The UK and European Regulations for Accidental Actions

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ABSTRACT

This paper presents the background to the recommendations for the disproportionate collapse of tall buildings (five storeys and over) given in the current UK Building Regulations and its associated Approved Documents and supporting material codes and standards. The proposed changes to these recommendations are also presented. Although the current recommendations have generally proved adequate there is a general belief that the recommendations for disproportionate collapse should be extended to all buildings. Consequently, a proposal to change the current recommendations has been developed by the UK's Department for Transport, Local government and the Regions (DTLR). This new approach is based on a risk and consequences approach and sub-divides building into four structural categories. The emerging European standards include a similar categorisation and this is also presented. Unlike the guidance given in the UK, which provides rules for a general level of robustness the European standard gives guidance on specific hazards.

INTRODUCTION

Following the initial shock, horror and outrage at the nature and scale of the attack on the twin towers of the World Trade Center on the 11th September thoughts have turned to ways in which such an event can be prevented in the future or, if this is not possible, on ways in which the consequences of such an event can be minimised. For engineers the complete collapse of the twin towers and the manner of the collapse has led to a great deal of reflection on the design and regulatory process. The balance between risk and consequence is one, which all designers consider either explicitly through a risk assessment process or implicitly through interpretation of the regulations and codes and standards. The nature of the terrorist attack where the building was subjected to a large impact force followed, almost immediately, by the combustion of many gallons of highly flammable aviation fuel is not a normal design situation. However, the consequences of failure of the twin towers or, failure of any building accommodating large numbers of occupants in a crowded urban area is such that complete collapse should be avoided under all conceivable scenarios. If this is not possible then the building should survive for a period sufficient to evacuate all building occupants and those in the immediate vicinity.

The impact of the two aircraft on the World Trade Center Towers, followed by the explosion of the aviation fuel and the subsequent conflagration weakened both towers to such an extent that the structure was unable to support the section of building above the crash sites. A progressive collapse of the whole of each building then followed as the potential energy of the each floor was released and the increasing kinetic energy caused complete and progressive failure of the lower undamaged storeys.

This paper considers the question of disproportionate collapse and examines the background to the development of the provisions given in the UK. The success of the methods used by engineers in the UK is also assessed by considering the performance of two modern multi-storey structures subject to large explosions.

The recommendations in the UK for disproportionate collapse currently apply to buildings of five storeys and over. Although this guidance has proved adequate there is a general belief that the rules should be extended to all buildings (rather than just tall buildings). Consequently, the UK's Department for Transport, Local Government and the Regions (DTLR) has prepared a proposal to extend the guidance. These proposed changes are similar to the recommendations given in the emerging European standards. The recommendations given in both standards are presented and the differences identified.

THE BUILDING REGULATORY SYSTEM IN THE UK

The Building Regulations (HMSO, 1991) in the UK are concerned with the safety of those in and around buildings. Issues of property protection are left to the insurance industry to provide or require standards in addition to those provided through compliance with the regulations. In the UK these regulations consist of a hierarchy of documents at the top of which are The Building Regulations which is a legal statutory instrument produced by the UK's government that gives the requirements, together with their limits, that each building must satisfy. For example the Building Regulations give the following requirement for disproportionate collapse:-

'The building shall be constructed so that in the event of an accident the building will not suffer collapse to an extent disproportionate to the cause.'

To provide guidance on some of the more common building situations the UK's Department for Transport, Environment and the Regions (DTLR, formally the DETR) produces what are called the Approved Documents. There are fourteen Approved Documents (A to N, excluding I and including Regulation 7) which range from Approved Document A - Structure to Approved Document N - Glazing - Materials and protection. Approved Document A - Structure (HMSO, 1991) provides guidance on disproportionate collapse. The Approved Documents give a mixture of prescriptive and performance based guidance for common building situation and compliance with the guidance is evidence tending to show that the design/construction complies with the Building Regulations. However, there is no obligation on the designer to adopt any particular solution contained in any of the Approved Documents and an alternative solution can be adopted. If this latter course of action is taken then the designer must demonstrate compliance with the requirements given in the Building Regulations.

The Approved Documents also makes reference to Codes, Standards and other documents that contain recommendations on the design and construction of buildings. The methods contained within these standards can be used in place of the guidance given in the Approved Document.

BACKGROUND LEADING TO THE UK PROVISIONS

The partial collapse of Ronan Point in 1968 alerted the UK's construction industry to the problem of progressive collapse. An explosion in an apartment on the 18^{th} floor, in the Southeast corner of the 22-storey tower block blew out the non-loadbearing walls of the kitchen and the living room and the external loadbearing wall of the living room. The upper floor slab fell on to the floor below initiating the progressive collapse of one corner of the whole block as can be seen in Figure 1. The cause of the explosion was leakage of town gas from a defective connection on a cooker, which was probably ignited by a struck match (HMSO, 1968). In the report of the Ronan Point Inquiry the following recommendations were made:-

Recommendations for existing tall buildings:-

'(29) All blocks over six storeys in height should be appraised by a structural engineer who should consider:

(a) whether they are susceptible to progressive collapse .
(b) whether they have been designed to resist adequately the maximum wind loadings which they may experience.
(c) Their behaviour in the event of a fire.'

'(30) In blocks that are judged to be susceptible to progressive collapse, measures must be taken to strengthen them to eliminate this risk, and the gas supply should be turned off until this has been done.'

Recommendations for new tall buildings:-

'(32) Designers of new blocks must design the building so that it is not susceptible to progressive collapse, paying particular attention to introduction of continuity at the joints and so disposing the load-bearing walls that alternative paths are provided in the event of local failure.'

'(43) The Building Regulations should include provisions dealing with progressive collapse.'

These recommendations resulted in changes to the UK's regulatory system for the design and construction of buildings. These changes are described in the next section.

Changes to the UK's regulatory system

Following the partial collapse of Ronan Point in 1968, the Building Regulations were changed to deal specifically with damage due to an accident such as a gas explosion for buildings of five storeys or more. The 1976 Building Regulations (HMSO, 1976) required that in the event of an accident the building will not suffer collapse to an extent disproportionate to the cause. Subsequently changes were made to the Approved Document A, which provides guidance on the interpretation of the Building Regulations concerning structural performance. These changes take cognisance of the Building Regulations and give three methods of ensuring that structures have a minimum level of strength to resist accidental loading. These methods are detailed below.

Tying - The first design option is to provide effective horizontal and vertical ties in accordance with the structural Codes of Practice. The provision of ties increases structural continuity creating a structure with a high degree of redundancy; providing the building with alternative load paths should part of the structure be removed by an accidental action. Subsequent quarter-scale testing was carried out at BRE (Armer, 1972; Armer, 1976, Kumar, 1977) to determine the effectiveness of this approach.

Bridging - Where tying is not feasible, it is recommended that the structure should be designed to bridge over a loss of an untied member and that the area of collapse be limited and localised. This is usually achieved by notionally removing each untied element, one at a time, and checking that on its removal the area of structure at risk of collapse is limited to the smaller of the following areas:-

a. 15% of the area of the storey or,
b. $70m^2$.

Key element - Finally, if is not possible to bridge over the missing member (which may be the case for a small minority of buildings) such a member should be designed as a protected (or key) element capable of sustaining additional loads related to a pressure of $34kN/m^2$. The value of $34kN/m^2$ ($5lb/in^2$) was chosen with reference to a rounded estimated failure load of the loadbearing flank wall at Ronan Point. This estimation was based on observational evidence. In practice the $34kN/m^2$ is used to determine a notional load that is applied sequentially to key elements and is not a specific overpressure that would result from a gas explosion.

The above requirements are considered to produce more robust structures which are more resistant to disproportionate failure due to various causes, such as impact as well as to gas explosions.

The guidance given in Approved Document A has been incorporated in some structural material Codes, albeit the various Codes provide a number of alternative or mixed solutions to deal with the problem. The accidental loading requirement has now been included in the British Standard, 'BS6399: Loading for buildings: Part 1: Code of practice for dead and imposed loads' (BSI, 1996) with the following text:-

'When an accidental load is required for a key or protected element approach to design (see appropriate material design Code), that load shall be taken as $34kN/m^2$.'

The methods for avoiding disproportionate collapse (tying, bridging and key element design) have been include in the various British Standard Material Codes. These include the British Standard for the Structural use of Steelwork in building (BSI, 2000), the British Standard for the Structural use of concrete (BSI, 1985) and the British Standard Structural work of masonry (BSI, 1978). The information contained in BS5950: Part 1 is described below as an example of the detail contained in the material Codes.

BS5950: Part 1 requires all buildings to be effectively tied together at each principal floor level. This is achieved by tying together all the principal elements of the structure. The Codes also requires that all horizontal ties and their end connections should be of a standard of robustness commensurate with the structure of which they form part. Furthermore, the ties and their connections should be capable of resisting the following factored tensile loads:-

- for internal ties: $0.5(1.4g_k + 1.6q_k)s_tL$ but not less that 75kN
- for edge ties: $0.25(1.4g_k + 1.6q_k)s_tL$ but not less that 75kN

where
g_k is the specified dead load per unit area of floor or roof
L is the span
q_k is the specified imposed floor or roof load per unit area
s_t is the mean transverse spacing of the ties adjacent to that being checked.

In practice the ties are usually the steel members, the steel bar reinforcement (provided that it is anchored to the steel frame and embedded in concrete), the steel mesh reinforcement in a composite slab with profiled steel sheeting or a combination of all three. It is relatively straightforward to demonstrate that these elements have the necessary strength to carry the tying forces. The connections of a steel frame must also be capable of transferring the horizontal tying force and research (Owens, 1992) has been carried out on the tying capacity of commonly used steel connections. This information has been translated into a set of design checks (SCI, 1993) for simple connections and these checks are regularly used in the UK to determine their tying capacity.

If tying is not feasible BS5950 gives recommendations for bridging and key element design that are the same as the guidance given in Approved Document A. But unlike Approved Document A, BS5950 gives some additional information on the loads and combination of loads to be used. In the case of bridging the Code recommends that only one third of the ordinary wind load and a third of the ordinary imposed load need be allowed for, together with the dead load except that in the case of buildings used for storage (or where the imposed load is of a permanent nature) the full imposed load should be used.

Similar recommendations are given in the other material Codes and have been used in the design of buildings in the UK for some time.

PERFORMANCE OF STRUCTURES DESIGNED IN ACCORDANCE WITH THE UK PROVISIONS

Since the introduction of the disproportionate collapse rules into the UK in 1976 a number of modern buildings have been subject to accidental actions including bomb explosions. Some of these incidents together with a description of the building and the damage caused by the explosion are described below to illustrate the performance of structures designed in accordance with the UK provisions for accidental actions.

Exchequer Court, St Mary's Axe, London 1992

In April 1992 a bomb exploded in St. Mary's Axe, London. The explosion caused damage to a number of buildings including Exchequer Court (25-51 St. Mary's Axe), the Baltic Exchange (24-28 St. Mary's Axe) and the Chamber of Shipping (30-32 St. Mary's Axe). Away from the immediate site of the bomb the damage was mainly non-structural with a large number of windows being lost. The non-structural damage occurred for several hundred metres from the bombsite. Although none of the buildings close to the explosion collapsed all suffered considerable damage. The most modern of these was Exchequer Court which at the time was a recently completed steel framed structure with composite floors and as such is worthy of further consideration.

Description of the building - The building was of modern construction and consisted of a steel frame with in-situ concrete floors acting compositely with a steel profile metal decking. In conformity with steel frame construction in the UK the building was designed to resist lateral wind loads by a system of braced steel bays. Consequently the main steel frame was designed to support gravity loads only. The beam to column and beam to beam connections were both of the flush end-plate type and were designed to transmit vertical shear only. However, because the building was over five storeys high the connections would have been designed to carry a horizontal tying force of not less than 75kN (this could have been higher if the general rules on tying had been used) to preserve the integrity of the structure in the event of accidental damage.

Summary of damage - The bomb was placed approximately 6m from the face of the building and consequently the cladding, columns, beams and floors close to the blast were badly damaged. Most of the cladding was removed at ground floor level and two of the ground to first floor columns close to the blast were bent 125mm and 406mm respectively as shown in figure 2. The edge beams connected to these columns were also badly damaged and a detailed inspection of the connection between the column and the edge beam showed that the connection had been displaced approximately 200mm vertically. None of the bolts could be found and no distortion of the end-plate was visible suggesting that the connection failed in shear.

The first and ground floors were also badly damaged. The first floor was bent upwards in a series of arches with the maximum displacement occurring between the secondary beams. In a number of cases the composite floor had come away from its supporting beam and shear studs were clearly visible as shown in figure 3.

The ground floor was bent downwards although the displacement was less pronounced that that of the first floor. A connection between a secondary beam and an internal column had moved approximately 150mm vertically.

Observations on performance - Although the building suffered considerable damage to both its non-structural and structural members the building remained intact. Furthermore the type of explosion at St. Mary's Axe was of a completely different nature to the internal gas explosions which were the principal cause for the disproportionate collapse rules given in the Building Regulations, Approved Document A and the material Codes. The explosion that occurred at St. Mary's Axe was produced by a large amount of Semtex being detonated. This type of material produces a very rapid pressure rise often followed by a negative pressure. In contrast, gas explosions are relatively slow and can be reasonably modelled by a uniform static load.

Kansallis House, Bishopsgate, London 1993

On Saturday 24th April 1993 a bomb exploded immediately outside the north-west corner of the parish church of St. Ethelburga on Bishopsgate, London. The explosion badly damaged a number of buildings in the immediately vicinity and damaged more than 2 millon square feet of offices in the City of London. Covering an area of 40 acres. Although, only one building suffered complete collapse, the 14th Century parish church of St. Ethelburga, many buildings suffered considerable damage to the cladding and internal fixtures and fittings. Only a hand full of buildings immediately adjacent to the explosion suffered severe local structural damage and this included Kansallis House.

Description of the Building - Kansallis House was constructed in the early 1980's and was built from in-situ reinforced concrete. It was eight storeys high and covered an area of approximately 900m^2. The building was clad in reconstituted stone formed into flat panels and various profiles, including semi-circular, to suit mullions and other architectural features. The cladding was made up from individual stones and other elements with estimated weights of between 50kg and 125kg.

The floors of the building were of in-situ reinforced concrete strip-beam and trough-slab construction. The trough slabs spanned between the strip beams and consist of 350mm deep troughs at 800mm centres with 100mm topping of reinforced concrete. The reinforcement in the troughs consisted of one 32mm diameter steel bar located at the bottom of each trough. This was achieved by running a single bar from either end of each trough and overlapping the bars at the centre. The top reinforcement was a fabric mesh type A142 placed in the top of the 100mm thick topping. Additional reinforcement was provided where the trough slab met either a slab beam or a perimeter beam.

The perimeter beam was a 575mm deep by 300mm wide reinforced concrete beam. A grid of reinforced concrete columns supported each floor and along the side of the building nearest the explosion the columns were 1200mm wide and 300mm deep.

Summary of damage - The bomb exploded within 6.0m of the south-west corner of the building, causing considerable damage to the cladding and the structure in the immediate vicinity. Some structural damage also occurred on the rear and side elevation of the building. The force from the explosion removed three of the ground to first floor columns on the front elevation of the building in the south-western corner. This damage is shown in figure 4. The explosion also removed the perimeter beam at first floor level and figure 4 also shows the remains of the perimeter beam.

On the southern side of the building the blast punched out part of the ground to first floor structural reinforced concrete wall and caused widespread bowing of much of the lower levels of the wall. The stone cladding largely remained in place although it suffered extensive cracking. The explosion also removed the 1st, 2nd and 3rd floors in the south-west corner of the building and badly damaged the ground floor.

Observations on performance - The building was subjected to an explosive pressure, which removed three load bearing columns and 127m^2 of the 1st floor and 73m^2 of the 2nd and 3rd floors immediately above these columns. In spite of this damage the majority of the building remained intact. The mechanism that enabled the remaining part of the building to bridge over the missing columns is unknown but clearly the design provisions provided sufficient redundancy in the structure to allow such bridging to occur.

REVIEW OF CHANGES UNDER CONSIDERATION IN THE UK

Approved Document A provides guidance on disproportionate collapse for buildings greater than 4 storeys in height in the event of an accident. Although this guidance has proved adequate it is generally believed that the fundamental property of resistance to disproportionate collapse should be a requirement for all buildings regardless of height. Furthermore, it was felt that the guidance on robustness should take account of recent developments in Europe. Consequently a proposal (DTLR, 2001) relating to the guidance on disproportionate collapse given in Approved Document A has been developed which removes the Limits of application and introduces a risk based approach similar to that proposed for the Eurocodes.

The proposal outlines four approaches to the design for accidental actions, each of which is assigned to a different Structural Category and given a range of risk factors within which the method is to be applied. A technical paper describing the background to this approach is to be published in The Structural Engineer.

The four Categories and the resulting guidance are briefly described below:-

Structure Category - 0 (Risk Factor less than or equal to 0.7)
If the structure falls into this category then no specific measures are required (i.e. typical construction details provide sufficient inherent resistance against disproportionate collapse).

Structure Category - 1 (Risk Factor greater than 0.7 but less than or equal to 2.0)
If the structure falls into this category then provide effective horizontal ties in accordance with the recommendations given in the Codes and Standards.

Structure Category - 2 (Risk factor greater than 2.0 but less than or equal to 4.0)
Provide effective horizontal and vertical ties in accordance with the recommendations given in the Codes and Standards. However, if horizontal ties are provided but it is not feasible to provide vertical ties then each untied member should be considered to be notionally removed, one at a time in each storey in turn, to check that its removal

would allow the rest of the structure to bridge over the missing member. This approach is identical to the bridging approach described earlier.

If is not possible to bridge over the missing member or the area at risk of collapse exceeds certain limits then the member should be designed as a key element. The limits on the area at risk of collapse are identical to those in the current Approved Document A and are described earlier. Similarly the recommendations for key element design are given in the section headed 'Background to UK provisions'.

Structural Category	Building Type
0	One family unit housing (detached, semi-detached or terrace) not exceeding 3 storeys. Storage, warehousing (without admission to those engaged in retail or wholesale purchase) of single storey.
1	One family unit housing (detached, semi-detached or terrace) exceeding 3 storeys. Flats, apartment and other residential buildings not exceeding 2 storeys. Warehousing exceeding one storey. Offices. Production areas. Retail premises not exceeding 2 storeys or $200m^2$ gross floor area. Multi-storey car parks.
2	Flats, apartments and other residential buildings other than hotels or those designed for the care of disabled or elderly people or children exceeding 2 storeys. Hotels and residential buildings for the care of disabled or elderly people or children not exceeding 3 storeys. Educational buildings (excepting those parts lying within Structural Category 3). All retail (including retail warehousing) premises not lying within Structural Category 1. Hospitals of not more than one storey. All buildings not lying within Structural Category 0 and 1 to which members of the public (being persons not in the employment of the building occupier) are admitted in significant numbers, and in which there are open spaces, measured within permanent enclosing walls, of floor area not exceeding $100m^2$.
3	Hotels and residential buildings for the care of disabled or elderly people or children exceeding 3 storeys. Hospitals of more than one storey. All buildings to which the public (being persons not in the employment of the building occupier) are admitted in significant number and which contain open spaces measured within permanent enclosing walls of floor are exceeding

	$100m^2$.

Table 1. Structural Category and typical building types

Structure category - 3 (Risk factor greater than 4.0)
The structures in this category are unusually tall or large buildings and house a significant number of people. It is therefore recognised that the treatment of disporportiate collapse requires more that a simple prescriptive approach. Consequently, the guidance recommends that the hazards to which the structure is likely to be exposed should be systematically identified and the risks assessed during the design process. The hazards considered should be those that are likely to occur in normal use and those that may occur in an accident. They should also include both naturally occurring and man-made hazards. The most critical situation for design should be considered and a structural form chosen identifying load paths and affected areas taking into account interactions between structural members.

The proposal also provides guidance on the Structural Categories for a range of building types and occupancy and this guidance is repeated in Table 1. UK structural engineers and regulators are currently debating the method given in the proposal and this process may result in changes to both the approach and the building types within each category.

STATE OF PRACTICE IN EUROPE

The pre-standard for the Eurocode on accidental actions (BSI, 1998) due to impact and explosions has now been published and is available for trial use in Europe. This draft standard proposes three approaches to design for accidental actions. Each of these approaches is assigned a different category of accidental design situation and is given below.

Category 1, defined as having 'limited consequences', requires no specific consideration for accidental actions.

Category 2, with 'medium consequences', requires either a simplified analysis by static equivalent models or the application of prescriptive design/detaining rules, depending upon the specific circumstances of the structure in question.

Category 3, which relates to 'large consequences', recommends a more extensive study, using dynamic analysis, non-linear models, and load-structure interaction if considered appropriate.

ENV 1991-2-7 (BSI, 1998) is currently undergoing conversion from a pre-standard to a Euronorm and as a result a slightly different set of strategies for addressing accidental design situations has been introduced. It should be noted that during the conversion the numbering system will be changed and ENV 1991-2-7 will be called prEN 1991-1-7.(CEN, 2002). The new consequence classes are described below:-

Consequences class 1 is defined, as 'Low' and no specific consideration is necessary with regard to accidental actions.

Consequences class 2 is defined as 'Medium' and no specific consideration is necessary with regard to accidental actions except to ensure that the robustness and stability rules given in Eurocodes 1 to 9, as applicable, are adhered to.

Consequences class 3 is defined as 'High' and depending upon the specific circumstances of the structure, a simplified analysis by static equivalent actions models may be adopted or prescriptive design/detailing rules may be applied.

Consequences class 4 is defined as 'Severe' and a more extensive study recommended, using dynamic analysis, non-linear models and load structure interaction if considered appropriate.

The proposed changes also allow for the possibility of treating some parts of the structure as belonging to a different category from the overall structure. For example where parts of the structure are structurally separate from the main building and may be subject to different risks and consequences of failure.

Class	**Building Type and Occupancy**
1	Houses not exceeding 3 storeys. Single storey storage/warehousing of less than 200m^2 floor area which in normal use is occupied infrequently by a small number of operatives.
2	Houses exceeding 3 storeys but less than 6 storeys. Flats, apartments and other residential buildings not exceeding 3 storeys. Offices not exceeding 4 storeys. Industrial buildings not exceeding 3 storeys. Retailing premises not exceeding 3 storeys of less than 200m^2- floor area in each storey. Single storey Educational buildings
3	Residential buildings not exceeding 10 storeys. Educational buildings not exceeding 10 storeys. Retailing premises not exceeding 10 storeys. Hospitals not exceeding 3 storeys. All buildings to which members of the public area admitted in significant numbers and which contain floor areas within permanent wall enclosures not exceeding 200m^2. Non-automatic car parking not exceeding 6 storeys. Automatic car parking not exceeding 10 storeys.
4	All offices, retailing, hospitals and car-parking buildings that exceed the limits on area and number of storeys described for Class 3 buildings. All buildings to which members of the public are admitted in significant numbers and which contain floor areas withinb permanent wall enclosures exceeding 200m^2. Stadis.

Table 2. Examples of Consequences Classes

The application of these requirements will be a matter for the relevant national regulatory authorities, and the actual categorisation may follow national traditions and preferences. However, draft prEN 1991-1-7 (CEN, 2002) does provide an example of the consequence classes for a range of building types and occupancy. These are given given in Table 2.

The ENV and the prEN standards include a more detailed approach to design for accidental situations than current UK practice. Both standards provide guidance for specific hazards, rather than providing a general level of robustness. For example consider the guidance given in ENV1991-2-7 for gas explosions. For category 2 the ENV considers the normative design situation to be a natural gas explosion in a vented single room. It provides two methods for determining the equivalent static pressure, p_d, to be used in design, either a single value of 20kN/m^2 is given or, if the volume of the room, vent area and vent failure pressure are known, the value of, p_d, can be determined by a formula. For situations where the provision of natural gas is totally impossible, an unspecified reduced value of the equivalent static pressure may be permissible. For Category 3 some information is given in an informative annex dealing with advanced design for explosions, although a normative design situation is not defined and much is left to the experience and skills of the designer.

CONCLUSIONS

Regulations for design against disproportionate collapse have been a part of the UK's design process for tall buildings (5 storeys and over) for over 26 years. During this period a small but significant number of buildings have been subject to large explosions, which have resulted in significant damage to the main loading bearing structure. In the cases examined the structural damage was limited to a local area and progressive/disproportionate collapse did not occur. Although the requirement and associated guidance to resist disproportionate collapse has generally fulfilled its intended purpose there is general opinion that the fundamental property of resistance to disproportionate collapse should be a requirement for other buildings. Consequently there is a proposal to amend the current guidance in the UK and extend the scope to other buildings. This proposal uses a risk and consequence based approach to categorise those buildings where the loss of life due to a lack of robustness could be severe. The European proposals are also under development and these recommendations are based on a similar risk and consequence approach. But unlike the guidance proposed for the UK the European recommendations include a more detailed approach to design for accidental situations. They provide guidance for specific hazards rather than providing a general level of robustness.

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Figure 1. Progressive collapse - Ronan Point.

Figure 2. Damage to ground floor steel columns – Exchequer Court, St. Mary's Axe

Figure 3. Damage to composite floors – Exchequer Court, St. Mary's Axe

Figure 4. Damage to ground floor columns –Kansallis House, Bishopsgate