Cross (confidential reporting on structural safety) is a UK scheme that collects, analyses and publishes personal reports about failures and the safety of structures so that engineers can learn from the experiences of others. Names of authors are confidential and identifying features from event descriptions are removed. When a trend is detected, action is taken to influence changes in culture and, when possible, in standards or legislation. Reported subjects have covered design, construction, use, demolition and regulation issues associated with buildings, specialist structures and bridges. Examples are given on fixings, temporary stage structures, snow load collapses, tall asymmetric structures, and false and misleading documentation. Data from identified trends have been passed to code committees, government departments, institutions or others who have influence on best practice. The information is also on a database on the site www.structural-safety.org.

1. History

Confidential reporting on structural safety, known as Cross, was established by the UK Standing Committee on Structural Safety (Scoss) in 2005. The objective was to improve structural safety by using confidential reports to highlight lessons that have been learnt, to generate feedback and to influence change. The aim is to help protect the public from potential dangers and those in the industry who could be affected by failures and collapses. Principal sponsors and funders are the Institution of Structural Engineers, the Institution of Civil Engineers and the UK Health and Safety Executive (HSE). Support has also been given by government departments, consulting firms and contractors. In 2011 Cross and Scoss were amalgamated as Structural-Safety.

The models for confidential reporting are the American aviation safety reporting scheme (ASRS) and the UK equivalent confidential human factors incident reporting programme (Chirp). Cross is the only such scheme for the engineering industry but it is hoped that participation will be extended to other countries. This paper describes the development of the scheme over the first 7 years illustrated by a number of case studies, and is intended to encourage additional reporting.

2. The process

Measuring success in any safety scheme is difficult as there are no parameters about incidents which did not take place, only about those that have occurred, and there are fortunately very few major collapses in the UK. Many of the reports, however, are about precursors which, when discovered in time, may prevent more serious events from occurring.

Most safety activities are the result of actual or near-miss events and this applies to structural and civil engineering processes. ASRS uses a pyramid of risk to differentiate between normal activities, those which may be considered as near-miss incidents, and fatal incidents. Figure 1 shows how this relates to structural safety where precursors (i.e. warnings of danger) can be reported to Cross, as well as being dealt with internally. Fatal incidents of course will be dealt with by HSE in the UK or other authorities elsewhere.

Reacting to precursors is an important preventative measure and, by recognising this, an increase in safety awareness can be promoted. The cost of a significant event, particularly when there are serious injuries or fatalities, is huge in human terms, in financial terms and to the reputations of firms and individuals. Failures involving death or serious injury may also result in prosecutions. In comparison, the cost of learning lessons from previous concerns, including near misses, is negligible. Most organisations have mandatory accident reporting systems but fewer have reporting systems for near misses, or indeed for near hits, which may be a more effective term.

Cross does not replace such systems but is complementary and provides a central reservoir of information that may be of use within the construction industry. Cross and Scoss are combined under the banner Structural-Safety (www.structural-safety.org), which collects, analyses and publishes information from both publicly available and confidential reports. There is no formal mechanism for investigating causes or carrying out forensic analysis and the information provided by confidential reporters is taken as correct although it may be amplified during correspondence or discussion with the reporters.
Reports are usually sent by civil or structural engineers, often those in senior positions, using email through the Structural-Safety website, although there is a facility for submitting them by post. The postal system leaves no electronic trail and hence may be preferred by those who want maximum security. Reporters must give their names so that follow-ups can be made, but the first part of the process is for names to be removed and reports depersonalised. The next stage is to remove identifying features so that reports become anonymised and there are no identifiable references to projects, products or firms. The system of processing is such that only the project director responsible for the scheme sees the original reports and he or she also depersonalises and de-identifies them. Other personnel in Structural-Safety see only the anonymised reports and reporters’ identities are not revealed.

3. **Categorisation and analysis**

After the concern has been described, further information is requested including

- professional or other affiliation
- job title and location
- type of organisation

Figure 1. Pyramid of risk

Reports are usually sent by civil or structural engineers, often those in senior positions, using email through the Structural-Safety website, although there is a facility for submitting them by post. The postal system leaves no electronic trail and hence may be preferred by those who want maximum security. Reporters must give their names so that follow-ups can be made, but the first part of the process is for names to be removed and reports depersonalised. The next stage is to remove identifying features so that reports become anonymised and there are no identifiable references to projects, products or firms.

The system of processing is such that only the project director responsible for the scheme sees the original reports and he or she also depersonalises and de-identifies them. Other personnel in Structural-Safety see only the anonymised reports and reporters’ identities are not revealed.

| area of concern |
| construction    |
| age of structure|
| structure type  |
| material        |
| type of structures|
| main materials used|
| building elements involved|
| nature of concern and stage of project|
| process at the time, for example design, construction, normal use or demolition. |

Figure 2 shows the proportions of the principal materials about which reports have been sent and similar information is collected for the other categories. Descriptions of what to report and how to report are given on the website. Before publication, the de-identified reports are reviewed by a panel of experts and comments are given with the intention of pointing out the lessons that can be learned so that similar concerns or events can be prevented. It is stated that although Structural-Safety has taken every care in compiling its publications, they do not constitute commercial or professional advice and this is because specific circumstances will differ from case to case. Reports and comments are stored on a database on the site and it is hoped that this will prove to become a useful resource for practitioners.

When a trend is detected, usually when three or more similar reports have been received, then consideration is given to issuing an ‘alert’ from Structural-Safety. These are also issued when a trend is seen from published information on failures that have happened anywhere in the world. The value of alerts is that they are circulated widely to engineers who can use the information to avoid similar events.

4. **Case studies**

The cases where the cycle shown in Figure 3 has been completed, and which have been included in Structural-Safety publications, include

Figure 2. Principal materials involved
4.1 Selection and installation of top fixing anchors

Anchors and top fixings are critical to the safety and security of suspended ceilings and associated equipment. Their importance is sometimes neglected when they are not seen to be structurally important. However, there have been many failures of anchors in the UK and elsewhere which have resulted in the collapse of ceilings, including a number that have been reported to Cross. Failures of heavy ceilings have occurred in some cinemas and other buildings and in underpasses structures (see Figure 4). Fortunately there have been no fatalities or injuries but, had there been people underneath any of these at the time, then the consequences could have been severe.

The causes for these failures, and advice on how to avoid them in future, are given by the Construction Fixings Association (2012). The document contains practical advice for those using such fixings both during design and on site. It stresses that the costs and impact of a collapse can be huge and affect the lives of those involved whether they are victims or those who are responsible for the failure. Using the correct approach and ensuring the proper selection and installation of anchors will lead to reduced risks. The report deals with the contractual and statutory responsibilities of those involved in the design and supply chain, and recommends the approach to be followed to ensure safe anchorages. Very important is the selection of suitable anchors, which is done by identifying application parameters such as applied load, base materials and environmental factors, and relating these to the type of structure providing the support and the type of anchor. Anchor installation information is given, as is preliminary and proof testing. The Cross reports were also considered when drafting the British standard in development BS EN 13964: Suspended ceilings – Requirements and test methods (BSI, 2012).

4.2 Ageing multi-storey car parks

Several reports were received concerning the condition and quality of ageing multi-storey car parks (MSCPs) which are common in city centres in the UK and elsewhere, and usually where large numbers of people may congregate. The reports suggest that there are structures which have deteriorated and could be at risk of failure and these echo concerns that have been expressed over a long period. Indeed in the relevant year it was reported that several car parks had to be demolished on safety grounds.

Headline events such as the Pipers Row car park collapse in the UK in 1997, a Montreal parking garage collapse in 2008 and others show that severe, and sometimes fatal, failures occur in such structures.

Multi-storey car parks are unique structures in many ways as they are

- subject to relatively severe weather conditions owing to exposed structure, carbonation of the concrete, reinforcement corrosion and spalling
- sensitive to waterproofing finish failure
- sensitive to expansion joint sealant failure
- subject to extremes of thermal loading akin to bridges but rarely detailed to the same standard as bridges
- subject to localised very high chloride concentrations from de-icing salts.
The typical pattern of deterioration is such that failure is likely to be indicated by spalling, but may be sudden and brittle with little or no warning. Given the history, and the likely consequences of failure, there may be a case for making it a legal requirement to have regular inspections of these structures. In the absence of such requirements, Cross (2012; in Newsletter No. 26) said that those involved should ensure that their concerns are expressed in clear terms to their clients, with the consequences to individuals and organisations of failing to act being outlined. It may be that some owners and operators tend to ignore current legislation, not to mention their own liabilities, on the basis that a collapse of an MSCP is a rare occurrence. This is true, but they may be unaware of how close inadequately inspected and maintained car parks can come to collapse. The British Parking Association (BPA) in its master plan Liability for Car Park Maintenance (BPA, 2011), therefore recommends that ‘Owners and operators set aside funds from income streams to finance periodic structural inspections and essential maintenance of car park structures’. Local authorities’ practices differ and some carry out their responsibilities very thoroughly and have excellent MSCPs. In the aftermath of the Montreal collapse a coroner called for tighter inspection rules after finding that a car park, which had collapsed and killed a man, was badly built and maintained. She said that the structure, built around 1970, was in a sorry state and had surpassed its useful life.

The reports were published in Cross Newsletter No. 26 (Cross, 2012), which was sent to local authorities and consultants, many of whom have involvement with MSCPs. The BPA has raised its concerns with government, and has assembled a body of evidence about structural conditions. Awareness has been raised as a result of publishing these concerns and it is hoped that more attention will be paid to improve the levels of inspection and maintenance.

4.3 Temporary stage structures

In 2011 there were collapses of temporary stage structures in the USA and in Europe during entertainment events, resulting in fatalities and numerous injuries. Reasons why the failures took place have generally not yet been published, although initially wind has been reported as a contributory cause in some cases. The temporary structures involved in these collapses may be similar to those used in the UK. One of the most dramatic events was the collapse of a stage structure at the Illinois state fair in 2011.

Cross had been sent two reports of concerns about temporary stages so, coupled with information on publically reported failures, a Scoss alert on temporary stage structures (Structural-Safety, 2012) was published. It was aimed at those who may commission or procure or license temporary stages and other temporary structures, for example large outdoor television screens, which offer potential risks to the public. These included owners of sites and venues, promoters, contractors and their designers, local authority licensing officers and building control officers, and insurers. Although the alert was primarily concerned with temporary stage structures, the principles apply equally to all temporary demountable structures. A prime responsibility of the client is to make sure that competent persons are employed to design, independently check, erect, inspect, monitor on site and dismantle the structure.

It was stressed that contractors should be able to demonstrate to the complete satisfaction of the client, or the client’s engineers, that the proposed structure has been specifically designed to accommodate all vertical loads, including self-weight, lights and sound equipment, and snow (if applicable). It should also be capable of withstanding agreed wind loads applied to the structure and equipment and any roofing and side cladding, such as advertising banners, and, if relevant, vehicle impacts. The design should be for the structure as a whole, taking account of overall robustness, strength and stability as well as the capability of the individual components. Elements such as trusses which are connected together should be able to withstand local member loads. To carry lateral loads there must be appropriate connections between vertical and horizontal elements and all loads must be taken safely to the ground through suitable foundations. Frames must be braced in each axis to avoid undue distortion and lack of stability.

Regardless of the competence of any engineers involved in the design process, systems sold to end users frequently rely on that end user making site-specific judgements about the anchorage of temporary structures to the ground. Positions of ground anchors or kentledge shown on drawings may be changed for operational reasons. End users may not appreciate that by taking decisions on anchorages they are attracting design responsibilities.

Almost all temporary stage structures are designed for an upper limit wind speed and guidance is given in Temporary Demountable Structures, Guidance on Procurement, Design and Use (IstructE, 2007) on how to consider wind loads, including advice on operational site management; for temporary structures there should also be a wind management plan. Wind speeds at which the recent overseas collapses have occurred have not yet been published, except in the case of the Indiana collapse where they were comparatively low; however, there have been cases in the UK of wind-induced failures of temporary structures where recorded wind speeds have been within foreseeable limits. The alert concluded by listing key points to look for.
design documentation has to include the basis of design, loadings, calculations, drawings and specifications, and a clear definition of the operating limits of the structure including the effects of all loads
- evidence of competence of the designer by way of qualification, experience and insurances carried
- evidence of independent design check by a chartered structural engineer
- evidence of independent erection check by a competent person
- completion certificate from the event organiser to confirm all of the above
- monitoring of wind speed and a plan of action to be in place if there are restrictions on safe wind loads.

The alert was widely circulated throughout the UK and internationally, prompted discussion among suppliers, contractors and others, and raised awareness among local authorities. The conclusions of detailed forensic analysis of the Indiana collapse (Thornton Thomasseti, 2012) demonstrated similarities to recommendations in the alert including

- inadequate lateral load-resisting system
- failure occurred at low wind speed
- gravity ballast inadequate
- inadequate structural analysis
- no third-party review
- gaps in code requirements
- no review by sound company to check capacity
- no record drawings or engineering data.

4.4 Snow loading collapses

Severe weather has been the trigger for many collapses, and snowfalls in the winters of 2009/2010 and in 2010/2011 caused over 3000 agricultural and associated buildings in Scotland to partially fail or to collapse. As previously reported (Soane, 2011), the likely causes included the build-up or drifting of snow on roofs, the age of the buildings, weaknesses in original design or construction, and lack of maintenance. Prolonged periods of snow deposition and very low temperatures were experienced, which contributed to snow compaction and increased snow densities. Throughout the north of Scotland depths of 1100–1200 mm on roofs were reported with snow overlying ice.

Most collapses were of agricultural and associated buildings with steel or timber portal frames, and these were described in Effect of Severe Weather on Farming Community – Winter 2010/11 (Scottish Government, 2011), but there have been other examples including the roofs of a series of substantial warehouses. There were also reports of rainwater channels freezing in the prolonged sub-zero temperatures and collapsing under the weight of ice. Substantial, and potentially dangerous, dumps of snow were experienced from the sloping roofs of domestic properties. Cross received a number of these reports directly and their technical content was shared with the Scottish authorities. An alert was published on Snow Loads on Agricultural and Other Buildings (Scoss, 2011), which recommended that designers take account of the recent collapses when considering structures where significant snowfalls may occur.

4.5 Demolishing large panel structures

In 2009 a local authority group was engaged in a scheme for the demolition of two 13-storey large panel structure (LPS) tower blocks which had been manufactured by a company, by then out of business, in the 1960s. A report was sent to Cross and subsequently published together with comments (Newsletter No. 18, Cross, 2010). A high-reach demolition rig with a concrete nibbling attachment was used to reduce a corner of the first building to ground level. The same method was used for five storeys of the opposite corner, but then the wall panels and floor slabs forming the bottom eight floors collapsed progressively and unexpectedly. After precautionary measures were taken, work recommenced to remove the damaged portion of the structure, which was now considered to be unsafe. However, this also suffered progressive collapse after the removal of panels from the top. The method of demolition was then reviewed and a new system was adopted of reducing four storeys at a time across the rest of the block, working around the building in a circular pattern. This was successful.

An analysis was then made of the second block. However, evidence gathered in the early stages led to such concern that the investigation was abandoned on safety grounds. Client and contractors then worked to determine a methodology and control measures for the demolition of the second block. After taking down three or four storeys in one corner, there was an uncontrolled collapse which affected the complete corner bay over its remaining height. Of considerable concern was the very clean shear failure across the slab to cross wall panel junction, indicating a significant lack of connection or mechanical tying between floor panels and the cross walls forming the structural cells.

Cross considered that there are two main issues: first the demonstration of the lack of robustness in these particular structures when exposed to demolition loading; and second the nature of the demolition process adopted. The forces involved during demolition should be taken into account by designers, and Cross has had previous reports of failure during demolition. There is always the legal need for a good management system to avoid excessive collapse, which could introduce unnecessary risks to operatives, to people who may be nearby, and to surrounding buildings. Learning from this
example, the system of work for demolishing similar LPS structures should take into account that sudden progressive collapse may occur. The pictures are very reminiscent of the Ronan Point collapse in 1968, which was the subject of a public enquiry in 1968 and guidelines on strengthening similar LPS tower blocks were later published. The lack of adequate ties between walls and floors and between adjacent floor panels on the buildings reported to Cross means that the buildings would not comply with current building regulation A3, but at the time of construction the need for horizontal and vertical tying through mechanical anchorages, or other suitable measures, was not appreciated.

4.6 Tall asymmetric buildings

One reporter touched on the topic of analysis and design of the structural systems for tall buildings which are asymmetric and may be irregular in plan (Newsletter No. 22, Cross, 2011). These might have a concrete core and an external steel frame with floors spanning between core and frame. Tall buildings which are complex in plan raise interesting issues concerning the methods of analysis that should be used, and there is conjecture that a first-order linear analysis may not represent the structure adequately. It has been argued that non-linear geometry effects should be included so as to provide a better representation of the behaviour of the structures.

Cross commented on the problems of validation of analysis models. The questions to be expressed and answered are as follows.

- Is the model satisfactory in its representation of structural behaviour?
- Are the software and the way it is used appropriate and suitable?
- Are the results correct?

Analysis software must be used within the limitations of its applicability. It is all too easy to believe that because a structure has been computer modelled the output is therefore accurate. As buildings become taller and more complicated, issues customarily ignored in smaller structures start to become critical. In tall buildings, for example, differential elastic shortening of vertical supports can cause significant redistribution of horizontal member moments. Moreover non-linear effects such as those due to elastic side-sway from non-uniform vertical loading start to become important as do P-delta effects. The design of connections and nodes at the ends of members is generally left to specialists, but the size and stiffness of the nodes will affect the analysis to a considerable degree. This is particularly the case with complex inclined buildings when many members intersect at a point. It is vital to be able to check whether the software has a built-in ability to consider both global and member buckling capacities.

Asymmetry in a structure may exacerbate such effects under both vertical and horizontal loading, but whether these could lead to potential buckling problems would depend upon the example being studied. In designing a non-standard structure, the process should start by ensuring that all possible aspects of behaviour can be represented by the model until there is confidence that they can be ignored. Some of the validation issues can be resolved by carrying out sensitivity analysis, for example making runs with and without non-linear geometry and comparing the results. Aspects not to be ignored are the horizontal and vertical elastic changes that occur during construction (perhaps exacerbated by asymmetry) which will have an effect on the stress distribution and stability in the completed structure (i.e. dependent on when separate parts are rigidly linked up). Thus the modelled stress distribution in the final structure is influenced by the sequence and manner of phased construction.

There is now an international consensus that ‘robustness’ ought to be a consideration in all structural designs, yet there is no agreement about what ought to be done for tall, novel structures (Class 3 structures in UK terminology). The Eurocode rules for lateral load envisage some proportion of this load is notional (as in UK practice) but some lateral load will arise due to out of plumb in the erection of the columns. In tall, asymmetric structures this ought to be a consideration, but the effects may not be apparent from the model representation of the structure. The report Practical Guide to Structural Robustness and Disproportionate Collapse in Buildings (IStructE, 2011), although not dealing with Class 3 structures, makes the following very important point: ‘A key presumption is that for any one building, there should be one engineer in overall charge of both stability and robustness and not least when multiple structural disciplines are involved, as in hybrid structures.’ In view of the complexities involved the question can also be raised as to whether buildings like these should have a mandatory check and, separately, a review, as part of regulatory control procedures. Should there, speculated Cross, be a process for checking on the competency of organisations and individuals to be responsible for such designs in addition to general safety legislation in the UK?

The validation of software, and its proper use, is a matter that needs to be addressed both in practice and in education and the publication of this report and others of a similar nature help, to support the argument.

5. Conclusion

These case studies demonstrate the range of topics that have concerned reporters to Cross. They illustrate how confidential reports can be the starting point for creating evidence that can be used to inform and influence engineers, and possibly regulators and the authors of standards. Without the programme, much of the evidence would not have been linked,
trends would not have been observed, and the alerts could not have been published. Data have been passed to code committees, government departments, institutions or others who have influence of best practice. Alerts have been widely published and circulated.

The Structural-Safety website is viewed from around the world with 60% of the visits from the UK and the balance from many other countries. The intention is to develop the scheme so that the database can be international and information can be shared between engineers wherever their location. Discussions are taking place with organisations in several countries to determine the best way to achieve this ambition.

Acknowledgements
The support and contribution of the members of the Cross expert panel and the Scoss committee is gratefully acknowledged. Without the confidential reports the case studies would not have been possible, so these reports are much appreciated and valued.

REFERENCES
Thornton Tomasetti (2012) Indiana State Fair Collapse Incident. Indiana State Fair Commission, Indianapolis, IN, USA.