The Committee believes any new code for engineers relating to risk, safety and responsibilities should be compatible with the rules of conduct of their professional institutions and should recognise the legal framework.

2.3 Feedback of information from litigation

Following the discussions with the Law Society reported in the Committee's Eighth Report (4), a Practice Note was published by the Law Society (5). It is reproduced below.

The Committee believes that the feedback of information from such sources could make a valuable contribution to maintaining safety. Methods of benefiting from the opportunity afforded by the Law Society Practice Note have therefore been sought. The original intention of the Committee was that information received after litigation is completed would be interpreted, collated and the essence relating to safety would be disseminated in anonymous form by a researcher. Both the Committee and the researcher maintain confidentiality. A more detailed proposal and brief for such activity is seen by the Committee as necessary before the full co-operation of the sources of information is likely to be obtained.

The benefits of this initiative depend upon a supply of pertinent information. Several suggestions have been considered for stimulating a feedback flow, including:

- Encouragement of expert witnesses on completion of a case to register a reference of their conclusions and recommendations.
- Establishing a database of failures to encourage feedback of data on a confidential basis from the professions.
- Gathering data through the co-operation of insurers.
- Encouraging feedback by circulating a booklet to all members of the profession on how to supply the information and reassuring them of the procedures used to maintain confidentiality.

The Committee believes that the co-operation of insurers would be valuable in this area and continues to seek a way forward. In the meantime the help of professional engineers who are aware of the existence of relevant reports would be welcomed by the Committee.

2.4 The influence of innovation

The Committee strongly believes that innovation is essential to enable structural engineering to meet new and increasingly demanding requirements. Although technical or organisational innovation often is a feature of the topics examined by the Committee, it is clear that innovation in itself does not lead to unsafe structures. There exist many controls to ensure that new practices and materials are scrupulously tested. Safety is generally maintained through appropriate research and development and the use of rigour and engineering judgement in assessing the initial application. For this reason the Committee has found that innovations are generally safe but, when applied second hand without full appreciation of their limitations and without the in-depth precautions of the innovator may be less safe. The Committee recommends that research on innovation and trends in structural engineering, in the context of their performance in service, would be valuable.

PRACTICE NOTE AGREED BY THE STANDING COMMITTEE AND THE LAW SOCIETY

The Standing Committee on Structural Safety was set up in 1976 to enquire into and report on matters affecting structural safety. In the course of its duties the Committee often becomes aware of the existence of experts' reports obtained by solicitors in connection with litigation on behalf of clients which involve issues relating to structural safety.

It would be of considerable assistance if the Committee was provided with copies of experts' reports in such cases. The Committee regularly takes evidence on a confidential basis from persons directly concerned in matters of public safety and therefore is fully aware of the importance of confidentiality.

The topic of confidentiality is dealt with in detail in chapter 10 of the Law Society publication "The Professional Conduct of Solicitors" and the first principle in that chapter makes it clear that a solicitor is under a duty to keep confidential the affairs of his clients and to ensure that his staff do the same. However, there is of course nothing to prevent a solicitor from obtaining his client's permission for the disclosure of confidential material such as experts' reports to specified persons. Therefore, if a solicitor receives a request from the above-mentioned Committee for disclosure of an expert's report, there is no reason why the solicitor should not take up with his clients the question of whether disclosure can be made. When advising the clients on this question, the solicitor can emphasise the public interest element in making this limited disclosure and that the report and the contents would remain confidential. No doubt, if it is thought necessary an express undertaking can be sought from the Committee to this effect.
3.1 Structural safety aspects of shopping, office and leisure complexes

Combining retailing and leisure activities in one building complex is not a new phenomenon. These complexes have become an increasingly important feature of urban development in the UK. They are multiple-use buildings which sometimes include hotel and office accommodation and often have underground service yards for access by heavy goods vehicles. They frequently incorporate malls and atria and have a roof covering which forms a complete and continuous envelope to the development. Long-span lightweight roofs for this purpose are mainly sheeted, glazed or possibly enclosed in synthetic fabrics.

An early example of large UK construction was the Brent Cross development. Many large building developments followed providing varying degrees of multiple use. Examples are Metrocentre (Gateshead), Summit Centre (London), Cavern Walks (Liverpool), Eastgate Centre (Inverness), Broadway Centre (Ealing), Drummond Centre (Croydon), The Gardens (Manchester), Lakeside (Essex) and Harlequin Centre (Watford). Some recent office developments, e.g. Whitefriars (London), BP Oil (Hemel Hempstead), have also incorporated some similar features, e.g. large atria. They have much in common with large exhibition halls. The Committee recommends that malls and atria in these large developments should be classified as places of public assembly for Building Regulation purposes in recognition that they may be occupied by many hundreds of people at any one time and require provision for emergency evacuation. Consequently barriers and handrails should be provided to suit anticipated crowd flow densities and patterns.

The Committee examined the structural trends and innovatory characteristics in these complexes from three points of view - occupancy, structural fire safety, and structure and cladding. Local authority surveyors and engineers and other engineers and architects were consulted. They provided much helpful information. It was noted that multiple-use buildings of the types being examined were not fully covered by codes, authoritative guidance documents or regulations. The design considerations for buildings enclosing large public areas were seen to be akin to those for indoor or covered stadia in that both increasingly incorporate a range of public facilities.

Multiple-use buildings may attract large numbers of people of all age groups. Pop concerts and public demonstrations may generate crowd behaviour and reactions to emergency comparable with those of crowds in sports stadia. Crowd safety in such buildings should be subject to similar consideration during the building design, particularly reactions to fire, smoke, gas explosion, vandalism or riot. The lay-out, proportions and the provisions for entry and exits have implications for the structural design, in particular the design of barriers and handrails. The Committee's examination of barriers and handrails is reported in 3.8.

Levels of occupancy and provisions for evacuation in an emergency should be determined in relation to consequences of structural failure which should be considered particularly in the design of long-span roofs. The consequences of 'disproportionate' collapse need to be considered in the overall design of large public structures.

The Committee recalled the disaster at the Hyatt Regency Hotel in Kansas City in 1981 where collapse of two walkways in the building caused 113 deaths. There were reports of people dancing on the walkways at the time of the collapse. There is growing evidence that such rhythmic effects arising from crowd behaviour may be underestimated in the design of structures, such as grandstands, in leisure facilities, arenas and sports stadia. The Committee's examination of this topic is reported in 3.3.

The access provided to heavy goods vehicles at service floor levels and basement parking for cars may in some cases lead to columns and beams being vulnerable to impact. The Committee noted that this hazard is often avoided by the use of protective vehicle barriers but recommends that there should be authoritative guidance on impact forces likely on columns in such circumstances and on appropriate design in relation to possibilities for disproportionate collapse.

There is a close relationship between fire safety and structural safety. It has long been recognised that fire safety is difficult to reconcile with all the other requirements of multiple-use buildings. BS5588 Part 7 (6) tackles this problem from the point of view of atria. Mixed use involving hotel (sleeping), commercial and leisure accommodation complicates the problems of provision for evacuation, structural fire resistance, fire suppression and smoke control.

Whilst compartmentation has always been a design consideration in fire safety, it is more difficult, and is sometimes virtually impossible, to achieve in multiple-use buildings not only because of the requirement for the flexible use of space but also because of the more sophisticated demands for providing and controlling services (including communications, computing and
management systems) in ducts which have to be isolated for fire and smoke control reasons.

Multiple-use buildings rely increasingly upon active systems for fire detection and suppression and smoke control. These systems work in combination under the control of sophisticated and sometimes automated management. An example considered was the use of mechanical extraction to provide a pressure reduction in tall atria where the natural buoyancy of smoke and gases from fire cannot be relied upon to remove them from occupied spaces. To be effective such extraction systems must be reliable and have adequate capacity.

Although relatively few fires have been experienced in large mall or atria structures, e.g. St. John's Shopping Centre (Liverpool) and in a New Mexico hotel, generally because such areas have been well managed to date, incidents have been reported of failures in detection and operational response when active systems have been subject to performance tests. No reliable statistics for failure rates of active systems are available. Regular and rigorous maintenance and testing are an essential part of reliance upon active fire control. Where passive fire resistance has been 'traded off' against the provision of active systems there should be annual inspection and certification of the active system by the fire authorities.

Where multiple-use buildings rely on active systems for safety it is recommended that there should be an appropriate level of full-time (24 hour) management, surveillance and control. The Committee noted that such arrangements may be vulnerable if there are changes of use or tenants. Remote interrogation and third party monitoring of the alertness of active systems may be essential precautions before relaxation of other controls is justified.

Decisions appear to vary as to the period of fire resistance required of glazing systems where the performance includes not only the glass but also the suspension system. Where fire containment by a glazed area is particularly critical, automatic shutter systems have been employed.

In buildings with large atria and malls there may be extreme differential movement between the lightweight cladding of metal, glass and plastics and the greater mass of the main structure. Such movement differentials may occur due to the more thermally active light cladding in a more rapidly changing environmental exposure. Movement is sometimes indicated by leaking roofs which may also suggest that there might be additional forces on fixings for which they were not designed. No reports have been received of a safety problem in this respect. However, the Committee noted the increasing complexity of cladding systems and the potential in the use of the new materials and cladding systems for long-term weakening effects (corrosion and fatigue and complex failure mechanisms, e.g. thermal pumping) which may not yet be fully recognised or understood. Substantial innovation in cladding has taken place, for example, in the use of structural adhesives, suspended glass and the rigging and tensioning of facades including in some cases structural castings. Ability to maintain safety and serviceability in the long term is not fully proven especially where fixings cannot be inspected or tested in situ. The Committee recommends that monitoring of the performance of these large innovative cladding systems be undertaken to provide a feedback of information to assist elimination of structural and serviceability problems in the future.

Whilst careful consideration is given by designers to the selection of glazing, prominence appears to be given to the avoidance of danger to persons inside the building to the possible neglect of those in the street. The Committee continue to believe that all aspects of cladding design, installation and maintenance would benefit from greater engineering input throughout the process from start to finish.

Forms of roof structure are often less conventional than for separate retail or office buildings. They may use:

- Longer spans whose design puts a high premium on lightweight construction making them more wind-sensitive both in overall stability and in securing the covering.
- Glass, polycarbonate or other translucent materials forming a large proportion of the roofing. These materials not only distribute wind and snow load to secondary members but may also be presumed to provide lateral restraint to glazing bars and purlins. The consequence of such an assumption may also need careful consideration by the designer.

The Committee has noted the progress in the work of the Institution of Structural Engineers Task Group on the structural aspects of cladding and looks forward to the publication of their report in 1993. The Committee welcomes the extension in the new Building Regulations (7) to control the structural safety of wall cladding and the associated guidance in Approved Document A (8).

In its Eighth report, in the context of sportsgrounds, the Committee advised against the use of PTFE - coated glass until tests have examined the possibility of extreme toxicity in fire. The Committee was pleased to note the intention of the Fire Research Station to issue guidance (9) on the ways in which this material can be used without undue risk or when its use should be avoided.

### 3.2 Safety in sports and concert stadia

The Committee has closely followed the response by the Institutions to the Taylor Report (10). The Institution of Structural Engineers' meeting on sports ground safety (11) provided a valuable updating on technical initiatives and organisations to assist the achievement of safety in sports grounds. The Committee welcomes the fact that the Football Stadia Advisory Design Council aims to provide an authoritative source of knowledge for all those involved in the design and construction of stadia.

Recent publications (12), (13) have provided much improved advice on appraisal of existing facilities and on design and construction. Appraisal should be undertaken...
bearing in mind the social and economic changes which have led to a greater frequency of large leisure events, e.g. golf, football, tennis, pop concerts, charity events etc., and to high levels of crowd participation in a wider range of these activities.

The Committee has considered the particular sensitivities of long-span structures in sports grounds. Its findings are given below. The Committee has also identified several features of stadia where further consideration of structural safety is needed. They relate to:

- Retractable and demountable terraced seating
- Temporary grandstands and staging structures
- Barriers and handrails

These subjects are discussed in 3.3, 3.4 and 3.8

The construction of all-seater stands, as recommended in the Taylor report\(^{(10)}\), requires major long-span roofs and long cantilevers if sufficient protection against inclement weather is to be given to spectators at the front of the stands. The Committee has noted the provision of some exceptionally long spans, e.g. Ibrox Stadium, for this purpose. These projects which represent major expenditures to comply with current legislation and to provide new standards of safety and comfort, require managerial and technical skills of a high calibre.

The Committee referred to the relationships between safety and structural size and importance in its Sixth Report \(^{(4)}\). The roof structures for stadia illustrate the particular sensitivities of long-span roofs in that:

- Seating areas with accommodation for many hundreds of people are often free of columns to permit a clear view by all spectators.
- The structural form generally involves large-span trusses (120 m or more) or long cantilevers (40 m or more), which may be subject to excitation by wind loading.
- The roof structures are unheated and generally uninsulated and are therefore exposed to extreme temperatures and condensation which may have an adverse effect on durability.
- The roof structures may comprise statically determinate primary elements with limited redundancy to redistribute loading in the event of a single element failure.

These particular aspects should be recognised in the design and appraisal of stadia structures. Special attention should be paid to structural form and redundancy, load factors, dynamic performance, fatigue, low temperature performance of welds, effects of corrosion and thermal movement. Useful guidance is given in references \(^{(12)}\) and \(^{(13)}\). The Committee emphasises the importance of appropriate quality management systems being used in design and construction processes, and in maintenance \(^{(14)}\).

The Committee recommends that owners should commission regular structural inspection and maintenance of these structures to assure their future safety. A permanent and comprehensive record of this activity should be kept and reviewed by a suitably qualified engineer.

3.3 Safety of retractable and demountable terraced seating

The attention of the Standing Committee was drawn during 1991 to disturbing sway movements of high tiers of seating at venues for pop concerts. Such terraced seating was designed to be retractable when not in use to provide larger areas for flat surface activity. Whilst small-scale structures with comparatively passive audiences have performed satisfactorily for many years, proprietary designs have grown progressively larger and to some professional observers appear to be excessively responsive to the exceptional dynamic rhythmic loading of pop concerts. Most critical conditions are reported to occur when a pop concert audience reacts with synchronous movements. In some cases the resultant sway in the structure became excessive before additional restraint was provided. Checking of such structures to assess likely movement requires particular expertise and the dangers inherent in such highly perceptible sway movements are difficult to quantify.

The owners of retractable grandstands, their professional advisers, manufacturers and engineers involved in design and checking were contacted and were responsive to the Standing Committee interest. As a result, a number of areas of uncertainty relating to structural safety were found:

- Criteria for design to satisfy the safety of spectators when the structure is subject to dynamic loading from crowd sway at moments of high excitement.
- Factors of safety taking into account local stresses resulting from dynamic load effects.
- The potential for progressive collapse.

Current design guidance is not sufficient \(^{(15)}\) to enable engineers to carry out a theoretical assessment of these structures with regard to sway and vibration caused by rhythmic crowd movement. The Committee therefore recommends further research on crowd loading be undertaken especially into the dynamic effects on sensitive stand structures (including temporary stands) and that additional technical guidance be prepared. It has been suggested that it would be appropriate for the Institution of Structural Engineers' report on demountable grandstands \(^{(16)}\) to be extended to cover retractable structures.

The Institution of Structural Engineers' report \(^{(16)}\) is relevant and should be followed. Design should take full account of the lateral stiffness required to resist dynamic side-sway forces.

In making its enquiries the Committee was surprised to find that retractable stand structures (and also other
temporary grandstand structures - see 3.4) are not necessarily checked by the Building Control Officer and that they are subject only to the Environmental Health Officer's approval. Licences for the use of premises, under such control, are only given when the facilities are seen to be safe, but there appears to be no legal obligation in this system of control for vitally important structures to be checked by competent engineers.

The Committee recommends that an independent structural check of the adequacy of all such structures should be required. All such stands for public events should become subject to local authority certification.

3.4 Safety of temporary stands and staging structures

The Committee is concerned that certain public events, such as golf tournaments and pop concerts, involve the construction of temporary stands, stages and towers which are not required to be subject to professional structural engineering safety checking because the events do not require a local authority licence. The Committee believes structural safety may be in jeopardy in these circumstances and proposes to seek means of establishing assurance of safety. The collapse of the stand at Bastia in Corsica in May 1992 was a tragic illustration of the danger to life of structural inadequacy of such structures.

The Committee has examined the draft Guidance Note (17) from the Health & Safety Executive referring to the management of pop concerts. The Committee welcomes the proposed recommendation in the Note which would require a competent and independent structural check on all structures associated with pop concerts. It is important that checking embraces whole structures including supports and foundations.

The Committee recommends that the use of temporary stands for public occupation and associated stage structures be brought within the requirement of an independent structural check and certification by local authorities even when they are on private property.

3.5 High-bay warehouses and large fully automated storage buildings.

Wholesalers, chain-store operators and manufacturers have for many years stored products or parts ready for assembly in large quantities in concentrated stores. Government Departments have had similar installations. For the last 25 years these requirements have been met increasingly by the use of warehouse techniques involving the automatic placing and retrieval of palleted storage in vertical stacks up to 20 metres high separated only by narrow aisles sufficient for the travelling pallets.

Whereas, in the past, storage racks had been introduced into large hanger-like sheds with trussed roof or portal frame construction, in recent years the racking has also been used to support the wall and roof cladding of the building. The clad-racking building principle is now well established. The Committee has found no evidence that there are any effects detrimental to structural safety in relation to normal loading including wind, snow or other environmental loadings.

One of the main inhibitions to the extensive use of high-bay warehousing has been the risk of excessive fire losses, not only because of the vulnerability of large stacks of highly-combustible materials and packaging, but also due to the difficulty of segregating high risk material, of tackling fires at source, and of fighting any fire that may occur.

The Committee has been concerned that a fully automated storage building might be considered a Class II building and as such not subject to the Building Regulations 1985 (18). Since high-bay warehouses generally employ stacker operators within the building this has generally not been the case. However, a more fully automated storage building 'into which people do not normally go or where they go only intermittently and then only for the purpose of inspecting or maintaining fixed plant or machinery', could be proposed and exemption from Building Regulations claimed as a Class II building. The new Regulations (7) would still make this possible if the distance from a boundary was greater than one and a half times the building height. Although no such buildings appear to exist in the UK, it remains a possibility that an automated storage building might be considered to be exempt from the Building Regulations and therefore any fire safety precautions would depend upon a local Act if such existed.

Given that such warehouses are subject to Building Regulation B, the 'means of escape' requirement should safeguard those operating and maintaining the mechanical operations of the warehouse. However, the Approved Document B (19) does not give guidance to assist in determining appropriate travel distances and means of overcoming obstructions in the event of power failure appropriate to these specific circumstances. The Committee considers that, as in the case of raised storage areas, precautions should be required to allow occupants to be aware of any fire starting in the store. The Committee believes that no storage building, however automated, should be exempt from provisions of this nature.

The new Regulations (7) require fire resistance of the external wall and its support structure only in relation to distance from the site boundary. New concessions are given for sprinkler provision but if sprinklers fail to control a fire involving an exceptional concentration of combustibles, structures with too little fire resistance may be in danger of collapsing more quickly than fire fighters may anticipate.

Sprinklers are generally installed either to satisfy local legislation, to reduce insurance premiums or to give added protection against extremely onerous consequential losses that may result from fires in such valuable and often irreplaceable storage. The main difficulty is that any fire at the bottom of a stack will not be quickly detected by traditional heat sensor sprinklers higher up and is then shielded from the water which they subsequently release. The Fire Research Station has for many years addressed the problem of improving fire detection and extinguishing.
apparatus for high-rack storage and has solved the problem for certain kinds of storage using fast-response, in-rack sprinklers. Their use in a larger number of buildings does however need to be implemented.

Several major fires have occurred in large storage structures throughout the world, including two recently in this country, with direct losses of about £70m and £165m. However, the most advanced fire prevention methods were not employed in these cases. Nevertheless these fires and those previously at Fords and British Aerospace are reminders that fires in large warehouses can be extremely expensive and can involve the fire service in very hazardous operations. For economic reasons, there seems to be a clear need to reduce fire spread by whatever means are appropriate in specific cases. The greater use of sprinklers, capable of operating effectively through racks, is a prime requirement as mentioned above. In addition to such improved active fire precautions, the introduction of compartmentation would be justified in the largest warehouses even though this might place some constraint on the flexibility of warehouse use.

There remains a concern about the inherent danger to staff who, for inspection and maintenance purposes, might be within the racking area in the event of a fire. The Committee recommends structural engineers involved in the design of such buildings should consider this problem. There is a need to provide safe escape routes, particularly in keeping means of escape free from smoke by suitable early detection, use of smoke reservoirs and smoke venting.

### 3.6 Controls over building alterations and changes of use.

During building alteration and refurbishment work responsibilities for the accuracy of information regarding existing construction are not always clear especially where the works may affect adjacent structures. The Committee has been concerned that confusion in this respect may add considerably to risks of failure and also to the likelihood of litigation. The concern was drawn to the attention of the two Institutions in 1990 and the Committee has noted the subsequent publication of the Institution of Structural Engineers report on surveys and inspections (20). The report contains a useful warning regarding responsibility for adjacent buildings when carrying out building alterations.

Whilst structural alterations are generally controlled as "Building Work" under the Building Regulations, the Committee continues to be concerned about the effects of alterations on adjacent structures since plans and calculations may only be submitted for the property first affected. The Committee has noted with approval that the Building Regulations Advisory Committee will be asked to clarify the need for building repairs, which may have structural significance, to be subject to building control.

Changes of use of structures may lead to increases of loading. The Committee welcomes the recent amendments of the Building Regulations (7) which requires a building to comply with the requirements for structure (A1 to A4) where there is a material change of use of a building into a hotel, boarding house, institution or public building.

The Committee also welcomes the publication of BRE Digest 366 (21), but notes that it contains no reference, when discussing structural alterations, to consideration of the effects of such work on adjacent and possibly not independent structures. The Committee therefore recommends the preparation of guidance relating to alterations, particularly from the point of view of clarifying responsibilities of the designer and contractor and the possibility of such alterations being cumulative over a period of time.

### 3.7 Cladding and controls over cladding repair and refurbishment.

Cladding has already been reported on in 3.1 in the context of the construction of new shopping, office and leisure complexes. The Committee also has examined the subject following reports of inherent defects in cladding facades leading to the structurally inadequate replacement, or refixing of cladding, and possible dangers in the addition of overcladding.

The Committee noted with approval the guidance regarding the safety of cladding now contained in Approved Document A (8) but is concerned that the definition of what constitutes "building work" as defined in Regulation 3 of the Building Regulations (7) does not cover the repair or refurbishment of cladding. The exclusion of cladding repairs applies even if they are structural, extensive in area or involve the use of additional components and different facings or materials from those permitted originally. The engineering expertise necessary for cladding repairs and refurbishment may be equal to that referred to above relating to new cladding.

The need for control of extensive repair or refurbishment of the structure of existing cladding applies irrespective of whether the need arises from the discovery of defects or suspected defects of cladding likely to cause structural failure (e.g. dislodgement or falls of panels or parts), serviceability failure (e.g. rain penetration), or purely because a different appearance is required.

Two examples of repair were cited to the Committee:

- Failure of cladding in high winds had caused several large panels on three twenty-storey residential tower blocks to fall to the surrounding grounds and roads beneath. Investigation into the cause resulted in proposals to remove the entire facing panels from all blocks and to refix them using some different fixing components and additional framing members to provide more secure support. The complete refixing of the cladding will, because of the regulatory definition of "building work", be most unlikely to be subject to building control checking of its structural safety.

- Two storey-height panels on a twenty-storey office building adjacent to a major highway were displaced
in high winds leading to the safety of similar panels becoming suspect. Investigation revealed defective workmanship in fixing the cladding over considerable areas of the facade. Amended fixings were proposed but, as they were being installed, their incorrect use, which would have led to them being grossly understrength, was fortuitously noticed by building control staff. A further investigation led to the specification and use of a much stronger replacement fixing.

These and other examples of failure reported to the Committee had placed people in the vicinity of the buildings in jeopardy and, in some cases, had resulted in death and injury. The Committee was concerned not only by this record but also by the evident inability of the repair process to ensure future safety. To overcome these weaknesses the Committee recommends that major structural repairs to cladding on buildings should be subject to the same control as Building Regulations (7) impose on cladding of new buildings.

3.8 Barriers and handrails

The subject of barriers and handrails is relevant to all situations where crowds gather and especially to leisure, office and shopping complexes and sports and concert stadia and arenas.

The Committee has been advised that there are wide differences in interpretation of handrail height and strength requirements in relation to retractable and temporary stands. It was disturbed by the report of an accident at the Earls Court Centre (15) where a barrier did not prevent a serious fall.

The Committee has continued to be concerned that there are inconsistencies and omissions in the design guidance of British Standards, the requirements of the Building Regulations and in other guidance (17) with regard to barriers and handrails. The Approved Document K of the new Building Regulations (22) has addressed these concerns to some extent and will improve the situation. However the Committee draws attention to the following points:

- The design load for handrails in BS 6399 (23) is substantially below that specified in the Home Office Guide (12). In the event of fire or other emergency, the crowd loading on barriers and handrails in a shopping complex, arena or large office complex could be of similar order to that in a sportsground. The performance of barriers and rails at floor edges and staircases is of particular concern.
- The design lateral load for barriers is 5kN/m in the Health & Safety Executive Draft Guide (17) and 3kN/m elsewhere (22). In Approved Document K (22) the value of 3kN/m is the requirement for assembly buildings whereas a value of 1.5kN/m is given for retail buildings where, in certain circumstances, large assemblies of people can be envisaged. Barrier loads set at 5kN/m to avoid structural collapse are above the pressure limit that can be tolerated by the human body. The Committee recommends that further research be carried out into crowd loading on barriers and handrails in shopping complexes, arenas, stadia and multiple-use buildings, particularly in relation to crowd densities and patterns of crowd flow.
- Barriers should be designed so that they do not fail in a brittle mode such that there would be sharp remains injurious to bodies thrust upon them. Guidance on the form of failure in the event of excessive overload should be provided.
- Terminological inconsistencies with regard to barriers and handrails remain between British Standards, BS6180(24), BS6399(23), the Institution of Structural Engineers' Report (13), the Home Office Guide (12), the Health & Safety Executive Draft Guide (17) and Approved Document K (22).

3.9 Freestanding masonry walls

Freestanding masonry walls used, for example, as garden walls or boundary walls, are prone to collapse, especially in high winds. There have been injuries and fatalities as a result.

The attention of the Committee was drawn to a report of a tragic incident in 1991 in Swansea in which a young child was fatally injured by the collapse of a recently constructed wall. Subsequently the Local Authority gathered information on similar occurrences. Over 35 deaths involving collapse of freestanding walls were reported in England and Wales of which over 30 might have been prevented had the walls been better designed to withstand the forces likely to be applied to them.

The enquiry amongst Local Authorities suggested some freestanding walls are jeopardising safety. Wind damage to freestanding walls is generally noted in reports of the effects of high winds on structures, and incidents are reported each year (25) (26).

The Committee noted that freestanding masonry walls have not been brought within the scope of the new Building Regulations 1991 (7), but that guidance has been published by the Building Research Establishment (BRE) during 1992(27) (28). The Committee is doubtful whether an improvement in the safety of freestanding walls will be achieved without some form of regulation.

Deterioration of freestanding walls due to weathering, activity in the ground such as tree roots, drains, trenches, and construction features such as membrane dpc's, are often factors contributing to collapse. Membrane dpc's at low level especially are a point of weakness. The Committee recommends consideration be given to including freestanding walls in the brief of the building surveyor when properties change hands.

The Committee recommends that failures of free-standing walls should be monitored to assess whether
improved performance results following the new BRE
guidance.

3.10 Structural safety in fire

The Committee noted the significant recent fire incidents
at Broadgate (July 1990), Knowsley Heights near Liverpool
(April 1991), Mercantile Credit Headquarters at
Basingstoke (April 1991) and Minster Court, City of London
(August 1991). These events were considered against the
background of discussion over the last two years regarding
the relevance of the Building Regulations (16) to special
structures such as automated storage buildings and
multiple-use buildings with malls and atria, and the possible
relaxation of passive fire resistance requirements in return
for the provision of more active fire precautions. It was
noted that each fire, being the result of individual
circumstances, highlighted different aspects of structural
fire behaviour.

Although structural factors contribute generally little to
the loss of life through fire in buildings, there is a need to
ensure that this situation does not suddenly change
through a progressive weakening in the requirements for
fire safety or the design to meet them.

The recent fire incidents have been the subject of expert
post-analysis, some of which has been published. In the
case of the Broadgate fire the detailed report (29) showed
that the framework proved its stability under a high fire
severity although not acting in the simple structural mode
envisioned by reference to the standard fire test. The
advantages and potential disadvantages of rigidities and
continuities were demonstrated by the long period of high
temperature withstood. Further assessment of column fire
resistance when subject to the restraint experienced in real
fires may be necessary. Attention was also drawn in the
report to the vulnerability to fire of buildings under
construction when compartmentation is not complete,
sprinklers not fully installed and operational, and when
large amounts of combustible building materials may be
stacked within the building. The Committee welcomes the
prompt, thorough and authoritative report on this fire
produced and published for the benefit of efficient and safe
construction.

The Committee was concerned that buildings under
construction are more vulnerable to fire than is generally
recognised. Fire loads may be more concentrated and take
longer to extinguish. In particular it was noted that modern
building designs incorporate more ducts which, during
construction may act as flues spreading fire very rapidly.
Fire protection to steelwork may not be fully installed.
In the absence or partial completion of fire protection the
possibility exists that the stability of a structure may be
jeopardised before a difficult fire is brought under control.
However, the Committee has no evidence of a structural
collapse involving more than local loss of stability.

The performance of cladding in the Knowsley fire and the
Basingstoke fire raised the question of whether resistance
against the upward spread of fire is adequately provided in
current design.
future. Without a growth in expertise and its application in this area it seems likely that the recent history of major fires will be repeated and the risk of major human fire disasters will remain significant.

3.11 Air-supported structures

Part of the Committee's recommendations relating to the performance of structures during the gale of October 1987 (Eighth Report, Section 2.2) was that 'The standards of design, construction and operation of air-supported structures should be reviewed...'. Fifteen such structures were destroyed in the gale. At first, it was suggested that the failures arose mainly because the structures did not meet the requirements of BS 6661 (30). The Committee continued its enquiries and, in January 1990, several more air-supported structures, some of which were used as indoor tennis centres, failed in a gale.

It needs to be recognised that the performance of such light structures is very dependent on their form, both overall and in the detail of their fabric cutting patterns, and on the quality and the nature of their inflation systems. Following its examination of the recent failures, the Committee recommends that BS 6661 should be withdrawn.

Although the Committee is not aware of deaths or injuries caused by the failure of the light flexible air-supported structures used for industrial purposes, the same would potentially not be true when they were used as places of public assembly. The construction of large span air-supported roofs is an attractive possibility for spectator sports. The Committee therefore recommends the development of design guidance for air-supported structures both for temporary buildings for storage or non-spectator sport and for uses as places of public assembly where failure might threaten people's safety.

The Committee has noted that air-supported structures are subject to control under Building Regulations in Scotland (31) and Northern Ireland (32) but not under Building Regulations in England (7) where they are regarded as a form of temporary structure. The Committee recommends that a consistent approach should be adopted throughout the United Kingdom and that local authorities should note the recent history of failures.

3.12 Hydrogen embrittlement of zinc-coated HT steel bars

A report on failures of zinc-coated HT steel bars 1-10 days after stressing at two separate sites in 1988 attributed the cause to hydrogen embrittlement. The bars involved had been quenched and tempered; in one case they were galvanised and in the other sheradised. Defects in thread rolling had initiated fracture.

Enquiries showed that principal UK manufacturers of HT bars, bolts and strands were well aware of the problem and observed precautions they consider necessary to avoid it, for example, by prohibiting acid cleaning. However, the Committee was concerned to examine whether:-
- existing British Standards dealt adequately with manufacturing processes for strand, bars and bolts, including thread treatments, with regard to hydrogen embrittlement.
- designers and specifiers are sufficiently aware of the problem and of the criteria they should apply in their acceptance of these components.
- means of avoiding hydrogen embrittlement are adequately dealt with in European Codes and Standards.
- there is the possibility of further instances of failure at other sites or at a later stage after stressing.

Following discussion with leading authorities, including manufacturers, designers and research workers, the Committee believes that designers should be provided with better guidance on the subject.

3.13 Tendons in post-tensioned concrete structures

The Committee has examined on several occasions since 1979 the safety of buildings and bridges constructed with grouted post-tensioned steel tendons (4). It has advised more positive methods for ensuring effective grouting, noted the particular technical difficulties of determining the structural condition of post-tensioned construction in service, and strongly encouraged the development of effective non-destructive testing techniques for the detection of tendon corrosion.

The Transport Research Laboratory (TRL) has worked towards establishing methods for ensuring complete grouting and at developing testing, inspection and appraisal techniques. The Committee notes with concern that the problems in these areas have not been overcome. The preparation of guidelines for the inspection and appraisal of post-tensioned concrete structures as recommended in the Eighth Report (4) has not been completed by the joint Working Party of the Institutions of Civil and Structural Engineers.

The previous findings of the Committee are confirmed following a review of the substantial efforts being made by the TRL with the support of the Department of Transport. Grouting is often incomplete in this form of construction leaving the steel tendons at risk from corrosion and there is at present no effective or non-destructive means of inspecting tendons. This experience has been found abroad as well as in the UK. The Committee has therefore considered the implications of these shortcomings in the technology of post-tensioned concrete construction for both new and existing structures.

The Committee recommends that a stringent regime of inspection and appraisal of existing building and bridge construction in post-tensioned concrete should be introduced. At the same time, research to establish an effective means of inspecting tendons should continue. Some forms of post-tensioned concrete structure are more sensitive to loss of tendon integrity than others. Particular
attention should be given in appraisal to determining the implications of tendon failure due to corrosion. Where implications are severe, additional structural capacity to offset the potential structural weakness should be installed.

For new post-tensioned concrete structures the Committee recommends that alternative stressing methods, which avoid the need for the grouting of steel tendons, be investigated. One possibility is to use unbonded tendons either placed externally or internally in such a way that individual tendons may be removed for inspection and replaced. Another is to use non-ferrous tendons thereby avoiding steel corrosion.

The Committee has noted developments in the practical application of non-ferrous tendons and trials with optical fibres for monitoring behaviour under load and changes in the condition of the structure. The emerging technologies of 'smart' structures and materials may have a valuable contribution to make. These possibilities require careful development and assessment to identify viable alternative concepts which will provide structural safety in practice.

### 3.14 Damage to bridges by ships

Major bridge collapses due to collision by ships have occurred at Almo (Sweden), Hobart (Tasmania) and, more recently, at the Herbert C Bonner Bridge (N Carolina). Collision by a Swedish freighter with the Goole railway bridge in 1988 caused £2m worth of damage, and it is reported that the same bridge was struck 19 times during 1990. Enquiries by the Committee during the period of 1988-90 identified 12 other incidents, including those which caused serious damage to the Battersea, Chelsea and Albert bridges.

The Committee drew attention to the potential seriousness of the problem to major bridge owners such as the Department of Transport, British Rail and local authorities (through the Country Surveyors Society). Causes and possible solutions were discussed with British Associated Ports, the Port of London Authority and the Marine Accident Investigation Branch of the Department of Transport. The following measures were suggested by the Committee:

- improving navigational control
- improving the design features of soffits and piers of new bridges
- installing fendering systems on existing bridges, to divert (breasting dolphins) and absorb impact (fenders)
- installing height and channel warning systems (infra-red)

The Committee believes that there is now a better understanding of the problem but has noted further collision incidents. However, some conflicts of interest between navigation authorities and bridge owners, as well as technical and legal problems, make it difficult to reduce the risks. Some beneficial changes to navigational control and warning systems have been introduced. The Committee recommends that further consideration be given to improving the design features of bridges and piers and to the wider use of fenders and dolphins.

### 3.15 Durability and strength effects associated with cement additives and concrete admixtures

The Committee first considered the use of admixtures in concrete in its Third Report. Since that time substantial changes have occurred in concrete technology which have led to examination of questions concerning effects on durability and strength.

It has been suggested to the Committee that wide variations in the properties of concrete can occur when using additives and admixtures whose chemical composition and characteristics are not yet fully known. The purpose of such materials is usually to make concrete more durable and to meet much higher strengths than was once generally the case.

In 1989, the Committee was alerted to concern that the draft European pre-Standard prENV 197 on cement, in admitting the use of cement types previously unfamiliar in the UK, would bring risks of misapplication of such cements or the use of incompatible additives or admixtures with unpredictable effects on strength or durability. Cements considered included those with the addition of up to 20% of limestone filler and other types of cement with which the UK industry has not been familiar. Agreement to prENV 197 was subsequently delayed and, in 1990, results of research by the Building Research Establishment (BRE) and the British Cement Association (BCA) were published indicating the precautions necessary with cements containing higher proportions of filler. The BCA, in cooperation with the UK cement makers, has undertaken to ensure that specifiers and users have full information before any changes are made to UK cements.

The Committee recommends that comprehensive information should also be made available concerning any imported cements which have properties or compositions differing from previous British Standard requirements. A similar undertaking should also be sought from admixture manufacturers for the provision of corresponding information on the suitability of their products for use in conjunction with the new cements.

The use of chemical 'super-retarder' treatments of wash water in the drums of mixers has raised the question of whether any residue may adversely influence the performance of a concrete subsequently mixed in the drum. The Committee believes it would be prudent for specifiers to proscribe this practice until the results of research are known.

Chemical admixtures such as plasticizers and superplasticizers can improve the performance and durability of concrete, mainly by allowing reduction of water-cement ratio and consequent reduction of the volume of capillary pores. Mineral admixtures are either pozzolanic or hydraulic; both types react with the lime generated during hydration and thereby modify the pore structure.
structure of concrete. Mineral admixtures like pulverised fuel ash, trass, santorini earth and blast furnace slag have been used for 40 years and there is evidence of their adequate performance. If additional care is taken over the placing and curing of the concrete, performance and durability can be enhanced. However, the use of microsilica is relatively new and reports of the performance of concrete containing this material are still controversial. Caution is needed when extrapolating results from short-term studies to the expected design life of concrete in structures.

The variation in the strength properties of cements and the requirement generally for higher characteristic concrete strengths are reported to have resulted in the cement contents of mixes being increased by up to 20% to cope with the acceptance criteria of BS5328 (35) which involves evaluation of a running mean of four results. Apart from the unnecessary cost, the additional cement use could be detrimental to the avoidance of cracking and alkali silica reaction.

3.16 Safety of chair lifts and cable cars

The Committee has been pleased to note the Health & Safety Executive initiatives in preparing guidance on the safety of chair lifts, a topic discussed in the Committee’s Seventh and Eighth Reports (4). Publication of the guidance note (36) is believed to be imminent.

The International Organisation for Transportation by Rope (OITAF) has produced Technical Recommendations (37). The Committee will examine this guidance and the guidance note (36) to assess whether they provide appropriate information for local authorities and others.

3.17 Cranes - safe operation and structural design

The development of the offshore oil and gas industry has led to substantial developments in structural engineering technology. The Committee has made a preliminary study of one area, the operation and structural design of cranes both offshore and on land.

Platform cranes offshore are required to load safely thousands of tonnes of materials from supply ships onto the platform. To protect all areas against items being dropped the crane operating envelope is restricted by the use of mechanical limit switches or, increasingly, by the use of solid state electronics by means of which it is possible to limit the operating envelope to a very complex shape without undue difficulty.

Cranes servicing construction sites on land may also traverse areas which should be avoided. Tower cranes used in the construction of buildings are often working in very confined areas and their lifting gauge usually extends over areas beyond the site boundary. Their operation may therefore lift loads over roads, pavements and public areas and hence, should a strap break or be inadequately attached, there is a chance of a load falling outside of the site.

Building site cranes are used to lift a complex variety of loads, a factor contributing to the incidence of dropped items; a statistic which is difficult to determine.

The Committee believes there may be scope for extending to land-based cranes the more sophisticated control systems which are used in the more advanced offshore cranes thereby providing greater safety. The means of control can simply be an alarm which warns the driver that he is about to enter a restricted area. It thus serves as an aid to the driver so that he does not have to memorise the envelope. Alternatively, the device can actually control the crane and stop the motors. This facility is preferable to an alarm which could be switched off or ignored.

Cranes collapses continue to occur. They have generally resulted from stability problems at the base and have not been reviewed at the time by the Committee on the grounds that they were related to site safety practice rather that structural adequacy. The Health & Safety Executive has indicated that these collapses often arise from lack of observance by management of BS7121 (38). The procedures which are followed in determining safe bearing pressures for the jacking points of mobile cranes may also not be adequate.

A recently well publicised collapse of a crane at Lower Thames Street illustrated the possible danger to the public of cranes on building sites. At the time of reporting the Committee has no official information as to the causes of the collapse and regret that lessons that might need to be learned by those involved in the safe installation and maintenance of site cranes, cannot yet be made public. The Committee recommends there is a need for guidance on the design and construction of foundations for cranes on construction sites.

Structural reliability is only one of several requirements for crane safety. More often crane accidents appear to be caused by faulty load indicators or overload alarms, or by operator error, than by structural failure. However, the Committee has noted reported damage to cranes in gales (26) and that there are several relevant British Standards apart from the crane design code BS2573 (39) which do not share the same basis for treating the same component. For example BS5400 (40) requires smaller weld gaps in intermittently welded stiffeners of steel box members than does BS2573 although cranes are probably more frequently subjected to the maximum permitted design loading than bridges.

Limited enquiries have revealed examples of structural failure of cranes in which important contributory factors were related to design. Cranes may be exposed to operational hazards or maintenance deficiencies and therefore should be relatively robust. Codes of practice should take account of operational conditions and warn of possible hazards and reflect service experience. The few structural failures identified by the Committee suggest that these matters may not be adequately covered in the Codes of Practice. It also seems that guidance may be required
regarding the type and extent of acceptance testing. The Committee therefore recommends there is a case for review of BS2573 (39) with a view to:

- Bringing strength formulations in line with other codes, or vice versa, if BS2573 is shown to be superior.
- Including further guidance on loading conditions or forces which need to be considered, and on structural detailing taking account of experience from service.

3.18 Other topics considered

Effects of rising groundwater

The Committee's Seventh and Eighth Reports (4) referred to the potential problems of rising groundwater levels in cities. The Committee has noted the possibility that the Thames Water Authority may extract water from the aquifer of the London Basin and welcomes this reaction to the CIRIA report (41) on the basis that regional treatment is more reliable than local dewatering protection.

It is noted that local problems still exist in London through a possible rise in the water levels perched above London Clay.

The Committee notes that water continues to rise in the deep aquifer of the London Basin despite the regional drought. Rising water may have an adverse effect on the engineering properties of the London Clay. Design should take account of this possibility.

Safety of old tunnels

An immense amount of tunnelling was initiated by the Victorians as they constructed railways, sewage and water pipelines, canals, hydraulic tubes and passageways under rivers. Tunnels were designed using available materials to resist foreseen loads and uses of the time. In consequence, materials of construction vary considerably with age and many tunnels are experiencing loadings and uses for which they were not designed, particularly as a result of more recent construction in the vicinity.

These tunnels, many of which are now almost 150 years old, have been subjected to a wide range of external and internal agencies which may bring about collapse over time. Degradation of their structures is becoming increasingly pronounced. Close inspection and remedial action is required to maintain structural safety. The Committee has been interested to determine whether owners operate formal inspection and maintenance policies to guard against these eventualities.

The Committee noted the formal inspection system operated by British Rail following the procedures in its own examination handbook which closely follow the UIC code (42).

Most Victorian rail tunnels are lined with brickwork. The major concern in maintaining safety is the development of voids behind linings caused by water flow or the deterioration of the ground structure at 'blind' shafts which were driven when the tunnel was originally constructed. Historical records of tunnels are incomplete and detection of voids before failure occurs remains difficult. Local failure of brickwork associated with the development of a void is the most frequent event. Such failures are quickly detected by the regular patrols of the railway and repair is initiated. In some cases extensive areas of unsound brickwork are revealed requiring substantial repair works.

The Committee was pleased to note the dedicated effort by British Rail to maintain the safety of tunnels. It emphasises the need to make full use of geological and construction records and to maintain inspection and maintenance records for the future reference of the tunnel safety team. Development work on techniques to detect voids behind tunnel linings should be strengthened. The Committee hopes to receive similarly reassuring reports from other major owners of tunnels regarding condition surveys.

Overcladding

This topic has been discussed in relation to the unknown and possibly aggressive conditions which may be created in the original cladding and void behind the new cladding leading to deterioration of the original fixings. The Committee noted the fire incident involving overcladding at Knowsley. It looks forward to the report of the Task Group of the Institution of Structural Engineers on the structural aspects of cladding.

Void formers

The formation of voids under floors as a means of avoiding forces due to heave has led to the use of a number of techniques, one of which uses cellulose material which in some circumstances can decompose to produce methane. The Committee is pleased to note that there are alternatives to such materials. It is equally conscious of the need to design, and reliably construct, voids which can be safely vented for the dispersal of both radon and methane; topics which have previously been examined by the Committee and which have now been introduced into the Building Regulations Approved Document C (43) with guidance available from recently published BRE Reports (44) (45).

Safety of offshore structures

The Committee made a preliminary review of the approach to safety and reliability currently adopted by official agencies and designers in offshore structure design. Performance requirements, failure modes and risk analysis were considered and it was noted that, following the Piper Alpha disaster, the Health & Safety Executive are now charged to introduce safety audits and hazard analyses which aim to minimise loss and maximise the safety of personnel.

The Committee is keeping this subject under review particularly from the point of view of the relevance to structures generally of experience gained in the techniques of risk analysis and of precautions against the effects of fire and explosions.
4 Topics for future action

4.1 Topics of continuing interest
Topics already examined by the Committee often require further consideration. During the next two years some of the topics discussed in 3 above are expected to require further examination or action to promulgate the Committee's recommendations.

4.2 Appraisal of strength of old masonry
The difficulty of assessing the strength of old masonry has been drawn to the attention of the Committee. Preliminary discussion concluded that attempts to extrapolate from BS 5628 (46), a standard intended to deal only with masonry as currently constructed, may be dangerous. The Committee will consider the most appropriate way in which a warning might, if necessary, be issued to engineers on the difficulties and dangers of such extrapolation. It notes that work has recently commenced at the Institution of Structural Engineers on updating its report 'Appraisal of Existing Structures' (47) which might address this topic.

4.3 Mis-use of computers
As a result of previous consideration of this topic, a CIRIA research project was undertaken which led in 1989 to a Technical Note (48). The safeguards necessary to reduce risks from the use of computers for structural analyses by those who have insufficient experience of traditional methods are thought to rest with those who supervise training. The Committee therefore will be considering the need to address graduates and their supervisors on this topic and the best means of doing so.

4.4 Education and training
At various times the Committee has discussed the influence of current education and training on the likelihood of structural mishaps through design or construction. The Committee expects to return to this topic.

4.5 'Smart' structures
The Committee has noted the development of 'smart' structures and materials (33). Although such developments are only in their infancy they may offer possibilities of monitoring and prediction in the future so that some structural failures may be avoided.

4.6 Other topics
- Techniques for facade retention as a development of falsework methods
- Refurbishment and Building Control
- New structural materials and innovation
- Draft Health & Safety Executive report and European Directives as they influence designer's responsibilities
- Bridge access gantries
5 Recommendations

5.1 Recommendations of highest priority

- Retractable and demountable stands provided for public events: an independent check of structural adequacy should be carried out before they are licensed for use (3.3).
- Retractable and demountable stands: additional technical guidance should be prepared to supplement the advice available on demountable stands (3.3).
- Temporary stands and staging structures: the use of temporary stands for public occupation and associated staging structures should be brought within the requirement of an independent structural check and certification by local authorities (3.4).
- Retractable and temporary grandstands: further research leading to design recommendations should be carried out on the dynamics of crowd loading (3.3).
- Sports stadia structures: owners should commission regular structural inspection and maintenance and permanent records should be kept and reviewed by a suitably qualified engineer (3.2).
- Multiple-use buildings: malls and atria should be classified for design as places of public assembly (3.1).
- Multiple-use buildings: appropriate levels of management, surveillance and control should be provided where reliance is placed on active systems for safety (3.1)
- Multiple-use buildings: monitoring of the performance of cladding systems should be undertaken (3.1)
- Multiple-use buildings: guidance on design for impact of vehicles on structures should be prepared, particularly in relation to the possibilities for 'disproportionate' collapse (3.1).
- Cladding repairs: major structural repairs to cladding should be subject to control under the Building Regulations (3.7).
- Barriers and handrails: further research for development of design recommendations should be carried out into crowd loading on barriers and handrails in shopping complexes, arenas, stadia and multiple-use buildings (3.8).
- Freestanding walls: consideration should be given to including freestanding walls in the brief of the building surveyor when properties change hands. Failures should be monitored to assess whether improved safety results from the issue of guidance for owners and builders (3.9).
- Structural safety in fire: the overall efficacy of active fire and smoke control systems and associated passive measures should be examined (3.10).
- Post-tensioned concrete structures: a stringent regime of inspection and appraisal of existing building and bridge construction should be introduced. Research to establish an effective means of inspecting tendons should continue (3.13).

5.2 Other recommendations

- Structural safety in fire: greater effort should be given to investigating fires and to providing feedback of experience to engineers (3.10).
- Structural safety in fire: the growing use of fire safety engineering should be matched by growth in the education and training of fire safety engineers and in research (3.10).
- High-bay warehouses and automated storage buildings: greater use should be made of sprinklers capable of operating through racks. Compartmentation in the largest warehouses, even where sprinklers are fitted, should be considered. Safe escape routes for maintenance workers in the event of fire should be provided even in "Exempt Buildings" (3.5)
- Post-tensioned concrete structures: for new structures, alternative stressing methods (which avoid the need for grouting of steel tendons) and the use of the emerging technologies of 'smart' structures and materials should be investigated (3.13).
- Damage to bridges by ships: further consideration should be given to improving design features of bridges and piers and to the wider use of fenders and dolphins (3.14).
- Cement additives and concrete admixtures: comprehensive information should be made available to specifiers and users on the compositions and properties of imported cements, additives and concrete admixtures (3.15).
- Cranes: guidance is required on the design and construction of foundations for cranes on construction sites (3.17).
- Cranes: BS 2573: Part 1 should be reviewed (3.17)
• Building alterations and changes of use: guidance should be prepared relating to alterations and responsibilities (3.6).

• Research on innovation and trends in structural engineering in the context of performance in service would be valuable (2.4)

• Air-supported structures: British Standard BS 6661 should be withdrawn (3.11).

• Air-supported structures: design guidance should be developed both for temporary buildings for storage or non-spectator sport and for uses as places of public assembly (3.11).

• Air-supported structures: a consistent approach to control under Building Regulations should be adopted throughout the United Kingdom and local authorities should note the recent history of failures (3.11).
6 Acknowledgements

The Standing Committee is encouraged by the actions taken by the Institutions, Government Departments and other bodies as a result of its enquiries and recommendations and is grateful for the information and help it has received from many engineers and others in both public and private sectors. Their cooperation has greatly facilitated the Committee's work towards preventing disasters involving structural failures.
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(39) BS 2573 : Part 1 : Rules for the design of cranes

(40) BS 5400: Steel, concrete and composite bridges

(41) The engineering implications of rising groundwater levels in the deep aquifer beneath London. Special Publication 69, CIRIA, London


(46) BS 5628: Code of Practice for use of masonry

(47) Appraisal of existing structures, Institution of Structural Engineers 1980

(48) Guidelines for checking computer analysis of building structures, CIRIA, TN133, 1989
Appendix 1 Terms of reference

The terms of reference of the Committee are:

- to consider both current practice and likely developments
- to be aware of trends and innovations in design, construction and maintenance from the standpoint of safety.
- to consider where further research or development work, or warning of risk appears desirable from the standpoint of safety but avoiding duplicating the work of the Health & Safety Executive or the two Institutions
- to report to the Presidents of the Institutions of Civil and Structural Engineers annually
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