Standing Committee on Structural Safety

Sixth report for the 3 years ending 30 June 1985

The Standing Committee on Structural Safety reports to the Presidents of IStructE and ICE. By publishing the sixth report of the Standing Committee, the President invites comments on its contents and suggestions for further investigations. These should be sent in the first instance to the Institution, at 11 Upper Belgrave Street, London SW1X 8BH.

Conspectus

The fifth report of the Standing Committee, issued in June 1982*, referred to the decision made by the Presidents of the Institutions of Civil, Municipal and Structural Engineers to reconstitute the committee under a new Chairman, following the retirement of Lord Penney, who had been the committee's Chairman for 6 years. Sir Derman Christopherson was subsequently appointed Chairman, and the new committee started its work in November 1983.

This, the Sixth Report of the Committee, covers the period of 20 months, to June 1985.

The committee first reviewed the 37 topics studied by the previous committee, specifically to examine what effects the recommendations contained in its earlier reports might have had in averting or reducing risks which had been identified and to establish whether some further advice or warning was necessary on these topics in the light of new evidence or recent trends and innovations.

The most frequent cause of structural collapse was accidental damage by gas explosions and by vehicle impact. In its second report, the committee drew attention to the need to ensure that any voids, including ducts, in a building are vented to prevent accumulations of gas. It advised local authorities and the suppliers of the risk from use of bottled gas in large panel high-rise dwellings which had not been strengthened following the Ronan Point inquiry. Suppliers of gas in refillable containers immediately gave appropriate advice to their agents to discourage the use of liquefied petroleum gas cylinders in dwellings above two storeys high, but the extent to which local authorities reacted to the committee's advice is not known. The Department of the Environment issued similar advice to local authorities following the collapse of flats in Putney in 1985. The gas explosion in Putney resulted from the infiltration of gas from a fractured main. Collapse of these prewar flats illustrated that traditional construction, as well as large panel structures, can be vulnerable to progressive collapse.

Gas explosions cause between 20 and 40 significant cases of structural damage each year, and they result in an annual average of 12·6 fatalities. The risk cannot be eliminated altogether, but wider acceptance of the committee's earlier advice would result in a worthwhile reduction of this risk. The tragic gas explosion at the pumping station at Abbeystead in 1984 drew attention to a further and unexpected risk of large quantities of methane from the ground or groundwater penetrating pipelines.

In its first and subsequent reports, the committee drew attention to the risk of structural damage to railway and highway bridges, including footbridges, as a result of impact by vehicles with tall loads. The Department of Transport accepted and implemented many of the committee's recommendations and intensified their attempts to deal with this difficult problem. Action has been taken to inform and educate transport firms and drivers, and various methods of bridge protection are under investigation. However, the risk remains, and although no loss of life is known from bridge collapses as a result of vehicle impact, the collapse in 1985 of a footbridge over the dual carriageway A2 highway, struck by construction equipment on a low-loader, illustrates the potential significance of such accidents. The committee strongly recommends the Department of Transport and others concerned to accelerate their efforts to reduce this risk.

Another important recommendation in the committee's first and second Reports concerned the need to periodically inspect concrete and masonry claddings, particularly those abutting busy thoroughfares and areas of public assembly. It is not known whether closer or more frequent inspection of the brick cladding to the tower block at Plymouth Polytechnic might have given warning of potential collapse, but the incident illustrates the importance of the committee's advice on this subject and the extent of the disaster which could have occurred if the adjoining cafeteria had been occupied.

The committee has frequently pointed to the importance for designers to take account of the need to facilitate inspection and, when required, the replacement or strengthening of critical elements of any structure. The committee finds it necessary to reiterate and emphasise this advice.

Turning now to some of the other topics which the present committee has studied during the past 20 months, some advice is given on the subjects of misuse of computer programs, the relation of size and importance to structural safety, safety of demountable stands, and further consideration of the safety of large concrete panel structures. This sixth report gives advice and recommendations on all of these subjects. The committee has also considered the structural safety implications of concrete deterioration from corrosion of reinforcement and prestressing tendons, and from alkali silica reaction (ASR) in concrete. In a good deal of its discussions, the committee has been concerned about the effects of increased litigation, professional liabilities, and the introduction of design-fee competition on structural safety. This report gives some views on these subjects.

With regard to the deterioration of concrete because of reinforcement corrosion and ASR, discussions with the Department of Transport and British Rail satisfied the committee that bridges for which they are responsible were regularly inspected. Both ASR and reinforcement or tendon corrosion take some years to develop, and tell-tale signs of damage are usually visible well before there is any risk of structural collapse. The committee therefore considered that, apart from an accelerated R&D programme, no urgent additional measures were required to deal with the deterioration of these concrete bridge structures because of reinforcement or tendon corrosion, or because of ASR. However, the committee is concerned that many other bridges and structures are rarely inspected and that some critical elements (such as halving joints and foundations) cannot be inspected adequately. Consequently, the presence of corrosion or ASR may not be established before their effects become apparent. Buildings at risk include swimming pools, but high internal humidity can occur in other buildings, sometimes as a consequence of ineffective air-conditioning.

The risk of reinforcement and tendon corrosion will continue as long as it is necessary to apply deicing salt to highways, and the committee strongly recommends that active research programmes should be pursued to find means of protecting concrete or reinforcement against the effect of salt, effective means of repairing affected concrete, and, in the longer term, suitable alternative means of deicing road surfaces. The committee was pleased to find that such programmes of research were already in hand.

Although at present the number of structures affected by ASR is quite small in relation to the total national stock of buildings, bridges and other structures, it cannot be predicted whether ASR will become yet wider spread. So far, only one motorway bridge in the UK, in which ASR was implicated, has been demolished and rebuilt, but remedial work has been necessary on a number of other structures. Recent specifications and guidance notes to limit the alkali level in concrete should be sufficient to ensure against the effect of ASR in structures in the future, but the committee once again stresses the need for regular and adequate inspection of existing sensitive structures of all kinds. As with the case of reinforcement corrosion, programmes of research to establish effective methods of protection and repair must be vigorously pursued, and structures exhibiting signs of ASR should be carefully monitored.

On the subject of the safety of earth dams, the committee concluded in its fourth report that little was known about the condition of privately owned dams and, in cases where inspections had shown remedial works to be necessary, these works were not always carried out. In 1982, the Department of the Environment circulated relevant advice on the matter to the local authorities, and it is hoped that the risk of structural failure and consequent loss of life from collapse has been substantially reduced.

Several recent events have reinforced the committee's concern that legal and insurance considerations now often preclude professional engineers from technical discussion with their peers on matters of safety. On a number of occasions, professional engineers have appeared to the public and to clients as having different opinions on technical matters which may impinge on safety, such as on the Severn Bridge, Great Ormond Street Hospital, Carsington Dam, Ronan Point, and other high-rise large panel structures. In no case has it been possible to give an authoritative statement reassuring the public and clients.

The committee believes that there should be no obstruction to communication or discussion between professional experts concerned with a project. Wherever matters of safety are concerned, professional engineers should be able to decide, if necessary after discussion with other engineers, the actions necessary to ensure the safety of a structure and to present their recommendations to the clients and others concerned without recourse to lawyers or to litigation.

The committee was pleased to learn that the Presidents of the two Institutions have already put in hand the preparation of guidelines to professional experts on both of these points.

The committee is also concerned that the courts' interpretation of professional liability, coupled with the fast expanding extent of litiga-

*see *The Structural Engineer*, **61A**, No. 2, February 1983, p65 tion in the UK, could have a detrimental effect on safety. This does not increase the safety or serviceability of structures, and it cannot be in clients' best interest to stultify innovation by encouraging over-conservative design.

The committee considered the implications of design-fee competition on structural safety. On the one hand, it might lead to reduced safety by encouraging a reduction in the quality of staff employed, and on the other it might lead to more conservative designs, by not refining the structure to its most economical form. However, there could be an advantage in that the onus is placed on the client to specify his requirements clearly. The committee will keep the influence of this trend under review.

The committee continued to examine statistics, reports of incidents overseas, and concerns expressed by the profession about individual risks to safety. As in previous reports, the committee concludes that the UK record of structural safety is good. However, it must be recognised that the profession's reputation in terms of lives lost as a result of structural collapse could have been very different if the Camden School, the Edmonton swimming baths, or the Plymouth Polytechnic cafeteria had been occupied at the time of collapse, or if the footbridge over the A2 had been carrying pedestrians in a period of high traffic intensity. For this reason, the committee wishes its advice and recommendations to be widely disseminated to the professions and others concerned.

The loss of life in the UK from structural collapse has been small, almost negligible over the past 20 years or more. However, the loss of life of construction workers is significant, and, more particularly, the loss of life of those who maintain and repair our buildings and structures is unacceptable. The committee will be considering these and other matters concerning structural safety during the next year, and information and suggestions from the professions and from the public will be welcomed.

New topics discussed during the period November 1983—March 1985

Misuse of computer programs in design

Bridges, offshore structures, and complex buildings, are now often analysed by computer programs involving finite element and other routines. This situation has developed not only because of the increased power and availability of computers and the associated software, but also because complex loading patterns and dynamic analysis are frequently specified, making hand analysis extremely tedious or uneconomic. Computer drawing has developed considerably, and many reinforcement detailing and scheduling packages are currently available.

A review of computer programs for the building industry[1] showed that almost 300 software packages existed in 1979 for structural analysis. Liability for the misuse of such programs rests almost entirely with the user. 'Bugs' in programs and unforeseen errors arising because of choice of the input data are not uncommon.

There have been recent cases of structures being inadequately designed, because of errors by the user in interpreting the required form of the data and ignoring 'comment statements' included in the output of the program. The detail and minutiae of computer output can also lead to omission of very important factors in the design, such as overall stability. There is therefore a strong temptation to ignore the simple qualitative approach to analysis and to have 'blind faith' in the results of computer solutions.

The committee recommends that a preliminary proportioning of the structure by 'hand' analysis should be a prerequisite of computer solutions. The output should be carefully checked for ambiguities in the internal and external force distributions and for all large displacements. A plot of the member geometry and the output displacements often assists in interpreting the many pages of results from the computer solution. Checking by an alternative program may show up any discrepancies.

The rush to obtain quick answers to complex problems should be tempered by careful choice of the structural modelling to obtain adequate accuracy with respect to the predicted behaviour. The intuitive element in design is difficult to teach, but it is an essential part of what is termed 'engineering judgment', derived from experience.

Safety of structures affected by alkali-silica reaction in concrete

The phenomenon of alkali-silica reaction (ASR) in concrete has been known for more than 40 years. The reaction takes place in concrete only when the following three conditions occur together:

—a reactive form of silica in the aggregate
—a sufficient concentration of sodium, potassium, and hydroxyl ions to produce a sufficiently alkaline pore solution in the concrete
—moisture within the concrete, or which can be absorbed

ASR is a long-term reaction resulting in the formation of a gelatinous alkali silicate hydrate which causes the concrete to expand, and, in extreme cases, to crack. The actual crack formation depends on the nature and level of stress in the structure, its geometry, and the detailing of the reinforcement. The signs of ASR are usually apparent about 10 years after construction.

In the UK, nearly all cases have been limited to the use of either Trent Valley sand or sea-dredged aggregates from the Bristol Channel or Isle of Wight areas. The precise number of cases where ASR has been attributed to be the major cause of cracking is not known. The number is somewhere between 50 and 100, all built between 1930 and 1975, and represents a very small proportion of the total volume of construction during that period. The implications of ASR on the safety of structures are as follows:

Because it occurs relatively slowly, it can usually be recognised before the strength of the member is seriously affected. To this extent, it is a serviceability problem which can be identified by normal inspection procedures. When definitely identified and the scale of the potential (but finite) expansion assessed, it may be necessary to evaluate the loadcarrying capacity (depending on the type of the structural member, the climatic, and other moisture conditions) and to check on the possibility of secondary deterioration from corrosion. Depending on the outcome of this assessment, remedial action may be necessary, ranging from continued surveillance to effecting the repair once the reaction has ceased. In extreme cases, it may be necessary to replace certain elements. Each case requires careful assessment and sound engineering judgment.

As the reactions can take place only in the presence of moisture, concrete foundations, bridges, and areas of buildings exposed to high humidity, may be most affected. Loss of integrity of the concrete can cause structural weakening, particularly in shear and bond. Examples of structural elements that may need to be carefully examined are corbels and halving joints, flat slabs, and pile caps. There is also a risk to foundations and other parts of the structure that cannot be easily examined, in that cracking resulting from ASR may not be detected.

The limitation of damage from ASR in new structures is covered by specifications such as those issued recently by the Department of Transport[2] and the Concrete Society[3]. The provisions in these documents are still under review, as more data become available from research and *in situ* tests. The emphasis in these specifications is on limiting the alkali level in the concrete from whatever source, but mainly the cement. Attention is also given to the use of aggregates with proven good performance.

It is felt that ASR is unlikely to become more widespread in new construction if this type of specification is followed.

With regard to existing structures and buildings, there is a clear need for periodic inspection, particularly of bridges and sensitive buildings such as swimming pools and others in which high humidity can occur from industrial processes or through ineffective air-conditioning. High priority should be given to R&D, with the object of improving methods of identifying ASR and assessing its effects, methods of prevention by coatings or other means, and effective methods of repair. There is also a continuing need to review specifications to limit damage by ASR in new construction.

Safety of demountable grandstands

Temporary grandstands are a relatively common feature at most sporting and open-air events. The failure of a temporary grandstand during filming of a BBC programme in May 1982, and the all-too-frequent failure of scaffolding systems, brought the safety of such structures to the attention of the committee.

In a paper to the Institution of Structural Engineers[4] the following main factors contributing to the 'failure potential' of temporary grandstand structures were stated:

—slender members subject to compression
—importance of lateral support by bracing
—possible large openings in the framework for access
—flexibility of the joints (depending on the systems used)
—possible omission of joint couplings or damage to members
—high indeterminacy for 'hand' analysis
—possible dynamic response leading to overload

There was also a strong possibility of 'unzipping' or progressive collapse following failure of one element. The most vulnerable members were usually at the rear of the structure.

The committee supported the Institution of Structural Engineers' initiative to produce a guidance document on the subject, and it recommended that the manufacturers should carry out appropriate testing and analysis to determine the stability of these structures with representative bracing patterns.

Structural safety related to size and importance

The importance of size and scale of a structure is not considered specifically in Codes of Practice. The basis of the treatment of risk in structural design is presented in CIRIA Report 63[5]. The means of obtaining a global level of safety for the whole structure is expressed in terms of partial factors. One of the three main factors (γ_c) takes into account the nature of the structure and its function.

The factor γ_c may itself be divided into two parts, depending first on whether partial or complete failure can occur without warning, and second, on the social and economic implications of failure. A parallel system may be defined as one in which redistribution of load occurs among adjacent elements at failure, and a series system is one where failure of one element leads to complete failure (e.g. loss of bearing).

The number of people affected by failure is usually related to the scale of a structure. The risk of failure is likely to be affected in various ways:

—Knowledge about spatial distribution of loads on large areas is limited (e.g. asymmetry of loads on shell roofs).

—Large structures demand more accurate analysis than smaller structures and can justify a greater proportion of the designer's time.

—Larger structures may develop greater movements (e.g. from temperature, shrinkage, creep, etc.).

—As structures become larger and more slender, they are more influenced by instability and dynamic effects.

The committee felt that the implication of size and importance of a structure should be reflected in Codes of Practice, so that the above effects could be treated in a more rational way in design. This could be achieved by an introductory section in the major structural Codes, and the committee recommends that this action should be proposed to the British Standards Institution.

Implications of the introduction of design-fee competition on structural safety

Tendering for design of structures on the basis of fee competition is becoming more common. Some members of the committee were concerned that this might lead to cost cutting on checking and detailing which may adversely affect structural safety. On the other hand, it was felt that it could lead to a more conservative approach to design by not refining the structure to its most economic form, which would eventually be more costly to the client than any fee saved.

In all competitive tendering, the onus would be on the client to specify the design requirements clearly, so that competition for design would be on a common basis and would result in safe structures. Advice to clients on the form and scope of the design brief would be essential in such cases. This should also extend to any site-supervisory role of the designer.

Competitive tendering for site investigation was felt to be one example of where cost cutting has reduced the quality of the investigation by placing more emphasis on rates of boring than on the quality of information obtained.

In the short term, fee competition might lead to a reduction in the quality and number of staff used in order to minimise design costs. The committee felt that this might lead to more errors in design with consequent implications on the safety of the public and the user. The influence of fee competition on design should be monitored.

Collapse of brick cladding to the Plymouth Polytechnic tower block

In December 1983, the south-facing brickwork skin to a reinforced concrete shear wall building at Plymouth Polytechnic partially collapsed under a high, but not extreme, wind. The single skin brickwork was five storeys high, beginning at the third floor of the building, and was about 20 m wide. The gap between the concrete and brickwork was plugged with mortar and the connection provided by galvanised mild steel ties cast into the concrete. This wall to the building was completed in 1962.

A possible contributory factor to the failure was that the tie spacing was greater than the spacing specified in the design. Apparently, some ties had corroded and some had reduced embedment length, because they did not align with the brick courses.

At the time of collapse, the wind was from a south-easterly direction almost parallel to the face of the wall, creating relatively high suction forces on the eastern side of the wall which had only a nominal return of brickwork. The prevailing south-westerly wind would have loaded the western edge, which was provided with a more substantial return and was more robust.

Since this building was designed and built, several significant changes have occurred in design practice for brickwork. CP121[6], published in 1973, requires that brickwork is supported at every third storey, for buildings in excess of four storeys high. More recently, attention has been drawn to the occurrence of corrosion of ties in brickwork, and several types of non-ferrous and high duty ties are available.

The committee concluded that all walls of this structural form not designed to the requirements of CP121 should be suspect. It was unlikely that walls of this type built after 1973 in accordance with new Codes would suffer similar collapse. It was also believed that few such walls had been built prior to 1973. Nevertheless, the committee recommends that building owners should be alerted to the potential risk and that they should be encouraged to commission regular inspection of suspect walls, particularly those adjoining busy thoroughfares or areas in which the public may gather.

In making this recommendation, the committee would remind building owners of a similar recommendation made in the committee's second and third reports concerning the need to inspect and monitor certain types of concrete and masonry cladding.

Collapse of the Carsington dam during construction

The Carsington dam in Derbyshire failed during construction in June 1984. The 1250m-long 35m-high earthfill dam developed a massive slip failure over nearly half its length. The Secretary of State for the Environment appointed an independent inspector to inquire into the cause of the collapse. The committee cannot comment further until the report is released and they have had time to consider whether there are any matters of structural safety that need to be drawn to attention.

However, the committee felt that press reports, following the collapse, left an impression with the public that professional experts could not agree on the technical questions involved and further, they did not discuss these questions with each other. The committee believes that guidance should be given on the procedures to be followed by a professional expert reporting on some aspect of a project to ensure adequate communication with other experts concerned and to provide suitable means of resolving any disagreements.

The committee wishes to emphasise that safety should take precedence over all other considerations in the event of disagreement between the parties or their representatives concerned.

The safety of large panel buildings

The stability of high-rise large panel buildings under both normal and extreme loads, including fire conditions, was considered by the committee. Their concern was to establish whether any unacceptable risk of failure exists of building systems strengthened or constructed since the 'Ronan Point' partial collapse in 1968 and, if not, to allay public fears following recent press speculation about their safety.

The Building Research Establishment (BRE) is currently undertaking technical assessments of the performance of large panel buildings, based on their own investigations and information obtained from local authorities and consultants. The committee considered it important that adequate Government resources should be made available for this work to aid BRE in their task.

It is estimated that there are about 35 building systems contributing to about 140 000 dwellings in England and Wales, of which some 30 000 are houses and 110 000 are flats up to 22 storeys. The Taylor-Woodrow-Anglian system used in Ronan Point totals about 90 buildings over five storeys high, with 10 buildings more than 20 storeys high.

Following a statistical analysis of gas explosions, it was deduced that one building in 25 years might be subjected to an explosive pressure in excess of $34kN/m^2$($5 lbf/in^2$), the design pressure used in developing the rules for structural integrity in the Building Regulations of 1972. This was considered to be an acceptable risk. However, there was also a risk from bottled gas, as noted by the committee in its second report. Some buildings built prior to 1969 had been strengthened to a lower pressure of $17 kN/m^2$, on the understanding that gas would not be used. Every attempt should be made, therefore to restrict the use of bottled gas in high-rise buildings, particularly those strengthened to this lower pressure requirement.

The results of a recent fire test on an apartment within a high-rise block are currently being studied by the BRE. One observation was the effect of distortion of the floors and walls caused by temperature differentials during a fire, prior to any general structural weakening.

This could cause deformations at the joints and transfer the vertical load to parts of the joint not previously loaded. In cases of badly concreted external joints, their behaviour in fire might be suspect. This highlighted the need for more data on the behaviour of large panel structures under normal and abnormal loads, including fire conditions.

General conclusions about the wide range of large panel building systems could not be reached. In some buildings, areas of poor concreting were found, leading to stress levels higher than normally permitted. A number of cladding panels and fixings had failed. However, other than Ronan Point, no structural collapse has occurred in large panel structures in the UK.

A recent report by BRE[7] concluded that strengthening measures were necessary in the case of Ronan Point, but that there was little probability of progressive collapse because of fire. At present, there appear to be insufficient test data on the capacity of critical joints if poorly constructed and subject to fire, and further work in this area is recommended.

Corrosion of reinforcement and prestressing tendons in concrete bridges

The mechanism of corrosion of steel embedded in concrete is complex. However, it is known that corrosion occurs only if the alkalinity (pH) of the cement matrix falls below 9·5 or if chlorides are present at a level sufficient to cause depassivation of the steel, leading to an electrolytic action between anodic and cathodic areas. The corrosion cell can be very localised, and it normally requires oxygen and water to be present at both the cathode and the anode so that ferric oxide (or rust) can be formed at the anode. In saturated conditions, corrosion without the formation of rust can occur at anodic sites starved of oxygen.

Loss of passivation and corrosion generally occur by three forms of attack: chlorides within the concrete, chlorides penetrating the surface of the concrete, or carbonation of the concrete cover. In bridges and marine structures, it is salt spray that is important but, in buildings, carbonation appears to be the main cause. The rate at which corrosion occurs depends very much on the presence of oxygen and water. General corrosion of a large area of reinforcement may occur relatively slowly, but it is pitting corrosion, or localised loss of steel (sometimes without much rust staining), that is more serious from a structural safety viewpoint.

There are about 60 000 reinforced concrete bridges in the UK, of which 6000 are relatively long-span motorway bridges. Where corrosion has occurred, it is most serious on bridge abutments, piers, and decks, exposed to salt spray or dripping water. Corrosion of bridge decks in the UK is far less common than in the United States, where, in contrast to the UK, it is not the usual practice to provide a waterproof layer above the deck. In the UK the worst problems seem to occur at leaky expansion joints where water is not properly drained. This has affected not only the concrete reinforcement, but also the bridge bearings.

However, current design of bridges stipulates positive drainage of joints, and continuous members, rather than repeated spans with numerous joints, are often preferred. Control of ingress of chlorides by surface coatings is being actively studied both in UK and overseas, as is the use of alternative deicing methods.

The long-term performance of post-tensioned concrete bridges, of which there are about 600 of relatively long span in the UK, was reported in the third report of the Standing Committee. The results of a survey of 12 post-tensioned bridges were presented, and since then a further two bridges have been investigated. Although voids have been found in the grouted ducts containing the tendons, little corrosion has been found. Theoretical studies of a number of bridges concluded that the overall level of safety was relatively insensitive to the loss of one tendon and that there was a sufficient safety margin, after first cracking, to give adequate warning of failure.

The committee concluded that corrosion of reinforcement or prestressing tendons created a serviceability problem rather than one likely to cause sudden structural failure. Nevertheless, it was essential to maintain adequate procedures for inspection and repair. High priority should be given to R&D to improve methods of detecting corrosion and to provide effective methods of prevention and repair.

Items of continuing interest

Inspection and maintenance of railway structures

In 1976, the committee examined the procedures adopted by British Rail for the inspection of railway structures and arrangements made for repair and replacement. In the committee's first report, it was concluded that British Rail's policy for inspection and maintenance was satisfactory and that, in spite of budgetary cuts on maintenance and in the rate of renewals, the present condition of railway structures gave no cause for immediate concern.

At that time, the maintenance budget was £35M on stations, bridges, and tunnels, which had a replacement value in 1976 of about £20 000M. It is understood that the maintenance budget has been kept at about the same relatively low level in real terms over the past 9 years.

While the committee has no reason to alter its earlier conclusion on the safety of railway structures, it is concerned that the effect of a prolonged period of restricted maintenance will inevitably reduce their margins of safety.

Inspection and maintenance of earth dams

In its fourth report, the committee drew attention to the unsatisfactory position with regard to the inspection and maintenance of earth dams in the UK, particularly those in private ownership. At that time, the 1975 Reservoirs Act enforcing inspection and maintenance of dams had not been implemented.

The committee was pleased to note that the 1975 Act is now being implemented, but points to the further need to include, within the Act, similar requirements for inspection and maintenance of canal banks and of tailings dams operated by the mining and quarrying industries. The recent collapse of the tailings dam at Stava, Italy, underlines the importance of this recommendation.

Damage to bridges by impact from vehicles and vessels

The incidence of damage to bridges through impact by vehicles with tall loads was pointed out in the committee's first report, and recommendations made to the Secretary of State for Transport were given in the second report and subsequently endorsed by the Presidents.

Many of the committee's points have been covered in amendments to the Motor Vehicles (Construction and Use) Regulations, No. 1017 (1968), and the committee has noted work by the Transport & Road Research Laboratory to examine means of reducing the incidence of vehicle impact. However, it is considered that the measures taken to date have had too little effect and that the risk of a serious accident, involving bridge damage followed by train derailment or multiple traffic accident, remains unacceptably high.

The committee reiterates its recommendation for a statutory height limit to vehicles and their loads—a recommendation not yet implemented by the Secretary of State for Transport—and emphasises the need to continue drawing the attention of all transport operators to the problem, including organisations concerned with the transport of construction plant.

The importance of the problem is illustrated by the collapse, in 1985, of a footbridge over a dual carriageway section of the A2 in Kent, following impact by the bucket of an excavator carried on a low-loader. Fortunately, in this case, no multiple traffic accident resulted and no lives were lost.

With regard to the added risk, pointed out in the fourth report, of parapets being inadequate to withstand impact from the very heavy vehicles, the committee was pleased to find that the Department of Transport had issued a memorandum[8] requiring more substantial parapets over railways.

Use of resin bonded plates to repair reinforced concrete

The committee reported some conclusions on the use of resins in civil and structural engineering in the fifth report. Subsequently, the use of epoxy resin to bond steel plates to the soffit of reinforced concrete sections was brought to the attention of the committee. This technique had been used with apparent success to strengthen a number of bridge decks and beams, but the committee advised against its wider application until its long-term performance had been proven. Epoxy resins are also used in the construction of segmental bridges, but are not required to have long-term durability.

Resin bonded plates have also been used recently as a repair method for a multistorey carpark which had developed cracks in its principal beams between columns shortly after construction. The composite plate-concrete section had been designed to provide the additional factor of safety required to resist the subsequent imposed loads on the floor.

In this particular case, the committee was satisfied that adequate arrangements had been made to control the application and to monitor the performance of the resin bonded plates. Furthermore, because of the relative low probability of severe fires in buildings of this type, which is recognised in the fire regulations, the fire resistance of the resin bonded plates was not critical. However, for this and other applications, it is important to draw attention to the loss of strength of resins at relatively low temperatures. In a fire, the unprotected plate might debond, which would not only be a hazard if it fell, but also the structural strength of the beams would rapidly reduce. The use of such bonded plates in other forms of structure with a higher period of fire resistance remains suspect. In the case in question, the plates had additional mechanical fixings to the concrete to prevent them becoming detached, and similar precautionary measures should be adopted in all instances where resin bonding is used.

The performance of resins under long-term loading is not well known. However, most buildings and bridges receive only relatively little permanent service load, and therefore creep strains may not be important. Ingress of moisture and fungal growth were felt to be possible further hazards. The resin manufacturers should be encouraged to carry out long-term load and indicative fire tests. *In situ* monitoring of the performance of structures where this repair technique had been used was also emphasised as a prerequisite to its wider acceptance.

Structural damage caused by gas explosions

The death of eight people in an explosion causing progressive collapse in a block of flats in Putney in January 1985 drew attention again to gas explosions as the most common cause of structural failure in buildings in the UK. Since the Ronan Point incident in 1968, the number of mains gas explosions causing structural damage of varying severity ranged from 20 to 40 p.a., with fatalities averaging 12·6 p.a.[9].

The Putney flats were of traditional brick wall and concrete floor construction, built in the 1930s, and it has been reported that leakage of gas from a fractured main accumulated in a service duct and underfloor void before ignition. The effects suggest that a range of building types—not just large panel structures—are at risk of progressive collapse in the event of severe gas explosions or bomb explosions. In its third report, the committee:

—emphasised the need to ensure adequate venting of confined spaces, including ducts and basements

—advised the Local Authority Associations in 1978 to consider prohibiting the introduction of refillable liquefied petroleum gas cylinders into buildings particularly at risk.

In 1984, the Department of the Environment took similar action to warn the local authorities, and the committee now recommends that guidance notes should be prepared and widely circulated to assist in reducing the risk of severe explosions and in reducing the structural effects of explosions in buildings.

The Abbeystead valve house explosion[10] in May 1984, which resulted in 16 people killed and 28 injured, has drawn attention to other matters which need to be publicised throughout the civil and structural engineering professions.

An investigation by the Health & Safety Executive concluded that the explosion was caused by ignition of a mixture of methane and air. The methane, of ancient geological origin, percolated, either in gaseous form or dissolved in water, through the walls of a tunnel and thence into the valve house during pumping operations. The valve house was vented, but the pressure from the explosion was such as to lift the robust roof construction of reinforced concrete beams and slab from its supports and cause several of the roof beams to fall into the chambers below.

The Abbeystead explosion highlights the need to extend the committee's recommendation to ensure adequate venting of confined spaces or underground construction into which methane

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could permeate in gaseous form or in solution. Further, the designer and operator should ensure that all such ventilated paths are clear throughout the life of the structure and are not affected by changes in operation or of machinery therein.

References

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Appendix 1. Terms of reference

The terms of reference for the committee were determined by the Presidents of the Institutions of Civil and Structural Engineers as follows:

To study trends and innovations in design, construction and maintenance of structures from the safety standpoint

To consider where further research and development work, or some warning of risk, appears desirable from the safety standpoint.

To report to the two Presidents and to make recommendations

To produce an annual report on its activities

To seek, receive, and authorise the expenditure of, funds necessary for the implementation of these terms of reference

To suggest to the two Institutions any changes to its terms of reference it considers to be necessary or desirable.

Appendix 2. List of members

Chairman: Sir Derman Christopherson, KT, OBE, DPhil, BA(Oxon), FEng, FIMechE, MICE, FRS
University of Cambridge

C. J. Evans, MA, FEng, FICE, FIStructE, FCIArb, FIHT
Wallace Evans & Partners

A. Gordon, CBE, LLD, DipArch, FRIBA
The Alex Gordon Partnership

H. B. Gould, CEng, FIStructE, FICE
Property Services Agency (until 1 January 1985) G Maunsell & Partners (from 1 January 1985)

Professor E. F. Happold, RDI, BSc, FEng, FIStructE, FICE, FCIOB, HonFRIBA
University of Bath

D. J. Lee, BScTech, DIC, FEng, FIStructE, FICE, FIHT
G Maunsell & Partners

P. F. Mead, FEng, FICE
John Mowlem & Co. plc

D. N. Rogers, BScTech, CEng, FICE, FIHT
Mott, Hay & Anderson

R. E. Rowe, CBE, MA, ScD, DEng, FEng, FIStructE, FICE, FIHT, FACI
Cement & Concrete Association

A. C. E. Sandberg, BSc, ACGI, CEng, FIStructE, MIMechE
Messrs Sandberg & Partners

R. S. Taylor, BSc, FEng, FICE
Taylor Woodrow Construction Ltd.

J. Uff, QC, PhD, BSc(Eng), CEng, FICE, FCIArb
Consulting Engineer

F. Walley, CB, PhD, MSc, FEng, FIStructE, FICE
Consultant to the Ove Arup Partnership

Secretary: L. S. Blake, PhD, BSc(Eng), CEng, FIStructE, FICE, FIHT, CIRIA

Technical Officer: R. M. Lawson, PhD, BSc(Eng), ACGI, CEng, MIStructE, MICE, CIRIA

Appendix 3. List of topics reported on by the committee since its inception in March 1976

1. The final report of the Advisory Committee on Falsework (Bragg Committee)
2. High pressure gas pipelines
3. Fires in schools and other buildings exempt from control under the Building Regulations
4. Maintenance and inspection of British Rail structures
5. Concrete Society working party on structural safety
6. Building Integrity Division, BRE
7. Cladding failures
8. The influence of Building Regulations on structural safety
9. The influence of safety factors on overall structural safety
10. Investigation of structural failures
11. The relevance of Agrément Certificates to structural safety
12. The risk of brittle fracture in high tensile steel structures
13. Liquefied petroleum gas containers in dwellings
14. The stability and durability of timber roof trusses
15. Tolerances and accuracy in building
16. Responsibility of local authority inspectors
17. The strengthening of reinforced concrete bridges by attachment of resin bonded steel plates
18. Damage to bridges through impact by high vehicles and high loads
19. Welded structures
20. The Building Research Establishment, Garston
21. The use of chemical admixtures in concrete
22. Various factors influencing the structural safety of buildings
23. Safety of post-tensioned concrete bridges: corrosion of tendons
24. The role of the Health & Safety Executive in building control
25. Cavity wall ties and metallic components
26. Ground anchors and reinforced earth
27. The use of pulverised fuel ash in structures
28. The stability of buildings during partial demolition and reconstruction
29. Failures of medium-sized public assembly buildings
30. Earth dams
31. Lighting columns
32. Deterioration of buildings and other structures
33. The effect of complex and comprehensive Codes on structural safety
34. Structures in the nuclear power industry
35. Structural failures during construction
36. Some cases in which the Building Regulations may not provide appropriate safeguards for structural safety
37. The use of resins in civil and structural engineering
38. Misuse of computer programs in design
39. The safety of structures affected by alkali-silica reaction in concrete
40. The profession's reactions to some matters of public concern
41. Safety of demountable grandstands
42. Structural safety related to size and importance
43. Implications of some recent court discussions on structural safety
44. Implications of the introduction of design-free competition on structural safety
45. Collapse of brick cladding to the Plymouth Polytechnic tower block
46. Collapse of the Carsington dam during construction
47. The safety of large panel buildings
48. Corrosion of reinforcement and prestressing tendons in concrete bridges
49. Inspection and maintenance of railway structures
50. Inspection and maintenance of earth dams
51. Damage to bridges by impact from vehicles and vessels
52. Use of resin bonded plates to repair reinforced concrete
53. Structural damage caused by gas explosions

Continued from page 26
provided a number of analytical problems for us to solve at Christmas, which our readers tackled with various degrees of success. He now asks a question of a different kind:

Simply—the problem

A concrete ground-floor slab is cast on a polyethylene sheet, on a well-compacted granular sub-base. On the basis that the slab does not support load, and is shrinking, the only resistance to contraction is the friction to the underside of the slab/top of polyethylene (due to the self-weight of the slab).

What coefficient of friction 'μ' would you initially use in a calculation to determine the resistance to contraction in order to calculate the area of reinforcement to resist shrinkage forces?

Response required

Make an immediate note in the Journal of the 'μ' value you would use. Then check this value in next month's issue.

We are grateful to Martin Ashmead for his letter and will publish his comments next month.