Temporary Works Toolkit

Part 5: Temporary works failures – what are the common causes?

The Temporary Works Toolkit is a series of articles aimed primarily at assisting the permanent works designer with temporary works issues. Buildability – sometimes referred to now as 'construction method engineering' – is not a new concept and one always recognised as vital to the realisation of one's ideas; it ought to be at the forefront of an engineer's mind.

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Promoting best practice in the construction industry.

In the first of two articles examining temporary works failures, Director of Structural-Safety, Alastair Soane, describes common reasons for their occurrence, illustrating the risks with a number of examples.

Introduction

The Structural-Safety organisation seeks to encourage learning from the experiences of others, particularly when then there has been a near failure, or near hit. Nowhere is this more important than when dealing with temporary works, which, by their nature, are often prototypes demanding high levels of skill and imagination, as well as scrupulous care in design and implementation. Failure can have many forms, but a useful definition has been given by Ratay[1]:

'Nonconformity with design expectations' or *'unacceptable difference between intended and actual performance.'*

Forms of failure include:

- total failure (complete collapse)
- partial collapse
- extensive failure (but no collapse)
- local failure
- signs of distress
- excessive deformations
- excessive differential settlement
- advanced (unchecked) deterioration
- unreasonable maintenance needs
- unacceptable aesthetic appearance.

The last three forms will not often apply to temporary works, but all of the rest are relevant. Otherwise, there are no differences in principle between failures of temporary works and permanent works. If there are signs of distress or other long-term indications of impending failure, then partial or total collapse may be prevented by remedial measures. The most dangerous failures are usually those which occur suddenly and without warning, thus leaving no scope for additional strengthening or stabilising works.

The reasons for failure can generically be attributed to the three Ps – **people, process** or **product** – although, ultimately, most are related to people – the human factor. Causes usually include one or more of:

- incompetence
- negligence
- oversight/carelessness
- greed
- disorganisation
- poor communication
- misuse
- neglect.

Incompetence is a widely used term for which there are many definitions, but generally it refers to the lack of ability to do something successfully or as it should be done. In a construction context this might refer to a person, or a group, or an organisation which will not perform in the way expected in terms of relevant skills and experience. The CROSS database[2] has reports about the concerns of engineers, and events which have occurred during construction on site make up about half of the total number. A considerable proportion of these refer to a lack of supervision as a prime cause and this often indicates incompetence, or negligence, or carelessness. This may be inadvertent and simply due to deficiencies in experience or the ability to spot potential problems, or it may be a more deep-seated failure to recognise risk.

Greed is rarely cited as a cause of failure, but it does occur when shortcuts may have been taken to maximise profit or enhance commercial value without thought to the consequences. There is a critical difference between striving for profit while using sound engineering principles, and reckless behaviour which does not address the laws of physics.

Disorganisation and poor communication, on the other hand, are frequent sources of failures large and small on sites whether the work is permanent or temporary. The final two causes, misuse and neglect, can apply to the selection of inappropriate equipment or components and the deterioration in performance due to repeated use and a lack of inspection and maintenance.

In many cases, of course, there are multiple factors involved when a collapse has taken place and an aggregation of causes has critically affected strength or stability.

Two other reasons for collapses may be given as 'bad luck' and 'act of God'. The first of these is not an acceptable explanation in a scientific environment, where good luck is generally acknowledged to be a result of careful planning and execution, and bad luck is a result of poor planning and execution. An act of God is sometimes said to be an event that cannot be prevented by ordinary human foresight and is normally a natural phenomenon, such as a flood or earthquake. The term is used by insurance companies to indicate that they are not liable for the consequences of such events. In the engineering world, however, the effects of floods and earthquakes, while not generally predictable, can be mitigated by appropriate design and construction.

Failure cases

Many examples can be found of failures related to temporary works and several are given here.

Fanum House scaffold collapse (UK)
Thirty tonnes of scaffolding fell from a 12-storey office building in Cardiff city centre, Wales, in 2000 while winds were gusting at 39m/sec (87mph)[3] (Figure 1). A catastrophe was avoided only because the street was deserted as it was after midnight. At a subsequent court hearing, it was said that the scaffolding should have withstood the storm, but 70% of the ties to hold it in place had never been installed. The remaining ties came away from the building because they were not fixed sufficiently well to the structure. It was also said that this was 'an accident waiting to happen' because it was built by untrained workers using the wrong equipment.

Hybrid concrete construction (UK)
A CROSS reporter was recently investigating a near miss involving concrete construction in which precast and *in situ* concrete were used in combination near the top of a shaft[4]. Such construction offers efficiencies and, as in this instance, can reduce the number of man-hours worked at height. It is growing in popularity but brings its own risks, and these need to be understood. The works under investigation comprised a circular shaft and the upstand part of an L-shaped precast beam acted as a 'shutter'. It had been assumed that the weight of the unit was sufficient to ensure enough friction at the ends of the unit. This proved not to be the case and the edge-most unit slid towards the corbel's edge, but did not quite fall off into the 20m deep shaft.

Bridge shuttering support near miss (UK)
Another CROSS report describes an $800m^3$ concrete pour for a bridge deck where there was a near collapse of the falsework

Figure 1
Fanum House scaffold collapse

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structure[5]. Collapse was prevented by bowing distortion of the standards which caused the proprietary ledgers to become wedged; fortunately, the decking was locked between reinforced-concrete walls, thus preventing sway at the top of the falsework. It is likely that further distortion would have resulted in local collapse, which could have precipitated a progressive collapse.

The structural concrete checklist was signed off by members of the construction joint venture and the design joint venture, but apparently without full knowledge of the circumstances on site. A hazard occurs in situations where individuals or groups either consider themselves, or are considered by others, to be competent in specific areas of knowledge, but are actually unaware of their lack of competence – and this is what happened. The incident could have resulted in fatalities, extremely high costs and damage to the reputation of all companies concerned.

Cline Avenue ramp collapse (USA)
In 1982, 14 workers were killed and 18 injured when falsework beneath a ramp failed during a concrete pour[6]. Unit 4, one of the bridge sections, collapsed, destroying the scaffold stairway and stranding workers on the remaining sections above. Workers on Unit 4 were then crushed to death when the section flipped and landed upside-down. Surviving construction workers brought in a cherry picker to rescue the remaining workers stranded on the ramp but, five minutes after the initial collapse, Unit 5, the neighbouring section, also collapsed. The most likely cause of the collapse was 'the cracking of a concrete pad supporting a leg of the shoring towers'. Investigators could not locate any engineering calculations supporting the pads as designed; worse, the pads were built substandard to the undocumented design.

Denver I-70 overpass girder collapse (USA)
In 2004, a sport utility vehicle (SUV) was hit by a falling fabricated steel girder line composed of two joined sections, which had been erected during the previous night[7]. The three occupants were killed. It was subsequently determined that the erection of the girder and installation of the temporary bracing were inadequate. Had the girder been installed in plumb or had the bracing been bolted effectively, the bracing might not have failed and the girder might not have lost stability. But in combination, the out-of-plumb girder and improperly installed bolts resulted in an insecure bracing arrangement that was not adequate in the short or long term. Moreover, it was concluded, the planning for the bracing lacked forethought and precaution.

B-tower building collapse (Netherlands)
In 2010, the 70m high B-tower building was being erected in Rotterdam city centre[8]. The floors of the first five storeys were made as reinforced wide-slab floors. Scaffolding was used for the temporary support of the precast planks during casting of the concrete. During casting of the floor, the temporary structure collapsed, resulting in injuries to five construction workers. Investigation by the Dutch Safety Board revealed that a large number of stability braces was omitted in one direction, resulting in instability and collapse of the temporary structure. This omission had been noticed, but because of a lack of clarity in responsibilities, no follow-up was given to this warning.

Queen Juliana Bridge crane collapse (Netherlands)
A new section of a bridge in Alphen aan den Rijn was due to be lifted into position in 2015[9]. Two mobile cranes were positioned on barges and the intention was to simultaneously lift the bridge section from another barge in a tandem lift. While the bridge section was being manoeuvred between the two cranes, the barges capsized, and the cranes and the bridge section fell onto adjacent buildings (Figure 2). A number of these were destroyed, but miraculously there were no injuries or fatalities. It was established during the

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Figure 2
Queen Juliana Bridge crane collapse

investigation that there were shortcomings in the preparation for the lift by both the crane operator and the barge operator. The barge carrying one of the cranes was insufficiently stable and movement of the load during the lift caused the crane to topple and bring everything else down with it.

Nicoll Highway collapse (Singapore)
Inadequate temporary works and design and construction errors led to the fatal collapse of Singapore's deepest ever cut-and-cover tunnel in April 2004[10]. The collapse of a deep excavation was on a section of tunnel being constructed for the city underground railway's new Circle Line, adjacent to the six-lane Nicoll Highway. Four workers died when steel struts supporting the excavation's diaphragm walls failed, causing the excavation to cave in. The official report into the disaster concluded that critical design and construction errors led to the failure of the strut-and-beam earth retaining wall system. These errors were:

- use of an inappropriate soil simulation model which overestimated the soil strength at the site and underestimated the forces on the retaining walls in the excavation
- an error in the design of the strut-waler support system, with the connections being under designed
- omission during construction of props which would have spread load from struts to walers.

The report stated that the net effect of these errors resulted in the strut-waler system being about 50% weaker than it should have been.

Conclusions
In almost all of these cases, there was a lack of lateral stability either because bracing was missing or bracing was inadequate. Indeed, it is thought that insufficient bracing is one of the most common causes of failures during construction. During construction, the load on an incomplete structure varies and temporary structures may become unstable. While these lateral loads should be supported by bracing, great changes in load may result in failures.

Reasons for failure will be discussed in more detail in a further article in February.

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REFERENCES
►1) Ratay R.T. (2007) 'Professional practice of forensic structural engineering: What every engineer should know', *Structure*, July, pp. 50–53

►2) Structural-Safety (2016) *CROSS database* [Online] Available at: www.structural-safety.org/search-database/ (Accessed: December 2016)

►3) Andrea Robbins (s.d.) *AA Fanum House, Cardiff: Scaffold collapse, 13 December 2000* [Online] Available at: http://bit.ly/2fTm3UR (Accessed: December 2016)

►4) Structural-Safety (2016) *Report ID 529: Risks from off-site manufacture and hybrid construction* [Online] Available at: www.structural-safety.org/publications/view-report/?report=7170 (Accessed: December 2016)

►5) Structural-Safety (s.d.) *Report ID 333: Falsework support to a bridge – a near miss* [Online] Available at: www.structural-safety.org/publications/view-report/?report=1444 (Accessed: December 2016)

►6) Wikipedia (2016) *Indiana State Road 912* [Online] Available at: https://en.wikipedia.org/wiki/Indiana_State_Road_912#cite_note-trib_20070401-5 (Accessed: December 2016)

►7) National Transportation Safety Board (2006) *Highway Accident Brief HAB-06/01* [Online] Available at: www.ntsb.gov/investigations/AccidentReports/Reports/HAB0601.pdf (Accessed: December 2016)

►8) Terwel K., Mud M. and Frijters A. (s.d.) *Structural safety during construction* [Online] Available at: www.iabse.org/Images/Docs/PDF/WG8%20Forensics/Terwel%20Mud%202014.pdf (Accessed: December 2016)

►9) Dutch Safety Board (2016) *Lifting accident Alphen aan den Rijn* [Online] Available at: www.onderzoeksraad.nl/en/onderzoek/2143/lifting-accident-alphen-aan-den-rijn (Accessed: December 2016)

►10) Hansford M. (2012) *No.11 Nicoll Highway collapse* [Online] Available at: www.newcivilengineer.com/latest/no11-nicoll-highway-collapse/8629881.article (Accessed: December 2016)