SPA Tech
TECHNICAL SECTION

Robustness and Disproportionate Collapse

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Part 1 General

1.00 Definition

EN 1990 (Section 2.1 Basic requirements) provides a definition of robustness as "A structure shall be designed and executed in such a way that it will not be damaged by events such as explosion, impact, and the consequences of human errors, to an extent disproportionate to the original cause.

The focus on disproportionate collapse followed the Ronan Point building disaster of 1968. In the collapse one wall panel sustained damage, due to a gas explosion, causing the whole corner of the building to give way.

Photograph of the Ronan Point Collapse 1968.

Following this collapse regulations were introduced to limit the effect of this type of event. In 2004 new regulations were introduced by the Building Regulations. The following summarises the requirement and gives some advice regarding details.

Building Regulations 2004 Part A

1.01 Why were the regulations introduced?

1. Increased numbers of structural collapse;
2. Situation aggravated by
   a. Design, erection errors.
   b. Design and construction methods.
   c. Use of specialist subcontractors, lack of engineer supervision.
   d. Lack of awareness by designers of stability issues, lack of connection between components.
   e. Increase in hazardous forces (blast and impact)
3. Local failure of building resulting in a chain reaction that results in instability of the structure.
4. Disproportionate collapse is referred to as the "Domino effect" or "house of cards effect.

Structures must be stable.

1.02 Classification based upon a risk-based approach.

Risk factor = N + E + S C D

N = Number of people at risk; 0 to 2 (for single occupancy dwellings to public assembly buildings)

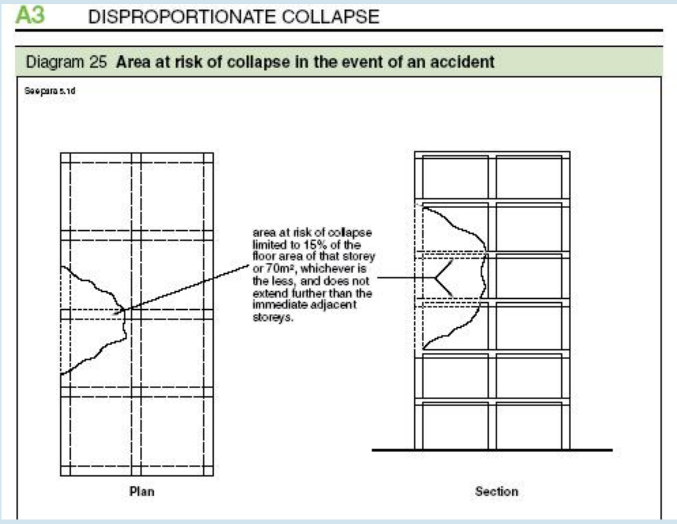
E = Environmental parameter (number of people at risk in proximity of the building); 0 to 1 (for suburban to city centre)

S = Social parameter (perception of society); 1.6 to 3 (for single family dwelling to multi domestic dwelling)

C = Load parameter (likelihood of human occupancy at the time of the event); 0 to 3 (for full occupied to non occupied)

D = Structural parameter (Load distribution and ductility); 0 to 0.70 (for brittle to ductile structures)

Refer to table 1.03 on page 6



Horizontal Collapse, must not exceed $70m^2$ or 15% of floor area,

Vertical Collapse, collapse only in the floor level of accident

But can accept damage to floor immediately above and below only.

1.03 Classification table.

Class	Building type and occupancy	Action required
1	Houses not exceeding 4 storeys. Agricultural buildings. Buildings into which people rarely go, provided no part of the building is closer to another building, or area where people do go, than a distance of 1.5 times the building height.	No additional measures.
2A	5 storey single-occupancy houses. Hotels not exceeding 4 storeys. Flats, apartments and other residential buildings not exceeding 4 storeys. Offices not exceeding 4 storeys. Industrial buildings not exceeding 3 storeys. Retailing premises not exceeding 3 storeys of less than 2000 m^2 floor area in each storey. Single storey educational buildings. All buildings not exceeding 2 storeys to which members of the public are admitted and which contain floor areas exceeding 2000 m^2 at each storey.	Horizontal ties to be provided or effective anchorage of floors to supports.
2B	Hotels, flats, apartments and other residential buildings greater than 4 storeys but not exceeding 15 storeys. Educational buildings greater than 1 storey but not exceeding 15 storeys. Retailing premises greater than 3 storeys but not exceeding 15 storeys. Hospitals not exceeding 3 storeys. Offices greater than 4 storeys but not exceeding 15 storeys. All buildings to which members of the public are admitted and which contain floor areas exceeding 2000 m^2 but less than 5000 m^2 at each storey. Car parking not exceeding 6 storeys.	Horizontal ties to be provided together with either vertical ties or allowance made for the notional removal of support.
3	All buildings defined above as Class 2A and 2B that exceed the limits on area and/or number of storeys. All buildings, containing hazardous substances and/or processes. Grandstands accommodating more than 5000 spectators.	Specific consideration to take account of the likely hazards.

2.00 Robustness and disproportionate collapse methods.

2.01 General. The principles of satisfying robustness and disproportionate collapse are described below. There are typically three methods, it is emphasised these separate methods are largely based on judgement, providing a level of robustness commensurate with routine risks and are achievable at affordable cost.

Method 1: The indirect method: provision of horizontal and vertical ties.

Method 2: Alternative load-path method: notional removal of elements.

Method 3: Specific load-resistance method: the provision of key elements.

2.02 Method 1 (The indirect method).

Applicable to Class 2A and 2B buildings, resistance to progressive collapse is considered implicitly *'through provision of minimum levels of strength, continuity and ductility* throughout the whole structure (this is sometimes called the 'Indirect Design Method). Adopting this method should provide buildings with sufficient robustness to survive a reasonable range of undefined accidental actions. The tying provisions are more onerous in Class 2B buildings than for Class 2A buildings as a reflection of the potentially greater risks. Tie capacity is typically provided by the structural members themselves but also by making sure that their connections or anchorages are strong enough. This is primarily achieved by design using conventional procedures to carry defined tie forces.

2.03 Method 2 (notional removal method).

The alternative-path method presumes that through abnormal loading a critical element is removed and the structure is thereafter required to redistribute its gravity loads to the remaining structural elements via alternative load paths. There is no requirement in the UK to consider dynamic loads associated with the element removal. In practice, elements are notionally removed one by one and the residual structure (members and connections) tested for strength. Local collapse is not prohibited but its extent must not exceed prescribed limits.

2.04 Method 3 (key element method).

Here certain elements are designed to sustain a notional upper bound to the abnormal loading (a value of 34kN/m^2 imposed pressure is used derived from the Ronan Point blast) albeit on a 'just survive basis; the presumption then is that such members are 'strong enough to cope with a range of events.

2.05 Interaction of methods.

It should be noted that methods 2 and 3 are principally concerned with vertical structure or elements supporting vertical structure. When applying these methods the designer must ensure that the horizontal structure, in both directions, is robust. This is generally achieved by providing horizontal ties.

2.06 TYING

The provision of ties having a defined capacity and linking components helps to constrain the elements from displacement during an event and can make possible alternative load-carrying systems including catenary and vierendeel action.

2.06.1 HORIZONTAL TIES

The demands for horizontal ties for Class 2A are different from those for Class 2B. In Class 2A, it is possible to apply effective anchorage of suspended floors to walls; in Class 2B ties should be provided. Ties around the structure are called peripheral ties whereas ties across the structure are internal. Along a particular load path (which must be continuous), different structural elements (say a series of beams) may be used as the ties, providing they have adequate interconnection. Rules for tie location and for their design forces are given in the material codes (BS and EN).

Ties can act to prevent a structure being dislodged, which is particularly important when supports are narrow or at a perimeter where the ties must be capable of resisting any outward force on the supporting vertical element. The need for such tying was demonstrated in the Ronan Point collapse where a gas explosion blew out a loadbearing wall, causing the slabs above to collapse. Lack of tying was also a factor in the Camden school collapse.

Ties need to be continuous (i.e. lapped or connected) across from edge to edge or around the structure, while at the ends horizontal ties to edge columns and walls must be satisfactorily anchored back. All tie force paths should be geometrically straight; changes in direction to accommodate openings or similar discontinuities should be avoided wherever possible. Where such changes are unavoidable, the tendency of the tie to straighten under load should be considered and restraining elements provided. For buildings composed of separate structures, or incorporating joints creating structurally independent sections, the tie force requirements are applied to each independent section, each treated as a separate unit.

The code-specified tie forces aim to ensure that beams or slabs can span across a removed support. However, there is no theoretical justification that ties designed to the codes will in fact enable the structure to span across a damaged area in all possible circumstances.

One difficulty in relying on the benefits of either catenary or membrane action lies with justifying the significant ductility required. Rules for tie design and location are given in the material codes but there are no direct requirements for providing a ductility magnitude, this being assumed.

The rationale for ignoring all these objections to the nominal regulation rules is that a balance has to be drawn between the risks of an event occurring on the one hand against the cost of tie provisions on the other. The implication of the Approved Document A is that a notional tie provision represents a reasonable level of precautionary investment. The consensus is that horizontal ties are an important safeguard that should always be incorporated and will safeguard most buildings for most hazards. But, outside that usage, their potential weaknesses should be accounted for more directly, especially for more demanding structures.

2.06.2 VERTICAL TIES

Vertical ties have two roles. The first is to provide some form of minimum resistance to the removal of vertical elements. The second is to enable load sharing between floors above a damaged vertical element. By linking a number of floors together, it is possible to provide a load path back to intact structure above, perhaps by developing vierendeel action.

2.06.3 The rule for vertical ties is that each column or wall should be able to support the largest dead and imposed load reaction applied to the column or wall from any one storey (above or below). In practice, if it is possible to provide vertical ties at all, their capacity is not usually a problem.

2.06.4 When required, vertical ties must be continuous from the lowest level to the highest level and this includes anchorage into the footing or foundation. The rationale for tying into foundations is that it helps reduce the possibility of column removal. Where such ties into the basement are not practical, consideration as a key element normally provides a practicable solution.