

SCOSS ALERT

February 2017

Structural stability/integrity of steel frame buildings in their temporary and permanent condition

BACKGROUND

There are occasional collapses of steel frame structures during construction and this Alert is to draw attention to matters which need to be borne in mind by designers, fabricators, and contractors. CROSS has had a number of reports about concerns which could have led to failure and actual failures and comments on these have been published in the Structural-Safety data base ^[1]. An example is a significant failure which took place on 31 January 2012 when the City Gates Church building frame collapsed catastrophically. Figure 1 shows the frame before the collapse and Figure 2 shows the aftermath.



Figure 1: Fifteen days before collapse
Courtesy of the Ilford Recorder



Figure 2: Collapsed structure
Courtesy of the Ilford Recorder

Fortunately, there were no casualties as the site had been closed for the night but clearly there could have been severe consequences. Lessons learned from this and similar events can be applied to help improve the stability of steel frames in their construction phase.

WHO SHOULD READ THIS ALERT?

This Alert is aimed at designers, steelwork fabricators, main contractors, building control officers and approved inspectors. It applies to permanent and temporary buildings particularly those with unusual features (such as elements supported by hangers), where partial, or local failure could lead to more widespread catastrophic collapse.

COLLAPSE OF CITY GATES CHURCH

Some of the Information in this Alert was obtained from HSE through a Freedom of Information Request.

HSE Investigations focused on the main roof truss, which is shown in Figure 3, and consisted of 5 bays with a total span of some 36m and a depth of 3.5m. Sections of the truss were shop welded and these were assembled by site welding. This truss supported the roof and was connected to the fourth floor. The third floor was suspended by square hollow section (SHS) hangers from the underside of the truss. A second floor balcony was suspended from the third floor by high tensile steel rod hangers. From the debris analysis, failures were reported as having been identified in welded truss joints and at hanger connections. An example is shown in Figure 4 where the welds between a hanger and its pedestal connection to the underside of the truss have failed. Gusset plates welded to SHS hangers failed

through the bolt holes which had been double drilled as shown in Figure 5 thereby significantly reducing the shear capacity of the plate.

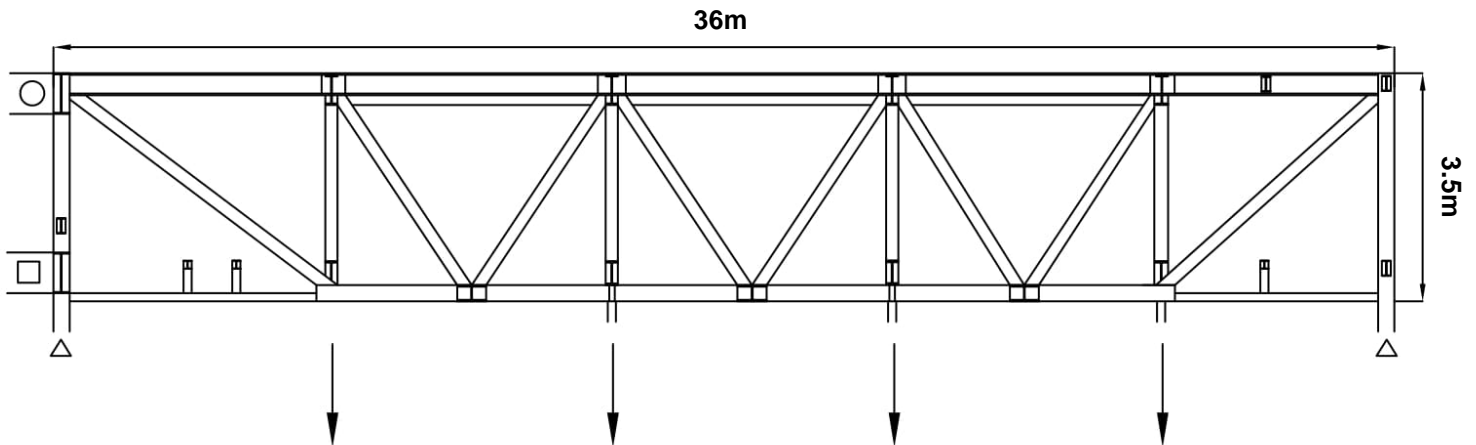


Figure 3: Main roof truss showing SHS hanger positions



Figure 4: Third floor hanger weld figure (viewed from underside)



Figure 5: Hanger gusset showing both shop holes and site drilled holes

The most likely failure scenario, according to the investigation, was that some of the areas weakened by misalignment of welded joints, undersized welds, and double drilled gusset plates, once loaded with building materials may have resulted, initially, in slow plastic yielding, followed by brittle fracture of some of the thicker sections.

CONSIDERATIONS TO AVOID COLLAPSE

In general terms, the initiating cause of a complex collapse may be a localised failure due to design, fabrication, or construction deficiencies. The risk of a local failure triggering a disproportionate collapse must be considered at every stage of design and construction. Where disproportionate collapse is identified as a risk, robustness is essential and can be provided, for instance, by having sufficient horizontal and vertical ties, properly connected to give continuity, and for such ties to be suitably anchored at their ends. Overall the structure will then have a better chance of being protected against local failure. The probability of disproportionate, or progressive collapse, is higher when hangers are incorporated in the overall structure. The Institution of Structural Engineers *Practical guide to structural robustness and disproportionate collapse in buildings* [2] provides common sense advice on what constitutes robustness.

Local failures re-distribute loads so there must be alternative load paths. Secondary effects including shock loading, impact, and dynamic effects which may have to be evaluated. In some cases, a sudden release of load due to a tension failure can lead to stress reversals, whilst the impact of a falling member, or assembly of members, can rapidly increase the stresses in members below. This may lead to yielding and fracture. Retaining stability is always a prime consideration when considering disproportionate collapse as the loss of a critical member may remove its contribution to global stability. Note that different member loads may be arrived at depending upon whether a complex structure is analysed as a whole or in parts. Such variances in theoretical stress levels emphasise the approximations inherent in numerical approaches, and, where different analytical approaches yield quite different predictions, designers are advised against working to stress levels too close to code limits.

Strength, continuity, and stability considerations apply at all stages of construction. An example where loss of stability led to major failure was described in the SCOSS Topic paper [FC Twente stadium roof collapse](#) when temporary bracing was mistakenly removed before the permanent bracing was installed. The cantilevered roof fell and there were fatalities. Cantilevers always merit special attention because of their lack of continuity and the absence, generally, of an alternative load path. A similar category of structures is those with major components in tension and SCOSS has published an Alert on [Tension cable and rod connectors](#). Sudden failure of a tension member or, as is probably more common, the failure of its end fixing, can instigate progressive collapse. Where the end fixing is weaker than the tension member itself, overall ductility will be extremely limited.

Connections are of vital importance and failure has often been attributed to deficiencies in the design or fabrication of connections. Welding processes must be rigorously adhered to in terms of design, preparation, implementation, inspection and testing, and approval. The difficulties that may be encountered with site welding must not be underestimated. Should bolted connections on site not fit, then the designer should be consulted before any physical amendments are made.

The more sensitive a structure is to minor effects having major consequences, the greater the care that has to be given by all involved and this includes the client who has a responsibility in selecting an appropriate team for the job. It may be difficult for a client to ensure that suitable firms or persons are engaged, but this is a requirement under the CDM 2015 Regulations.

Where an adventurous or unusual form of structure is proposed, the designer has a responsibility to ensure that those assigned to analyse and design the frame have sufficient experience and knowledge to make the structure work safely and reliably. Are they, and the checkers, capable of assessing possible risks, envisaging failure scenarios, and taking steps to avoid these? As has often been said by Structural-Safety, there has to be a competent person in charge of the process who keeps an eye on all aspects including designs by suppliers and contractors: the “controlling mind”.

Similarly, the chosen contractor has to be conscious of the risks involved with unusual structures. These may not be obvious, so the designer should work closely with the contractor and suppliers to point out unconventional features and be sure that difficulties associated with them are appreciated. If unusual temporary works are required, then these too should have the attention of the whole team. Contract conditions will set out legal responsibilities, but it is in the overwhelming interest of everybody concerned to avoid failure and the dire consequences that follow.

FACTORS TO CONSIDER

The following lists are to highlight some of the particular areas of concern for unusual structures. They are not definitive nor are they complete, but should be taken into account at high levels with the design and the construction teams and added to as necessary.

APPOINTING DESIGNERS AND CONTRACTORS (EXTRACT FROM CDM 2015 REGULATIONS)

*Anyone responsible for appointing designers (including principal designers) or contractors (including principal contractors) to work on a project must ensure that those appointed have the skills, knowledge and experience to carry out the work in a way that secures health and safety. If those appointed are an organisation, they must also have the appropriate organisational capability. Those making the appointments must establish that those they appoint have these qualities **before** appointing them. Similarly, any designers or contractors seeking appointment as individuals must ensure they have the necessary skills, knowledge and experience.*

PRIOR TO CONSTRUCTION

- Ensure that contractual arrangements enable team-building and team-working; with effective communication channels between Principal Designer, permanent works designers, Principal Contractor, Temporary Works Co-ordinator, temporary works designer(s), design checkers(s), fabricator(s), installer(s), supervisor(s), and others who are involved
- A risk assessment of the whole design must be carried out
- There must be a clear and comprehensive method statement for the design
- Documentation should include a comprehensive summary of the design parameters and intended load paths and stability systems
- Compliance must be ensured with building regulations and codes of practice
- Modelling and the competence of the modellers must be evaluated and an assessment made that the model replicates reality. Any in-built assumptions (such as connection continuity) must be realised in practice. No amount of sophisticated modelling will compensate for poor detailing
- The quality of calculations, specifications and drawings, must be appropriate to the demands of the project and they should all be checked and validated
- Full consideration of possible disproportionate collapse modes must be undertaken
- Thoroughly review cantilevers, tension structures, and any unusual features
- The main design must ensure that it is feasible to make the connections envisaged
- Design for ease of fabrication and erection and to maximise fit-up tolerances
- Be aware that structures deflect during erection and allow for this
- Minimise on-site cutting, fabrication, and welding
- Ensure that the design, and especially the connection design, is workable e.g. 3- and 4-D modelling with overlap and underlap clash detection
- Ensure good geometry cutting and fit-up
- Possible site difficulties, including those associated with welding, must be considered
- The structure must be robust (Reference 2) and that includes ensuring stability as a whole is not endangered by the minor deviations which will almost invariably occur
- Consider Independent Peer Reviews ^[3] of the design

DURING THE CONSTRUCTION

- Appoint a person who has overall control of the construction process
- Appoint experienced and capable persons to supervise the work
- Maintenance of quality standards is crucial
- Keep control over suppliers and sub-contractors
- Have continuous liaison with the designer (may be subject to contract conditions)
- Liaison with the temporary works designer and contractor
- Control of *all* changes including getting documented clearance from the designer
- Have proper detailed supervision of the works (the designer should ensure that what is built is what was intended by the design)
- Ensure that all welding is carried out to approved procedure, that there is post welding non-destructive testing of all site welding and check test certificates for all welding
- Ensure correct module assembly; including under self-weight at height
- Ensure that fabricators and installers are clear about allowable tolerances and the action to take where these cannot be achieved
- Understand the effects of construction sequencing on stability
- Understand the effects of high winds on a partially built structure
- Provide temporary bracing until permanent bracing is installed
- Check that stored construction materials do not overload the structure
- Ensure that construction plant does not overload the structure
- Look for unusual situations that might go wrong and if in doubt then ask
- Have a common sense approach to structural safety

REFERENCES

1. Structural-Safety data base, www.structural-safety.org
2. [Practical guide to structural robustness and disproportionate collapse in buildings](#), **The Institution of Structural Engineers, 2010.**
3. [Independent Peer Review](#), Structural-Safety Alert 2009

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