Structural-Safety

Alert

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SCOSS ALERT

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Hazard identification for structural design

WHO SHOULD READ THIS ALERT?

This Alert, which is a reproduction of part of The Institution of Structural Engineers' Manual for the systematic risk assessment of high-risk structures against disproportionate collapse [1], is aimed at those involved in identifying and managing hazards associated with a structural design, including principal designers, designers (permanent and temporary works), clients, principal contractors, contractors and external stakeholders. It is published at this time to emphasise the need for care by all engaged in design work.

INTRODUCTION

At the outset of the design, it is recommended that the structural engineer should document the proposed structural design philosophy and the approach to design against disproportionate collapse and agree this with the client. This will be a live document that will be updated throughout the project. The purpose of preparing this prior to starting the systematic risk assessment is to establish some principles and consensus about items such as:

- The basis of design
- The assumptions that will be made in the analysis and design, particularly any simplifying assumptions
- The basic approach envisaged for design against disproportionate collapse

The identification of the hazards is often best done through a hazard identification and risk assessment workshop. A workshop, which might usefully be chaired by a person with specialist expertise in risk identification such as a Principal Designer or a HAZOP chairman, will often lead to a greater flow of ideas than a desktop exercise. In some cases, particularly in buildings where hazards are less readily identified, a formal HAZOP will be prudent (refer to guidance from the Chemical Industries Association [2], the Health and Safety Laboratory [3] and Kletz [4]).

The structural engineer should give careful consideration to who should be involved in the hazard identification and risk assessment workshop. As well as considering whether to have a Principal Designer or HAZOP chairman leading the workshop, ensure that different designers (e.g. temporary works designers, contractors' designers) are represented. The client should be involved. The architect, geotechnical engineers, fire engineers, blast engineers, transport engineers and external stakeholders (such as emergency responders and counter-terrorist security advisers) should be involved where relevant.

Temporary works designers and contractors' designers may not be appointed, so provision needs to be made to ensure they are able to prepare a safe design which does not compromise the robustness of the main structure, and to ensure that the limits on their subsequent design are properly communicated through their appointment. If a contractor is not appointed to provide pre-construction advice through a pre-construction services agreement, consideration should be given to an appointment which permits contractor participation in the hazard identification and risk reduction workshop and support of the subsequent risk assessment process. Facilities management should also be represented at some point in the process to consider proposed inspection and maintenance regimes.

TYPICAL HAZARDS
Some of the hazards that a systematic risk assessment might typically need to consider in the design of a building against disproportionate collapse are listed in Table 1. This is best used as a list of prompts to think about the hazards to which a building might reasonably be subjected. It is intentionally incomplete: the structural engineer is responsible for ensuring that all reasonably foreseeable hazards with the potential to cause harm are identified, and must ensure suitable qualification and experience is available to do so. The identification of hazards will be a team effort, coordinated by the structural engineer. In some cases it may involve specialists being brought into the design team to provide advice in specialist design fields such as fire engineering and blast engineering or pre-construction advice.

Hazards are best identified by approaching the design from several different angles (Figure 1):

- By the nature of the design (e.g. whether innovative, complex or unusual) and by reference to what has gone before (including past failures and the lessons learned)
- By the type of action (e.g. environmental, imposed)
- By the nature of the action (whether normal or abnormal; or whether natural, accidental or malicious)
- By the origin of the hazard (from the structure itself, external to/independent of the structure, deriving from the use/maintenance of the structure or owing to procedures surrounding the design, construction or use of the building)
- By the state of construction: during construction (including specific states at the different stages of construction e.g. due to lack of stability, overloading, lack of fit, the occurrence of specific significant hazards or governing loads, or unforeseen loading conditions), during the building’s operation and maintenance, due to deterioration or lack of maintenance, or during demolition
- By part or section of the structure (substructure, braced frames, sway frames, stability system; original construction, extension, alteration; transfer structures, long spans, connection details)
- By what has the potential to go wrong, be ignored, overlooked or misinterpreted (e.g. due to lack of knowledge, failings in communication, the cutting of corners)

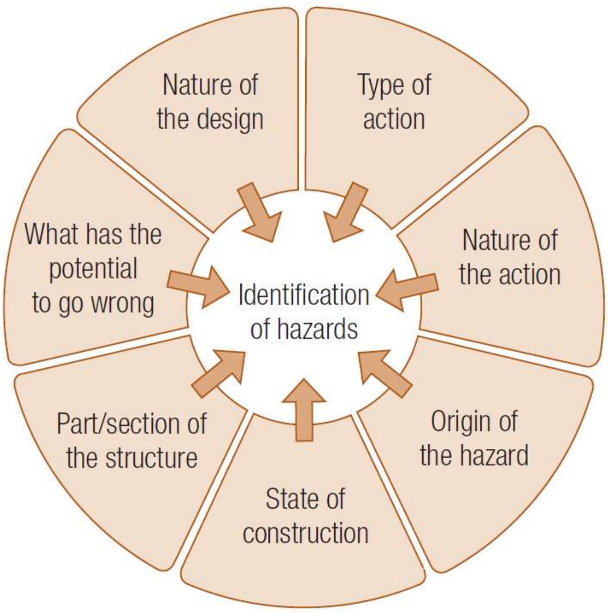

Figure 1: Approaches to the successful identification of hazards

Approaching the design from different angles is advantageous on the basis that several attempts to identify the hazards affecting the design are better than one. It will lead to repetition, but will also help identify some hazards that had been missed through the earlier approaches. Designers tend to think first of the technical things that could go wrong – a car crashing into a column, a sustained fire, a fatigue induced failure. However, this is often at the expense of the procedural failings which are often much more important factors in the actual level of risk to which the design is exposed.

It must be recognised that hazards are not merely technical but also procedural. An error in design is rarely the sole cause of the collapse. Almost without exception it will be accompanied by errors in the communication of the design, errors in the construction, failures in the quality assurance and quality control procedures for the design and construction, failure to stay within the limits of the defined usage for which the building has been designed, malfunction of mechanical plant or machinery, unauthorised alteration of the building, and so on.

Human error is persistent and invidious. People make mistakes, take short-cuts, are put in a role they are not qualified to undertake, fail to carry out effective checks, fail to ensure they are understood, fail to understand what others have done, and fail to ensure design interfaces are defined and controlled (‘I thought someone else was doing that’). Checking procedures break down, audits fail to detect errors, safeguards fail to operate, quality management systems and procedures are circumvented. Complacency, lack of knowledge, programme and commercial pressures all play their part in generating hazards.

Advanced structural analysis tends to persuade us that we understand the structural behaviour of a system: a BRE/CIRIA survey of 120 structural failures found that by far the biggest single reason for failure is a grossly inadequate understanding of real loadings and behaviour of the structure [5].

Study of past failures is simultaneously illuminating and sobering, and is an essential but under-utilised tool in the structural engineer’s armoury. Agarwal [6], Delatte [7] Levy [8], Feld [9], Kaminetzky [10], Campbell [11], Kletz [12] and Mann [13] contain extensive discussions on lessons learned from failures.

The importance of identifying and considering all such procedural (‘soft’) hazards alongside the technical hazards in a systematic risk assessment cannot be emphasised too strongly. In some cases procedural hazards will be considered individually, and in other cases they will be considered in relation to the effect they may have upon other hazards that could occur.

Table 1: Examples of hazards

Design and construction
• Analysis or calculation error • Uncertainty in the applied loads, and unrecognised effects of variation in the applied load • Unrecognised action (e.g. sensitivity to vibration or to a single dominant action) • Unrecognised structural behaviour/structural response • Factors customarily ignored in design of smaller buildings (e.g. wind-induced dynamic oscillation, verticality tolerances, elastic shortening, P-Δ effects, soil-structure interaction) • Unrecognised material behaviour (e.g. lack of knowledge about new materials) • Unrecognised sensitivity to design assumptions • Unrecognised uncertainty in analysis • Unrecognised load paths, i.e. stress distribution not as predicted in analysis (e.g. due to indeterminate nature of structure, failure to consider changes in stress distribution due to second-order (P-Δ) effects or movement/structural deformation elsewhere in the structure) • Lack of stability • Detailing error or the failure to appreciate the detailing requirements for the structure • Failure to communicate the design intent • Material defects • Gross construction error (e.g. omission of reinforcement, dimensional error, installation of precast slabs upside-down) • Unauthorised design change • Susceptibility of design to inadequate temporary works

Table 1: Continued

Robustness during construction (or demolition/alteration)[a]
• Construction method statement inconsistent with design intent or not competently developed • Effect of dropped object (e.g. wet concrete load) • Loading in partially-constructed condition or condition of partial strength • Incomplete stability system • Lack of stability during demolition
Permanent, imposed and environmental actions
• Wind, snow, ice accretion, rainwater ponding, flooding • Excessive loading (whether floor loading due to material stacking or imposed loading due to the malfunction or misuse of plant, e.g. overhead craneage) • Earthquake • Fire • Structural deformation/movement • Subsidence/ground movement • Groundwater level change (sensitivity to groundwater, upward pressure, buoyancy) • Influence of groundwater change on foundation/ground loadbearing capacity • Scour, undermining of foundations • Dynamic effects (e.g. vibration) • Fatigue • Material degradation, (lack of) durability, corrosion, rot • Component failure due to fatigue/durability/corrosion/rot, particularly the hidden failure of uninspectable components
Accidental actions
• Vehicle impact • Fire • Gas explosion • Aircraft impact • Events consequent on plant malfunction • Dropped objects (in plant)
Malicious actions
• Malevolent vandalism/arson/theft • Terrorist attack
From use/maintenance
• Overloading • Fatigue • Corrosion • Failure to design for inspection and maintenance • Failure to implement maintenance and inspection regimes • Unauthorised alteration • Deterioration
From procedural failings
• Competence to carry out the risk assessment • Poor definition of design brief • Failures in coordination and project interfaces • Failings associated with division of contractual responsibility • Lack of design supervision during construction • Lack of good change management • Lack of competence in design or construction • Failings in procurement (e.g. insufficient time/resources) • Poor design or construction supervision

Table 1: Continued

• Sub-standard specifications or quality of construction • Poor communication of information (e.g. poor quality management procedures) • Lack of quality assurance and quality control procedures • Sub-standard components (e.g. due to counterfeiting of quality control markings/certification)
Note [a] Risks during construction, alteration or demolition must be considered under the CDM Regulations but do not fall under the Building Regulations. Determining the need for robustness in a temporary condition would normally fall under the duties of the relevant contractor except if some sort of accidental damage would have a disproportionate effect, such as on an urban site or an air rights building where the consequences might spread beyond the site itself.

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