The Committee recognized that there were many events which were not of a scale to attract public or official attention but which, if information about them could be captured, would provide a rich source of data on structural safety. Using the American Aviation System Reporting System[i] (ASRS) as a model the Confidential Reporting on Structural Safety (CROSS) scheme was launched by SCOSS in 2005. In almost ten years of operation considerable experience has been gained on the collecting and analysis of concerns from structural and civil engineers. Many of the occurrences reported are near hits, which in slightly different circumstances could have had more severe consequences including deaths and serious injuries. These are pre-cursors from which lessons are learned.

For several years CROSS and SCOSS operated separately in administrative terms but were merged in 2013 to form the Structural-Safety Group[ii]. A major part of the work of the Group is to publish information of general benefit to the construction industry and these include quarterly CROSS Newsletters as well as SCOSS Alerts and Topic Papers. The papers are written in response to observed trends in the industry, and structural failure events. Alerts are to publicize the consequences of concerns or collapses that are in the public arena or that have come through confidential reports. Topic papers deal with events that have relevance but less urgency than Alerts. Examples of some reports and publications have been given previously[iii].

OPERATION

The CROSS system is web based and the most important, and challenging, task is to secure reports from engineers who are traditionally reluctant to reveal details of what might seem to be mistakes or weaknesses. Obstacles to reporting include:

- don't know about CROSS
- don't know how
- don't see the value
- loyalty to client/firm/colleagues
- fear of being blamed/shamed
- forbidden by insurers/lawyers.

Overcoming these has taken time and involved making many presentations, publishing articles in journals, and gaining a reputation for independence and probity. There is still work to be done to gain universal acceptance and one of the most difficult obstacles is to get information released on the causes of collapses when this is constrained by legal situations or confidentiality arrangements imposed by insurers.

Reports are encouraged which draw attention to:

- concerns about design processes which could contribute to failure,
- descriptions of incidents or near misses on site on in service,
- lessons learned, or identified, which will help others to contribute to a safer industry,
- concerns which may require industry or regulatory action.

Reports are submitted through a form on the web site and are only accepted from those who give their name and contact details. Anonymous reports are not accepted and neither are those where urgent action is required. In the latter case advice is given on how to facilitate reporting to a relevant source or how contact the relevant regulator. A report is composed of a description, associated material such as photographs and pdfs, and an optional initial categorisation. Most reports come from senior personnel within firms and with the agreement of the firms – this is not whistle-blowing.

The base reports are seen only by the director of the CROSS scheme who may contact the reporter for further information or to discuss the situation. Reports are then de-identified to remove details of the reporter and features that could identify a firm, a site, a product, or anything else that might be recognized. Backing up the system is a panel of volunteer experts chosen by the sponsors for their experience and ability as well as their independence. They are respected figures from all sides of the construction industry who review the de-identified reports and give comments on how such concerns might be dealt with in future. Blame is never apportioned and the aim is to enable lessons to be learned. Reports and comments are sent to the reporters for approval and finally to the group legal advisor for clearance to publish.

The most significant reports, together with comments, are published in quarterly on-line Newsletters and are added to a web site data base. Other reports are added only to the data base including some from other media publications if relevant to a trend. This free resource is used by practitioners, educators, regulators and others. Registration for publications is through the web site and whilst most respondents are from the UK there are others from around the world. In the year July 2014 – July 2015; 54% of web site visits were from the UK, 10% from Australia, and 6% from the USA, with the remaining 30% from a range of other countries. Subscribers are sent emails when a Newsletter, Alert, or other publication is issued.

Once Newsletters are circulated by email they are distributed further by representative and trade bodies and internally by some organisations, so the number who has access to them is greater than the 7,500 registered subscribers. More than 300 reports have been published so far and there are over 500 on the data base covering a wide range of issues.

REPORTS RECEIVED

The subject matter for reports is very wide and shows both the breadth of activities undertaken by structural and civil engineers and the extent to which they recognize concerns of actual or potential values. The following three examples; one about design issues, a second about a near hit on site, and the third about fixings, are abbreviated versions of reports that have been published in recent Newsletters.

Report No 1: Design of tall asymmetric structures
One reporter touched on the topic of analysis and design of structural systems for tall buildings which are asymmetric and may be irregular in plan. 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.

Comments from CROSS
The problem is of validation of analysis models; that is the consideration of whether the model is capable of properly representing the real structure, requires a logical and disciplined approach to computer assisted engineering. The questions to be expressed and answered are:

- *Is the model satisfactory in its representation of structural behaviour?*
- *Is 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. Asymmetry in a tall structure may exacerbate non-linear effects under both vertical and horizontal loading. 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. The validation of software, and its proper use, is a matter that needs to be addressed both in practice and in education.

Report No 2: Near hit
There was a near collapse of a birdcage scaffold falsework structure during an 800 m^3 (1050 yd^3) concrete pour on a highway bridge. Adjustable diagonal braces were designed to be used throughout. The structural concrete checklist was signed off by members of the construction team and the design team. Shortly after the pour there was evidence of buckled vertical members in the falsework. Collapse was prevented by bowing distortion of the verticals providing some moment capacity at each joint between the standards and the ledgers, and the propping effect of an adjacent retailing wall. During investigations it was found that a copy of a specialist's drawing had been marked up in an uncontrolled manner to show bracing every fourth bay rather than on every bay. Recommendations made by the reporter's organization included: more vetting of sub-contractors, adequacy of management procedures, training on management procedures, recognition of the temporary works coordinator role.

<u>Comments from CROSS</u>
Lack of appreciation of basic stability is a vital issue and the competency of the individuals making the decisions on site is part of the problem. It can and does lead to fatalities. Routing the inspection back to the designer of the temporary works is important as it emphasises that these are designed systems; the cost of an inspection is trivial. The general management issues recommended above could be extended to training of the people installing the equipment – tool box talks on the consequences of omitting parts of the design. The person signing the installation checks should be carrying out regular checks whilst an important structure like this is installed. It is very difficult to check on completion and much more time consuming and expensive to correct. A tagging system should be used to ensure the installer is certifying their work for use. Record photos and even video clips can be used to help check the installation against the drawings. Whilst experienced old hands on site may know as much or more than the designer this cannot be relied upon.

<u>Report No 3</u>: <u>Post-fixed RC anchors - erroneous assumptions leading to unsafe design</u>
A consultant on a project reported that a number of steel to reinforced concrete moment resisting connections were required. The steel fabricator proposed forming these connections using post-fixed anchors and the design was undertaken by their engineer. During construction the reporter became concerned about one of the fabricator's designs and undertook a check. It was found that several of the proposed fixings did not have the minimum concrete edge distance required, and when these fixings were disregarded the manufacturer’s software calculated that the design had only a small fraction of the required capacity. Extensive strengthening works were required and had these issues not been identified there was very real danger that part of the structure would have collapsed. The reporter is concerned that engineers may be using post-fixed anchors without complying with the manufacturer's guidance or ensuring that their design assumptions are applicable.

<u>Comments from CROSS</u>
Fixing problems make up 10% of all reports to CROSS and many of these have related to post-drilled fixings. The Structural-Safety Alert “Tension systems and post-drilled fixings” published in March 2014[iv] *gives details of several cases of failure, together with advice on inspecting existing installations and installing new fixings. The importance of following manufacturer’s instructions is stressed. Many failure studies highlight that they result from errors in apparently small items or that what one party thought was being built was not actually so. A feature in some of the ceiling collapses previously reported to CROSS*[v] *was failure of the anchorages. A lesson might be that where these are key components, part of the QA procedure should be site testing to ensure their strength capacity. The selection and installation of top fixings for suspended ceilings published by the UK Association of Interior Specialists*[vi] *gives advice on all aspects including testing for smaller fixings.*

Each report describes a unique set of circumstances but trends appear when several have similarities and it is from these that the most effective feedback can be generated. Trends have included problems with; structural fixings, tension systems, anomalous documentation and imported products, building control, equipment failure, competency, items falling from buildings, contractors changing designs on site, collapses during construction of new buildings, collapses during alterations to existing buildings, issues with temporary works, and others. Lack of competency is believed to be a major reason for most of the safety-critical matters. Almost a half of all reported events, 44%, are related to construction and temporary works, with design accounting for 13%, and in service operations 34%, with a few other minor categories.

ACHIEVEMENTS

Every two years the work of the organization is reviewed and summarized and a recent survey of all reviews since 1977 identified issues where recommendations from SCOSS, and from CROSS since 2005, had made an impact. The collection of hard facts and evidence from confidential reports has helped when lobbying for change both in terms of guidance from professional institutions and from trade organisations. Examples are given below.

To satisfy Building Regulations in the UK a design must be submitted for approval although there is no requirement that this shall be done by a chartered (registered) engineer. SCOSS campaigned for some time that the regulations should be updated particularly in relation to disproportionate collapse. Partly because of this influence updates have been made over the years to including requirements on robustness and disproportionate collapse. CROSS reports have highlighted concerns to regulators about the quality of submitted calculations and this has been addressed.

Risk appreciation is a subject that most engineers deal with on an intuitive basis and inadequate assessments are sometimes made. This is another subject that has been of interest for years and to improve the quality of assessments CROSS comments on reports give practical advice on common issues found in design and on site. Guidance has also been published by the Institution of Structural Engineers[vii]. Concerns about the implementation of the Bragg Report[viii] on the design and construction of temporary works have resulted in the Temporary Works Forum[ix] being established recently in the UK. Currently there is a Structural-Safety project to find how risks associated with temporary works can be better evaluated.

Site safety has been a recurrent theme with the recognition that construction is one of the most dangerous work place activities. As previously mentioned almost half of all CROSS reports are about events on site and statistics from the UK's Health and Safety executive show how many accidents and incidents take place. However the numbers of deaths and serious injuries has been greatly reduced due to action by industry and regulators; helped by the work of Structural-Safety.

It is difficult to assess the contributions of any safety scheme but the influence of Structural-Safety has helped to change the safety culture in the UK construction industry and encouraged others to act. Guidance resulting from these recommendations has been issued by Institutions and trade organisations, and there have been amendments to regulations and government advice. Apart from formal changes the information published is well received by the industry. It is used as a teaching tool in some universities, as a learning tool for younger engineers, and as a reminder and resource by more experienced practitioners.

INTERNATIONAL

All too frequently a building or engineered structure collapses somewhere in the world. Every year many people are killed and many more injured. Examples include major building collapses in India, Africa, parts of Asia and in many other places. The deadly collapse in 2013 of the Rana Plaza building in Bangladesh, when 1,100 people were killed, had the largest death toll of any structural event which was not precipitated by external action such as an earthquake or a terrorist act. These disasters emphasize the need for care at all stages of the structural cycle everywhere in the world.

The human toll is shocking to those of us in countries where we have few major failures. It is however most important to be able to know what has gone wrong and in due course it is hoped that forensic explanations of major tragedies will become routinely available so that lessons can be learned by clients and engineers everywhere. Checks and balances exist in any regime where there are responsible designers and constructers working in accordance with sound regulations which are properly enforced. But there are always cases where something goes wrong and the difference between a near hit and a catastrophe can be wafer thin. In a learning culture such events are recorded, acknowledged, analyzed, and the findings disseminated to make a difference in future. Cognizance of pre-cursors in any environment is a proven way of helping to reduce the consequences of more extreme events.

Expressions of interest in the operations of CROSS have come from groups in several countries. To provide a common platform for sharing information the web site was therefore further developed to create a CROSS Hub with sectors for new groups. The intention is for each group to be autonomous in terms of its local organisation with their final reports on concerns available to all. Lessons to be learned will hence be shared. The Hub concept is at an early stage and it remains to be seen how effective it will be on the international scene.

SCOSS maintains a watch on events globally but remains the only body of its type anywhere. Governments and relevant organisations in other countries are encouraged to adopt similar processes so that greater structural safety in their countries can be developed.

CONCLUSIONS

- CROSS is a unique project for gathering information on structural safety.
- It has been successfully implemented alongside the pre-existing SCOSS programme.
- Publications stemming from Confidential Reports contribute to structural safety by raising awareness.
- Guidance in the UK has been influenced by the findings and recommendations.
- There are benefits for clients, engineers and the general public.

ACKNOWLEDGEMENTS
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REFERENCES

[i] Aviation Safety Reporting System , <http://asrs.arc.nasa.gov> (July 8, 2015)
[ii] "Structural-Safety", < http://www.structural-safety.org/> (July 8, 2015)
[iii] Soane, A. (February 2013). *"Learning from confidential reporting",* Forensic Engineering, Vol 167, FE1, London
[iv] "*Tension systems and post-drilled fixings*", <http://www.structural-safety.org/media/358371/sc-14-03-alert-on-tension-systems-and-construction-fixings-final-3-march-2014.pdf > (July 8, 2015)
[v] CROSS, (2006 - 2014),"Keyword; 'Ceiling'", <http://www.structural-safety.org/search-database/> (July 8, 2015)
[vi] Association of Interior Specialists. (2012) "ceilings". The UK Association of Interior Specialists.
[vii] "*Risk in structural engineering*". (2013). The Institution of Structural Engineers, London.
[viii] Health and Safety Executive. (1976). *Final Report of the Advisory Committee on Falsework [The Bragg Report]*. London: HMSO.
[ix]Temporary Works Forum, <http://www.twforum.org.uk/> (July 8, 2015)

Challenges with a Roof Collapse:

Causation, Subrogation, and Structural Rehabilitation

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Abstract

During the winter of 2011/2012, historic snowfalls occurred throughout several parts of Alaska. This paper deals with a building complex where a part of the roof structure catastrophically collapsed due to snow. The collapse caused not only considerable damage to the structure below, but created a series of questions regarding the causation of the collapse, the original design of the roof and the appropriate approach to rebuild the structure.

As a result of the roof collapse, there were some significant challenges regarding the appropriate path for rebuilding. What requirements and obligations were there regarding the adjacent roof and would that roof need to be brought up to current code? What other structural requirements would be needed regarding the rest of the building complex? How would the insurance company and the building owner come to an agreement as to the proper course of action? The solution included close interaction and meetings among the structural experts and the local building official to provide direction where the local building code was vague and ambiguous.

INRTODUCTION:

At 6:02PM on March 2, 2012, a partial collapse occurred within the main sanctuary of a church complex, fortunately while that portion of the church was unoccupied. The collapse caused the west perimeter wall to fall outward and caused the western portion of the collapsed roof to drop to the ground while the eastern portion of the roof remained attached to a steel girder truss *(see Figures 1 and 2)*.

Immediately after the collapse, emergency clean-up was performed including removal of the west wall for access and safety reasons, which prevented an investigation of the wall framing from being performed. Snow removal by shoveling of the roof was ongoing at the time of the collapse, but the snow on that section of the roof had not yet been removed. Other areas of the roof were not shoveled at the time of the initial investigation, allowing for weight measurements to be taken both in drifted and undrifted locations.

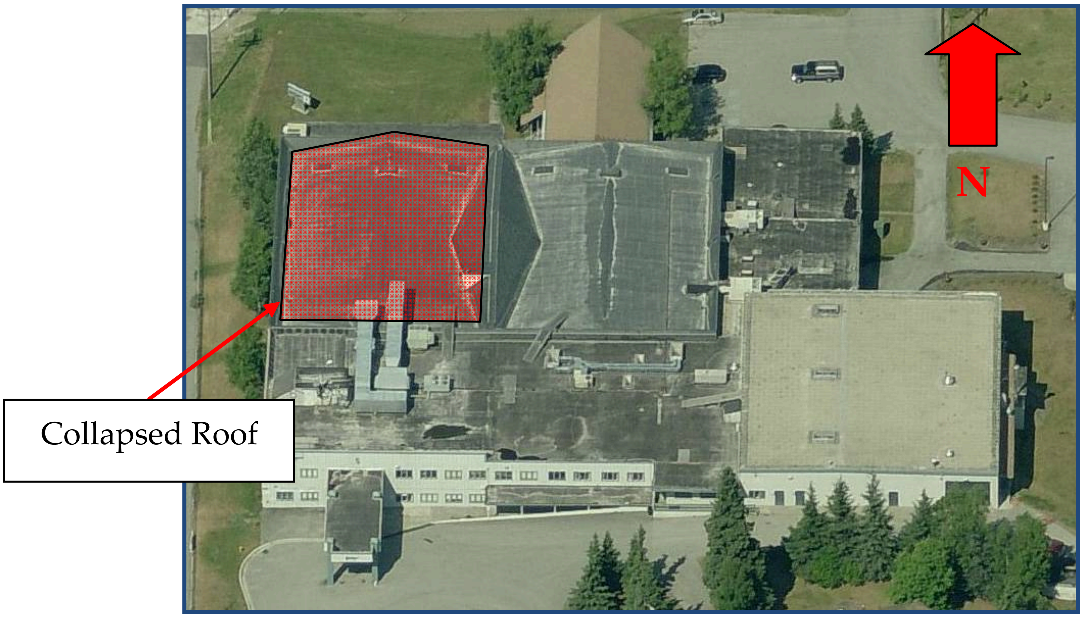

Figure 1- Aerial picture from Pictometry showing the complex prior to the collapse.

Figure 2- View looking north of the collapsed portion of the roof.

BUILDING DESCRIPTION:

The Church complex was comprised of several different structures built between 1959 and 1982. All of the buildings were tied to one another to make one large complex.

In the middle of the complex was a large sanctuary that is rectangular in plan measuring 160’ east/west by 110’ north/south. The sanctuary was built in two different phases, the east half was constructed in 1974 and the west half constructed in 1979. The western half is the portion of the roof that collapsed.

When the east half was originally constructed in 1974, the west end of that building consisted of a wood framed exterior bearing wall, which supported wood framed trusses spanning 80' east/west and spaced 4' on center.

As part of the remodel in 1979, the east roof was shored up and then the west bearing wall was removed and replaced with a large steel truss girder that spaned 110' north/south. The truss shape was a simple triangle with a horizontal bottom chord and a sloped gable top chord with a height in the center of 16'. The original existing east side trusses and the new west side trusses were supported on the top of the bottom chord channels of the steel truss girder. Since the top of the steel truss girder extended above the roof plane of the slope created by the east-west wood trusses, a wood framed shed roof was constructed on both sides of the truss to cover and protect the steel truss.

The west addition to the sanctuary was constructed similar to the east side. The original drawings showed the roof structure identical to the east side roof, consisting of 80' long top chord bearing trusses at 4' on center supported at the east end by the steel truss and at the west end by a 2x8 wood framed exterior wall founded on a CMU block foundation wall and strip concrete footings. At some stage during the design process, the truss design was changed from a system with steel web members pinned to the upper and lower chords (identified as TJH 36-84-36) to conventional metal press plate wood trusses with the same profile. The new design consisted of 2-ply trusses consisting of 2x6 top and bottom chords with a combination of 2x4 and 2x6 web members. The trusses were top chord bearing and measured 3' deep at the ends and 7' deep at the center ridge. Due to the size of the trusses, they were shipped in two pieces and bolted together in the field at mid-span. This consisted of a 2x plate on both sides of the top and bottom chord that was then bolted to the truss with ½" diameter bolts.

The roof structure at the west side of the sanctuary supported a roofing system consisting of a single ply membrane over two layers of ½" fiberboard over 6-1/2" of rigid insulation over ½" plywood. At the west exterior perimeter end of the roof, there was a parapet wall approximately 5'-6" tall that ran the entire length of the sanctuary. The wall was constructed on top of the roof trusses and was sloped on the backside at approximately a 45 degree angle. Drainage for the west side roof was provided by three 3" diameter interior drains located along the west perimeter wall that captured the western half of the roof drainage as well as a drain at the northeast and southeast corners of the west roof that captured the eastern half of the roof drainage. Along the west wall, the original drawings called for through-wall scuppers in addition to the roof drains, however the scuppers were never installed.

On the interior of the sanctuary, the ceiling was primarily comprised of a suspended acoustical ceiling with isolated areas of drywall above the stage at the north end of the room. Lighting and speakers were suspended from the ceiling in areas as well as a sprinkler system that was part of the original construction. Walls were typically finished with drywall and acoustical sound boards. The floor of the sanctuary was a sloped theater style slab on grade that extends down toward the stage to the north. Seats were bolted to the floor and the flooring consisted of carpet.