Structural-Safety
Incorporating SCOSS and CROSS
Alert

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SCOSS ALERT
Tension systems and post-drilled resin fixings

BACKGROUND

There have been collapses of tension structures in buildings and tunnels in recent years. Some have resulted in fatalities and numerous injuries. Reasons for the failures vary but the message is that these are safety critical systems that have to be treated with respect.

WHO SHOULD READ THIS ALERT?

This Alert is from SCOSS, the Standing Committee on Structural Safety, which is the independent body established in 1976 to maintain a continuing review of building and civil engineering matters affecting the safety of structures. SCOSS aims to identify in advance those trends and developments which might contribute to an increasing risk to structural safety. It is aimed at those who design, construct, inspect or maintain structures that have elements or components relying on tension to hold them in place. Owners, contractors, engineers, surveyors, local authority building control officers, insurers and others whose work brings them into contact with safety critical structures should pay attention to tensile fixings. Safety critical structures are those where failure would cause risk of human injury or death.

SCOSS has previously issued Alerts on failures of tension structures and of fixings[1], [2], [3].

FAILURES OF TENSION SYSTEMS

Lining failures occurred in the Boston (Big Dig) tunnel in 2006 and more recently in Japan's Sasago tunnel (2012). Both failures had similarities in that large concrete sections supported by bolts from the roof fell onto cars causing death. In the Boston incident, the falling unit measured 6m x 12m and weighed 2.75 tonnes. Some bolts were poorly installed and the surrounding epoxy was unsuitable for sustained loading, see the report; *Ceiling Collapse in the Interstate 90 Connector Tunnel*[4]. The Sasago lining failure has been reported by MLIT, the responsible Japanese Ministry; *Tunnel Ceiling Panel Collapse*[5], with the prime cause linked to the performance of tension bolts embedded in resin. As at Boston, some bolts were found to be too short and there was reported degradation of the resin capacity over time. There was also weakening under repeated horizontal loadings which were not appreciated in the original design, and there was a lack of inspection to detect the onset of trouble.

A recent report on an overhead liner failure at Balcome rail tunnel in the UK[6] identifies the cause as failure of resin anchored fixings. Again the resin appears to have degraded over time; there was insufficient resin around some fixings on installation, and a later failure to investigate the discovery and significance of loose and missing fixings. CROSS (Confidential Reporting on Structural Safety) Newsletters have also published reports of a number of heavy ceiling failures in cinemas and other venues which could have caused tragedy. Another group has occurred in swimming pools due to stress corrosion of stainless steel hangers[7] - see Table 1.

Table 1

	Failure	**Year**
1	Ceiling failures - CROSS reports	100, 101, 102, 103, 124, 130, 140, 148, 149, 203, 304 [To find these enter "ceiling" into quick search keyword box on www.structural-safety.org]
2	Switzerland indoor pool	1985
3	Netherlands swimming pool ceiling and suspended fitting	2001 and 2011
4	Finland hotel swimming pool	2003
5	Swiss swimming pool, Uster	2012

Frequently it is the coming together of more than one element of bad practice that either causes a failure or turns a simple failure into a significant event. For example a suspended ceiling fixing may fail due to poor selection or poor installation, and if the ceiling has sufficient redundancy a single failure may go unnoticed, but if the ceiling structure has insufficient redundancy (as many do) the failure of one fixing leads to the progressive collapse of the whole.

All these hanger failure incidents were serious and the ones in Boston, Sasago and Balcome have raised concerns about the reliability of older post-drilled resin fixings. There have also been cases where reinforcing bars have been inadequately anchored into concrete with resins and have pulled out causing collapse. Beyond that, it is considered that there should be concerns over hanging systems as a generic group. Over the years a number of such failures have occurred. Some better known examples are given in Table 2.

Table 2

	Failure	Year
1	Sea Gem	1965
2	Silver Bridge, USA	1967
3	Hyatt Regency Walkway	1981
4	Mianus River Bridge, USA	1983

- they were catastrophic
- they were sudden
- some showed progressive collapses

Fig 1 Heavy ceiling

Grids or service ducts can mean that the structures are indeterminate and may contain stiff load paths not considered in simple designs. This affects the way their load is applied to a grid of hangers and just how much load will be on any one hanger is imprecise. The Sea Gem failure was of a rigid unit supported at 4 corners, so the actual corner load was indeterminate. In any grid of hangers or multiple units, the probability is that some fixings will be carrying a load higher than the nominal one presumed in design, and this may be exacerbated by long term creep effects. Some of the bridge failures were precipitated by single support failure due to fatigue, the relevance being that fatigue life is a function of actual load not nominal load. If a hanger is subject to fatigue, and is carrying a heavier load that the nominal design value, then its life can be drastically shortened.

The safety of any hanging or tension system may depend on the capability of the hanger to exhibit ductility to share uncertain loading. In practice, unless the fixing is stronger than the hanger, it means that the fixing itself must exhibit ductility or plasticity. The capability of many fixings to cope with potentially severe overload in a controlled manner to allow for redistribution may be unknown. For safety, fixings ought therefore to have a substantial load factor and hangers would need to behave plastically under overload to permit redistribution.

If such capability is absent, and a single connection fails, the immediate consequence is extra loading on neighbouring fixings. Since failure may be sudden, such excess loading might also be dynamically enhanced. This can lead to a cascade type failure of the sort reported to CROSS. Moreover in any tension system failure, the supported structure falls towards ground level so is potentially catastrophic (in contrast, if the failure were in compression, there is at least some opportunity to observe and intervene to control buckling and excessive displacement). The accident report from the Balcome tunnel identifies that total failure was avoided because: *the configuration of the support system and liner could accommodate the accidental loss of several wall fixings without immediate catastrophic collapse*. Noting the form of failure and consequences identified in all of these incidents it is prudent for designers to assess tension system performance on the presumption that any single support might fail. Designers also need to be alert to the commonality of failure pattern between post-drilled resin anchored fixings. The Sasago report suggests that: *the use of adhesive bolts which are subject to constant pulling force should be avoided until a certain degree of knowledge is built up regarding long-term durability.* European Technical Approval Guidelines for bonded anchors take into account sustained loading tests.

CHECKING EXISTING FIXINGS

There are many structures incorporating tension systems in safety critical situations. Some may not have been inspected for years and there could have been deterioration which has not been seen. Some of these older fixings may be at risk of failure, and it is not safe to assume that simply having had a long service means the fixings are secure. Many of the reported failures occurred years after installation. In situations where the failure of a single anchor, or group of anchors, could lead to unsustainable load transfers to other anchors then progressive collapse could occur.

It is recommended that where there are hanging structures supported by anchors that have been in place for some time then they should be inspected by a competent person. Conditions requiring further consideration include:

- deterioration of the fixing/anchorage (including creep)
- tightness of bolts
- evidence of unexpected loading or vibration
- water or excessive damp
- corrosion, including the possibility of stress corrosion on stainless steel
- looseness (including retention nuts)
- sub-strate cracking
- debris adjacent to anchor
- records, if any, of installation procedures.

Should the results of an inspection give rise to safety concerns, especially where load redistribution possibilities are absent, then steps should be taken to get specialist advice on testing, repair, strengthening, or replacement. In the case of the Sasago Tunnel the recommendations from the Japanese Ministry include installing secondary fixings for certain heavy suspended components. On fairground rides in the UK it is of interest to note that the designers presume anything can work loose through vibration so secondary retention devices are standard.

SELECTION AND INSTALLATION OF ANCHORS

Resin bonded anchors

It has been recognised that resin bonded anchors are prone to poor installation practices and these have contributed to a significant number of failures, although not a high percentage in relation to the number of anchors used. Most problems have arisen from:

- holes not being drilled to the correct diameter and depth or not using the correct equipment
- holes not being adequately cleaned
- resin used outside its recommended installation temperature range
- injection resin not being pumped to waste to ensure even mixing before insertion
- insufficient resin injected into the hole
- air being inadvertently entrained in the injected resin
- anchor rods not properly inserted into capsule systems
- incorrect accessories used (e.g. for hollow or perforated masonry)
- anchor rods cut short when rebar is struck
- anchors loaded, tightened or tested before the manufacturer’s curing time has elapsed
- anchors over-tightened.

The use of injected resin for overhead applications, while possible, is particularly awkward. All of these issues can be avoided by ensuring that installers are trained, competent, provided with the correct equipment and supervised during the installation process. The specification of a proof testing regime can be a useful mechanism for checking that the resulting installations have been carried out correctly, especially if the installer is informed before carrying out the installation that a sample of all anchors will be tested at random.

Resin formulations

There is a wide variety of formulations which can have significantly different characteristics not only in terms of strength but also temperature limits for both installation and service and curing times. Variation occurs even within particular families of resin types. Specifiers are advised to check the suitability of a particular resin and its installation and service parameters and only to allow changes to the specification after all performance and other parameters of the proposed alternative have been thoroughly checked.

Resin anchors and long term use

Some resin formulations are known to suffer from creep and are therefore unsuitable for long term use. All resin anchor systems that have been awarded a European Technical Approval (ETA) will have been subjected to a sustained load test, along with many other tests, in order to validate their suitability for long term (50 year) loading. The ETA will specify compliance limits for their use including the base material, installation in flooded holes and service use in wet substrates. Temperature limits will be defined for installation and for both short term and long term service conditions.

BS 8539:2012 *Code of practice for the selection and installation of post-installed anchors in concrete and masonry*[8]

In 2012 this new British Standard was published to address the causes of identified failures and includes many of the recommendations made in the original SCOSS Alert. It sets out the roles and responsibilities of all stakeholders involved in the use of fixings from manufacturers and specifiers through distributors and contractors to installers and testers throughout the life of an anchor from before the selection stage through to commissioning. SCOSS views the implementation of this code of practice as fundamental to reducing, and potentially eliminating, fixing failures.

The code contains several key provisions:

- one person should be identified as having overall responsibility for fixings throughout a project including the temporary works phase
- wherever an anchor with an ETA is available then such an anchor should be used
- anchor specifications should not be changed without due process
- ALL stakeholders need to be competent
- preliminary tests need to be carried out on site when there is no performance data available from the manufacturer e.g. for masonry
- proof tests should be carried out on a sample of all jobs unless anchors with ETA have been used and installed by trained operators working under supervision
- completed installations should be certified by the contractor.

Sections of the code deal with roles and responsibilities; information provision; anchor selection; anchor installation; supervision; testing objectives and change management. Annexes handle design methods; testing regimes; anchor types; selection processes for anchors with and without ETA; static and non-static actions; and corrosion.

The standard generally deals with projects where the use of fixings is planned from the outset. Equally important are those instances where fixings are used in small numbers to address an unexpected problem, but may be just as safety critical.

Work is underway (2014) on Eurocode DD CEN/TS 1992-4-1:2009 Design of fastenings for use in concrete. The American Concrete Design Manual – ACI SP-17(11) Volume 2 Anchoring to concrete gives many worked examples including some for seismic design where ductility is required. In order to help understand its recommendations, the Construction Fixings Association has a range of guidance in the “8539 Toolkit” [9]. A *Code of Practice for the Design and Installation of Anchors*[10], has been published by The Health and Safety Authority in Ireland. There are examples of safety critical applications and guidance on all aspects of chemical fixings.

ACKNOWLEDGEMENT

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REFERENCES

1. Temporary event structures: ‘saddle span’ type roofs: SCOSS Alert 2010
2. Risk issues associated with large TV/video screens at public events: SCOSS Topic paper 2008
3. The selection and installation of construction fixings*:* SCOSS Alert September 2010
4. Ceiling Collapse in the Interstate 90 Connector Tunnel Boston, Massachusetts: National Transportation Safety Board, Washington, 2006.
5. Outline of the Report on the Tunnel Ceiling Panel Collapse by the Investigation and Examination Committee: MLIT, Japan, 2013.
6. Partial failure of a structure inside Balcombe Tunnel, Rail Accident Investigation Branch, London, 2014.
7. Stainless steel: the risk of failure due to stress corrosion cracking in swimming pools SCOSS Alert October 2005
8. BS 8539:2012 *Code of practice for the selection and installation of post-installed anchors in concrete and masonry: British Standards, London, 2012*
9. 8539 Toolkit, Construction Fixings Association, London
10. Code of Practice for the Design and Installation of Anchors, The Health and Safety Authority, Ireland

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