CROSS

Confidential Reporting on Structural Safety

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Reports in this Issue

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INTRODUCTION

Events in Japan and in New Zealand show the cataclysmic consequences of earthquakes on people, infrastructure, and structures. As the world becomes more crowded and complex more of its citizens will be at risk from the effects of extreme occurrences; some natural and some man made. A confidential reporting scheme such as CROSS is not going to be sent information about the aftermath of an earthquake, but the principle of searching for the precursors of larger failures must be relevant. There will be many lessons to be learned from the catastrophes of the last few months and if these can be analysed, stored, disseminated, and particularly if they can be used as reminders, then the severity of the effect of future events may be reduced.

In this Newsletter there are two significant reports about the design principles for very tall and unusual buildings and the comments from our panel of experts emphasise the need for proper analytical procedures and the importance of robustness. There are the reports about; falsified documentation, the failure of fixings used to connect a scaffold to a structure, a scaffold which did not meet design criteria, the question of errata in manuals, and once again the design of free standing masonry walls.

A SCOSS Alert - Snow loads on agricultural and other building structures (March 2011) has been issued following snowfalls in 2010, and in the early part of 2011, which caused a significant number of agricultural and associated buildings in Scotland, and a small number in the North of England, to partially fail or to collapse. The likely causes include 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. In some cases, snow depths of 50-60cm on roofs have been reported.

CROSS needs reports all the time so that lessons can be learned and if you can contribute please do so. Reports are edited to remove names and identifying details and are printed in normal text in the Newsletters. Comments from the panel of experts are printed in green italics. All reports together with comments are on the web site data base.

CONCERN ABOUT DESIGN PRINCIPLES FOR TALL BUILDINGS (Report 235)

A reporter raised questions about very tall and complex reinforced concrete structures that incorporate combined transfer systems some of which may be supported on corner columns. The reporter's question highlighted a common concern which is that in the case of accidental damage to, or removal of, any key structural element, such structures may not have adequate redundancy to redistribute the loads without collapse.

CROSS comments: *Very tall buildings require high standards of design and construction and the careful consideration of aspects which may not affect smaller structures. Architects are creating elaborate and complex building shapes to which engineers must match structures, some of which demand innovative solutions. There is a generation, worldwide, of striking buildings, sometimes described as 'innovative, complex and unusual' (ICU) buildings. Providing the processes are well thought out in terms of structural engineering, operation and maintenance, then all will be well.*

NEWS ITEMS

Ceiling collapse

Investigators have determined what caused a 4,000-pound ceiling to collapse in an accident at a university campus in the USA. Engineers concluded that ceiling suspension anchors were not sufficiently embedded in the concrete structure, and suspension wires were not uniformly tensioned. The flaws caused an unequal load in the ceiling, which led to progressive failure of the suspension system. No one was injured when the 500-square-foot ceiling, one of several steel-supported plaster-and-concrete structures covering open-air lobby areas at the building, crashed to the ground. The full report of the investigation into the cause of the collapse can be found at:
http://facilities.ucsb.edu/departments/dcs/default.asp

The collapsed ceiling

CROSS Comments: *CROSS Newsletters published a series of reports on ceiling failures including one very similar to this where a cascade failure had taken place initiated by pull out of a single ceiling anchor. As both reports highlight, ceilings are not necessarily flimsy items and proper precautions against all failures are required. Looking at the generic nature of the collapses it would suggest a) that all ceiling designs should include a check for a progressive collapse mode b) all design should account for potential uneven loading onto ties c) site installation should include QA/QC of the anchor fixings to assure that as- installed, capacity matches design assumptions. To access similar reports enter "ceiling" in the Quick Search box on the web site.*

Combined transfer structures may be taken to mean horizontal members whose supports then transmit loads onto other horizontal members whose ends, in turn, are eventually supported on corner (or other) columns. Such transfer beams need particular attention because of the difficulty in ensuring that they could span without one of their end supports. This was a significant reason for the extensive damage caused by the bomb attack on the Murrah building in Oklahoma as reported by FEMA (Federal Emergency Management Agency). A single member should not be carrying a disproportionate percentage of the structure.

In the UK buildings of this type would be Class 3 structures so a risk assessed approach would be taken. Part A of the Building Regulations for England says: "For Class 3 buildings – A systematic risk assessment of the building should be undertaken taking into account all the normal hazards that may reasonably be foreseen, together with any abnormal hazards. Critical situations for design should be selected that reflect the conditions that can reasonably be foreseen as possible during the life of the building." As a minimum Class 3 buildings should meet the principles of Class 2 buildings. Eurocode requirements are similar (see BS EN 1990 and BS EN 1991-1-7).

The three approaches commonly used to resist disproportionate collapse are: tie force design methods, alternative load paths, and key elements design.

Codes and guidance that advise on robustness draw attention to the special considerations that must be given to transfer structures.

The Institution of Structural Engineers report on robustness: "Practical guide to structural robustness and disproportionate collapse in buildings" published in October 2010 whilst 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." The subject is also being studied by NIST in the USA in the programme: Prevention of disproportionate collapse.

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. Within UK Safety legislation there are requirements for competency to be exercised by all concerned in a project but it is not thought that is often either appreciated or enforced. Going further should there be a new process for checking on the competency of organisations and individuals to be responsible for such designs?

CROSS would be interested in receiving other views on this important topic.

DESIGN OF TALL ASYMMETRIC STRUCTURES (Report 238)

A reporter has touched on the topic of analysis and design of the 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.

CROSS Comments: *The problems of validation of analysis models; that is the consideration of whether the model is capable of properly representing the real structure was the subject of the study 'The use of computers for engineering calculations' published by the Institution of Structural Engineers in a 2002 report prompted by a recommendation from the tenth biennial SCOSS report. The guidelines advocate a logical and disciplined approach to computer assisted engineering based around a process where each stage has built-in checks.*

NEWS ITEMS

Council responsible for death of child in wall collapse

A London council has been ordered to pay £137,000 after a wall it owned collapsed and killed a two year old child during a storm in 1997. The Council admitted two breaches of health and safety legislation. It was fined £72,000 and ordered to pay £65,000 prosecution costs. The council had claimed it was a sub-contractor's duty to maintain the wall but the court was told the wall was too thin for its height and was doomed to failure from the day that it was built in the mid-1970s because it did not conform to prevailing design standards for structural engineering safety.

CROSS comments: This report should remind owners of their responsibilities to assure proper designs and maintenance.

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 modeled 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 sidesway from non uniform vertical loading start to become important as do P-Δ effects. 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 e.g. 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 modeled 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 consensus 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. Codes that advise on robustness all draw attention to the special considerations that must be given to transfer structures. The Institution of Structural Engineers report on robustness: "Practical guide to structural robustness and disproportionate collapse in buildings" published in October 2010, whilst 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. As mentioned in the comments on report 235 should there 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.

CROSS would be interested in receiving other views on this important topic.

VERIFICATION OF INSPECTION DOCUMENTS (Report 226)

For steel products such as heavy plates, inspection documents/inspection certificates as per EN 10204 represent an important element for ensuring quality control along the different processing stages from the receipt of heavy plates until the finished product. A leading European supplier validates in these documents the delivery specification and the acceptance tests based on this specification, as well as the test results. In addition conformity to the agreed order specification is also validated. The supplier provides the original customer for their heavy plates with inspection certificates as original hardcopy documents or as electronic documents. The processing and distribution chain from the receipt of the heavy plates to the finished product is often complex. Therefore, in practice, it is not unusual that inspection certificates are transmitted to an original customer and then forwarded as copies along the distribution/processing chain.

Evidence has recently been received from some members in the chain of an increased number of “copies” of the supplier’s inspection certificates on which one or several items of data have been modified from the original state or falsified. As a consequence the supplier offers all users of their heavy plates a verification service. The enquirer will receive a confirmation as to whether or not the supplier originally issued the relevant inspection certificate in the form presented. The supplier explicitly points out that this verification does not represent any authenticity check of heavy plates on the part of the supplier. It is the responsibility of the customer (or user) to ensure that a certificate belongs to the corresponding heavy plate.

CROSS comments: *It is always disturbing to find uncertainty in the quality of building products. In the past, SCOSS has received information on defective bolts of dubious origin and CROSS has reported uncertainty in concrete block quality (report 174 in Newsletter 18). Users always need to take care that the products they rely on are authentic and ideally should conform to recognised product specification standards such as BS’s. See also report 230 below on defective anchor ties.*

DEFECTIVE IMPORTED SCAFFOLD TIES (Report 230)

On a contract where multi lift access scaffolds had been installed for a period of up to 18 months in an exposed coastal location, it was found by a reporter on one of the regular inspections that some of the scaffold ties had failed. The ties, including the anchor bolts had been installed in accordance with the scaffold design and load tested in accordance with TG4:04. The anchor bolts had been sourced from a reputable supplier. The failures were first identified when several heads of the screw anchors used for fixings into both concrete and brickwork were found broken off and lying on the scaffolding. Visual inspections over the following two weeks identified additional heads breaking away, with approximately 5% of over 440 fixings failing.

The anchors were of small diameter (6mm) case hardened boron steel with a zinc chromate coating. After testing was carried out the fixings were found to be made from substandard material. It was subsequently identified that they had been imported from the Far East, through a Mediterranean intermediary. Also, due to the diameter of the anchors, aggressive exposure conditions and the time that the scaffold had been erected there was little margin in the fixings to compensate for any deterioration of the fixings. Metallurgical testing indicated that the probable cause of failure was a combination of rolling and heat treatment (quenching) defects in conjunction with hydrogen from corrosion. The flexible nature of scaffold structures, with the slight movements resulting from wind and other loading appear to have caused the fixings to break. Additional stresses may have been incurred during installation.

When the failures were identified the scaffold was taken out of use and remedial works were carried out. These consisted of re-tying the scaffold using alternative tie arrangements or larger diameter anchors.

What should be reported?

- concerns which may require industry or regulatory action
- lessons learned which will help others
- near misses and near hits
- trends in failure

Benefits

- unique source of information
- better quality of design and construction
- possible reductions in deaths and injuries
- lower costs to the industry
- improved reliability

Supporters

- Association for Consultancy and Engineering
- Bridge Users Forum
- British Parking Association
- Communities and Local Government
- Construction Industry Council
- Department of the Environment
- Health & Safety Executive
- Highways Agency
- Institution of Civil Engineers
- Institution of Structural Engineers
- Local Authority Building Control
- Scottish Building Standards Agency
- UK Bridges Board

Learning Points, says the reporter are:

- Regular inspection of scaffolds is essential (especially for scaffolds that are to be erected for a long period of time). The failures were identified through the regular inspection regime.
- The incident defines that it essential that anchors are correctly load tested to achieve confidence at installation stage.
- Designers need to consider anchor installation methods, and whether that may affect the effectiveness of the design.
- Designers must consider the exposure of fixings and the potential reduction in performance over time.
- Designers need to ensure that they know and take into account the design life of the scaffold and exposure conditions.
- Selection of anchors may require the exercise of judgment as to the robustness of the fixings, for example to accept installation as well as service loads, as against the manufacturers' quoted performance.
- Designers should incorporate additional redundancy into fixings or tie arrangements for large scaffolds, those with long duration use or subject to high cyclical loadings.
- The source of the fixings (as far as possible) needs to be checked and the technical data noted on the boxes needs to be reviewed to ensure the anchors comply with the designer's recommendations.

Image of bracket showing where fixing head has broken

CROSS comments: *One of the key issues is the need for the designer to consider how fixings are to be installed and used, making sure that they are suitably robust to accommodate the environment, installation and imposed loads with a margin beyond the manufacturer's recommended loads given in their literature. These considerations should feature as part of the designer's hazard and risk management process. Whilst CROSS does not have access to the full reports this sounds as though the problem might be hydrogen embrittlement of higher strength steel. Such a degradation mechanism has been found in the past when galvanising high strength bars and CROSS is aware of failure of similar small diameter fixings in a roof deck diaphragm due to hydrogen embrittlement. In all metals strength is not the only acceptance criterion. The metal must retain toughness and not become brittle. Brittleness can be promoted by faulty quenching, leaving the steel too hard, and free hydrogen can promote cracking (as it does in welding certain steels). In a detail such as that shown, the use of a 6mm fixing is determined by the hole diameter and the size of the bracket. Recommendations from bracket suppliers should be consulted for fixing to the relevant substrate. If there are no recommendations then the bracket design may not be suitable.*

DEFICIENCIES ON ACCESS SCAFFOLD (Report 219)

Investigation by a reporter's firm into an access scaffold on a refurbishment contract on a city centre site brought to light a number of deficiencies which rendered the scaffold outwith its design parameters. The system was further compromised in that the basic components were a system scaffold, but the various add-ons made it a designed scaffold requiring more careful input and proper calculations prepared by and approved by competent personnel. Such records were lacking. Many scaffolds are designed such that only a certain number of levels may be loaded at any one time. The original brief must be clear on this. This particular scaffold had a number of lifts which could be, and were being, loaded concurrently. There were no barriers in use to prevent this. The hoist had defined anchorage loads which needed to be taken to a sound anchorage. This was not the case with the ties stopping in the middle of the scaffold with no enhanced bracing to dissipate the loads. There was a staggered base level necessitating three legs to extend below the general level. Two of those legs were consequently braced in one plane only giving rise to the possibility of lateral failure. The existing façade was an ashlar stone fixed to a sub frame. To prevent damage to the stone tie centres had been extended beyond that necessary to restrain the scaffold. In conclusion, says the reporter, it is apparent that the following should have taken place and been recorded. This in essence would follow the requirements for a temporary works coordinator.

- A clear brief defining the particular use and all loads required to be resisted should be prepared.
- A competent designer should be appointed to design and detail a scheme which should be checked before being passed to the user. The drawing should note loading requirements and any special points.
- Many sites will require a visit by the designer to confirm that his assumptions are correct and workable.
- The user should confirm that the points in his brief have been fully addressed.
- The drawings and calculations should be readily available on site.
- The scaffolder (suitably qualified for the type of scaffold) should erect to the drawing and sign off as complete and safe to use. Note: The handover certificate should clearly reference the design drawing and where applicable pull out/ proof tests of any ties should be attached.
- Any modifications should be confirmed in writing and drawing form by the designer.
- The scaffolder should put these into place and sign off and re issue an updated handover certificate
- As a minimum, weekly checks should be made in conjunction with the design drawing requirements and signed off by a person competent in the type of scaffold.

CROSS comments: *Scaffolds are often critical structures in their own right which need careful design to established standards (e.g. TG20.08 and Eurocodes). These standards should relate to the whole life of the structure as alluded to in the report. Collapses such as that in Milton Keynes in 2006 give emphasis to this essential care and attention. Historically there may have been many scaffolding failures due to lack of restraint from the main building. Casual observation on any site will also reveal that loading due to stacked materials can be significant and highly variable. This report reinforces the view that competent robust design is required just as much for temporary works as it is for main structures. Moreover, a sensible safety precaution might be for temporary works designers to visit sites and vet that their designs have been built in accordance with design assumptions unless this task is covered by the Temporary Works Co-ordinator. In addition the duty of care on a professional engineer for the main works would oblige him to make comment to the contractor should inadequate use or design of temporary works be suspected.*

CHECK FOR ERRATA WHEN USING MANUALS (Report 211)

A reporter from an international firm of consulting engineers noticed an alert on a global internal knowledge networks about an errata in an AISC manual.

Users of the 13th edition AISC Steel Construction Manual should check errata posted online (see link below) when using formulas and properties from this manual. AISC Technical Publications Revision and Errata Lists link at: http://www.aisc.org/content.aspx?id=2896

One of their staff discovered this while checking the design of a built up railing on a pedestrian bridge. The section modulus for an L4x4 angle changed by more than 75% from the value shown in the 1st, 2nd and 3rd printing of the manual.

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FEEDBACK

With the 'Feedback' facility you can send comments on any aspect of CROSS or of the site or on anything to do with structural safety, and also read the input from others. More feedback is wanted.

REPORTING

Use either the 'How to report' button on the top of the website www.cross-structural-safety.org or the similarly labelled button on the right hand side to send on-line or off-line reports. It is simple, confidential, and could be important. Click here to go directly to the reporting page

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It highlights reliance placed on published material and the need for vigilance in ensuring that we retain a 'feel' for correct design. The reporter thinks that in the UK the BSI are prompt to issue errata if critical design data is found to be incorrect, however there might be less attention paid to information from bespoke specialist companies e.g. fixings. The alert also highlights the increasing use of this media (internal networks) to share and transmit knowledge of issues/problems internationally.

CROSS comments: *Errata can occur across the whole spectrum of technical publications and in most cases it is very difficult, if not impossible, for users to check whether errata have been reported or published. Now that many national standards are produced at European level in CEN, the time between an error being reported and corrections being published takes much longer, more than a year in some cases. When standards were produced locally, corrigenda or amendments could be quickly agreed, published and notified by BSI. Now as the first generation Eurocodes are being adopted, designers should certainly pay attention to the possibility that corrigenda have been published or that errors have been notified. A web search (e.g. for "errors in Eurocode 2") can be productive. Eurocodes Expert and other materials sector web sites also aim to notify errors in published standards and users of such standards should be aware of these information sources.*

This is a difficult problem which raises issues similar to those in reports about dubious material certification (CROSS report 230). We are all reliant on the accuracy of published design information but it would be impossible to guarantee no risk of error. A safeguard is to always ensure approximate checks parallel to the 'proper' design to reduce the risk of gross error.

BUILDING CONTROL AND THE DESIGN OF A FREESTANDING WALL (Report 163)

A client wanted a garden wall 2m high, and a reporter referred to the OPDM leaflet (see below) which states that for the region in question the height of a freestanding wall should be brick 328 mm thick to resist wind loads. The reporter therefore recommended that a 328 brick wall should be built, but the client appointed another engineer who obtained approval for a wall of 140 block + 103 brick (i.e. 243 thick). The reporter advised Building Control in the City of the situation, and asked them to produce calculations to justify the design which they declined to do. The reporter believes that Building Control engineers have an obligation to comply with guidance, both on the grounds of individual integrity and public protection.

CROSS Comments: *CROSS has reported numerous cases of collapsed walls including cases where they have caused death. The cumulative evidence is that many walls are not designed to proper standards but there is no requirement for these types of boundary walls to be compliant with building regulations if they do not form part of a building. Nevertheless there is good guidance available to meet a duty of care for example in the DCLG advice mentioned by the reporter. See:*
www.rbwm.gov.uk/public/050728_odpm_breg_garden_walls_274.pdf
The consequences of failure from a free standing wall are shown in the News report on page 3 of this issue about a council being found responsible after a wall that it owned collapsed and killed a child.

DATES FOR THE PUBLICATION OF CROSS NEWSLETTERS

Issue No 23	**July 2011**
Issue No 24	**October 2011**