Department for
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Guide to the use of
EN 1991-1-7 – Accidental Actions

September 2006

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It should be noted that this guidance has been based on the latest draft Eurocode; no National Annex was available at the time.

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CONTENTS

CHAPTER 1 INTRODUCTION **5**

1.1 Eurocode terminology and symbosis **6**
1.2 Eurocode annexes **6**

CHAPTER 2 **7**

2.1 Introduction **7**
2.1.1 Objectives of this section 7
2.1.2 Definitions 7
2.1.3 Current status of prEN 1991-1-7 7
2.1.4 Current status of existing UK design recommendations and codes 8
2.1.4.1 *UK requirements before December 2004* 8
2.1.4.2 *UK requirements after December 2004* 9

2.2 The contents and scope of EN 1991-1-1-7 **9**

2.3 Consequence Classes **10**

2.4 Design Situations **11**

2.5 Recommended strategies to ensure that buildings are sufficiently robust to sustain localised failure without a disproportionate collapse **12**

2.6 EN 1991-1-7 recommendations for design for specific accidental actions **14**
2.6.1 Internal explosions 15
2.6.2 Impact 15

2.7 Risk analysis for Class 3 buildings **16**
2.7.1 Qualitative risk analysis 17
2.7.2 Quantitative evaluation 18
2.7.3 Statistical data 18

2.8 National Annex **19**

CHAPTER 3 REFERENCES **22**

1. Introduction

The project which led to the production of this report arose with the intention of producing a handbook to encourage the safe and consistent adoption of EN 1991-1 : Eurocode 1 - Actions on Structures: Part 1: General Actions, in the UK. The project was modified to consider only two specific sections of EN 1991-1, Actions on structures, which were:

Part 1.4: Wind Actions
Part 1.7: Accidental actions

However, both of these sections require information from EN 1990 'Basis of Structural Design', hence EN 1990 also had to be considered.

Although the original intention had been to produce one handbook, it became apparent that the various parts of the Eurocode could not be treated in a consistent manner. For example, parts of EN 1991-1-4 can be compared with BS6399-2, but EN 1991-1-7 has no equivalent UK code; hence it was felt appropriate to prepare separate reports for each section. This would also allow further parts of EN1991-1 to be considered later. The reports, which have been produced so far, are for EN 1990, EN 1991-1-4 and EN 1991-1-7.

An initial requirement was that the handbook should be concise, user friendly and summarise the major differences between EN1991-1 and existing UK codes. Therefore, information given in EN 1991 that does not conflict with UK codes is simply referenced and no explanation is given about its derivation. For this latter type of information, the reader is referred to the Thomas Telford publications on the Structural Eurocodes (www.eurocodes.co.uk).

Although several parts of EN1991 and their respective National Annexes are complete, others are still being processed. The current state of progress is given in Table 1. A consequence of starting the work before the codes with their National Annexes are published by BSI is that the work can only be based on the latest editions of the code, and some details may change when the Codes are finally issued.

Table 1 Current status of the various sections of EN 1991

Section	Title	Final text released by CEN	Anticipated publication date by BSI along with associated National Annex
EN 1990	Basis of structural design	April 2002	April 2004
EN 1991-1-1	Densities, self-weight and imposed loads	April 2002	April 2004
EN 1991-1-2	Actions of structures exposed to Fire	Nov. 2002	~ Nov 2004
EN 1991-1-3	Snow Loads	July 2003	~ Dec 2004
EN 1991-1-4	Wind Actions	~ May 2004	May 2006
EN 1991-1-5	Thermal Actions	Oct 2003	Oct 2005
EN 1991-1-6	Actions during execution	Sep 2004	Sep 2006
EN 1991-1-7	Accidental actions due to impact and explosion	Jun 2005	Dec 2007

Because EN1991-1-7 is not yet finalised, little guidance on its background and usage has been produced. A series of designer's guides on the various Eurocodes is being prepared by Thomas Telford and some user manuals are planned by the Institution of Structural Engineers (www.istructe.org.uk). It is recommended that these web pages be checked to obtain up-to-date information on the available publications

1.1 Eurocode terminology

Most of the definitions given in the Eurocodes derive from

- ISO 2394(1998) General principles on reliability for structures
- ISO 3898 (1997) Bases for design of structures -- Notations -- General symbols
- ISO 8930 (1987) General principles on reliability for structures -- List of equivalent terms

EN 1990 provides a basic list of terms and definitions which are applicable for EN 1990 to EN 1999, thus ensuring a common basis for the Structural Eurocode suite. Sections of EN 1991-1 contain terms and definitions which are specifically related to that section.

Attention is drawn to the following key definitions, which may be different from current national practices:

- "*Action*" means a load, or an imposed deformation (e.g. temperature effects or settlement)
- "*Effects of Actions*" or "*Action effects*" are internal moments and forces, bending moments, shear forces and deformations caused by actions
- "*Strength*" is a mechanical property of a material, in units of stress
- "*Resistance*" is a mechanical property of a cross-section of a member, or a member or structure.
- *"Execution"* covers all activities carried out for the physical completion of the work including procurement, the inspection and documentation thereof. The term covers work on site; it may also signify the fabrication of components off site and their subsequent erection on site.

1.2 Eurocode annexes

There are two categories of Annex used by the Structural Eurocodes. One type is labelled 'I' and is Informative (i.e. for information and not as a mandatory part of the code). The second type I labelled 'N' and is Normative (i.e. a mandatory part of the code). In their National Annex (NA), a country can choose to make an Informative annex Normative if they so wish.

2 EN 1991 Actions on structures - Part 1-7: General Actions - Accidental actions

2.1 Introduction

2.1.1 Objectives of this section

The objectives of this report are to:

– Review the provisions of the sections on Accidental Action in EN1991 'Actions on Structures' Part 1, in comparison with the current UK codes.
– Summarise the major differences between EN 1991-1-7 and the existing UK codes.
– Include the development of specific guidance on the means of addressing the robustness of buildings that fall into the category 3 consequence class structures.

EN 1991-1-7 deals with a range of structures including significant information for bridge design. For this report only the areas concerned with buildings are considered.

2.1.2 Definitions

consequence class
classification of consequences of failure of the structure or part of it.

deflagration
propagation of a combustion zone at a velocity that is less than the speed of sound in the un-reacted medium

impacting object
the object impacting upon the structure (i.e. vehicle, ship etc).

key element
a structural member upon which the stability of the remainder of the section depends

load-bearing wall construction
non-framed masonry cross-wall construction mainly supporting vertical loading. Also includes lightweight panel construction comprising timber or steel vertical studs at close centres with particle board, expanded metal or alternative sheathing

localised failure
the part of a structure that is assumed to have collapsed, or been severely disabled, by an accidental event

robustness
the ability of a structure to withstand events like fire, explosions, impact or the consequences of human error, without being damaged to an extent disproportionate to the original cause

risk
a measure of the combination (usually the product) of the probability or frequency of occurrence of a defined hazard and the magnitude of the consequences of the occurrence.

venting panel
non-structural part of the enclosure (wall, floor, ceiling) with limited resistance that is intended to relieve the developing pressure from deflagration in order to reduce pressure on structural parts of the building

2.1.3 Current status of EN 1991-1-7

At the final edit of this report, a revised draft of the prEN1991-1-7 (dated 1 March 2005) had just been issued to be submitted to CEN members for formal voting. This will still need to be approved by various committees, hence may be subject to change. The current timetable for further versions of the code is a DAV (Date-of-availability) of June 2005 and the BS EN to be published by BSI in December 2007 along with its National Annex.

2.1.4 Current status of existing UK design recommendations and codes

As an additional complication, the UK design requirements related to accidental actions (or robustness) changed part way through this project when an amendment to the Building Regulations Approved Document A was issued in June 2004 and became effective from 1st December 2004. Although these changes do align the UK practice with some of the EN1991-1-7 requirements, they provide a significant change to the former UK practice, hence the changes are described briefly below.

2.1.4.1 *UK requirements before December 2004.*

The UK 'robustness' regulations were implemented following the progressive collapse of one corner of Ronan Point in 1968 which resulted from a gas explosion (a deflagration) on the 18th floor of the 22 storey building. The event had a significant effect on the engineering community in the UK and this led to changes in the Building Regulations 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 [1] required that the building should be so constructed that structural failure consequent on removal of any one member in a storey should be localised and limited in its extent to a certain area of that storey. If this was not possible, that member should be capable of sustaining without structural failure, an additional load corresponding to a pressure of 34 kN/m^2*.

Subsequent revisions were aimed at reducing the sensitivity of a building to disproportionate collapse. One design option was to provide effective horizontal and vertical ties in accordance with the structural codes of practice, based on design strengths related to 34 kN/m^2. Where such provisions could not be made, it was recommended that the structure should be able to bridge over the loss of an untied member and that the area of collapse be limited and localised. Finally, if it was not possible to bridge over the missing member (which may have been the case for a small minority of buildings), such a member should have been designed as a protected (or key) element capable of sustaining additional loads related to a pressure of 34 kN/m^2. In practice the 34 kN/m^2 was used to determine a notional load which was applied sequentially to key elements in each possible direction and not as a specific overpressure which would result from a gas explosion. These requirements were considered to result in more robust structures which would generally be more resistant to disproportionate failure due to various causes, such as impact, and were not solely related to gas explosions.

The guidance given in the Building Regulations was then incorporated in some structural material codes, albeit the various codes provided a number of alternative or mixed solutions to deal with the problem. The accidental loading requirement was also included in the 1996 BS Loading Code BS 6399-1 [2] 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 34 kN/m^2."

The current UK material codes and standards dealing with robust design are:

- BS5628: Code of practice for use of masonry. Part 1 - 1992 Structural use of unreinforced masonry. Clause 37
- BS 5950: Structural use of steelwork in building. Part 1 - 2000 Code of practice for design – Rolled and welded sections. Clause 2.4.5
- BS8110: Structural use of concrete. Part 1 - 1997 Structural use of plain, reinforced and prestressed concrete. Clause 2.2.2.2
- BS8110: Structural use of concrete. Part 2 - 1985 Code of practice for special circumstances. Clause 2.6

* The value of 5 psi (34 kN/m^2) was chosen with reference to a rounded estimate failure load of the load-bearing flank wall at Ronan Point

2.1.4.2 *UK requirements after December 2004.*

In June 2004, Approved Document A (2004 Edition) was published [3]. The new provisions became effective from 1st December 2004 [4]. Section 5 of the document, which is entitled 'Reducing the sensitivity of the building to disproportionate collapse in the event of an accident' introduced significant changes to the previous UK practice.

The document gives an approach for ensuring that a structure is sufficiently robust to sustain a limited extent of damage or failure, depending on the class of building, without collapse. It introduces a new classification of buildings and the design procedures which should be adopted for the various building classes. As mentioned earlier, this aligns closely with some of the guidance given in the EN1991-1-7, hence the relevant UK classification information will be presented later with the equivalent EN1991-1-7 classification and the recommended design procedures.

2.2 The contents and scope of EN1991-1-7

The contents of EN 1991-1-7 (1 March 2005) are given below. Under each section heading (given in **bold** text) a brief paragraph explains the contents of the appropriate section in EN 1991-1-7 as follows:

Foreword

The foreword of EN1991-1-7 covers similar topics to the other structural Eurocodes giving the background of the Eurocode programme, the status and field of application of Eurocodes, National Standards implementing Eurocodes, links between Eurocodes and harmonised technical specifications (ENs and ETAs) for products, additional information specific to EN 1991-1-7 and the choices which are allowed in the National Annex.

Section 1 General

Within this section the scope of EN 1991-1-7 is given along with normative references, the difference between Principles and Application Rules, terms and definitions and the symbols used.

Section 2 Classification of actions

This short section refers to the clauses in EN 1990 specifically addressing accidental actions.

Section 3 Design situations

This section starts with a general discussion, then considers three different accidental design situations: the strategy for identified accidental actions, the strategy for limiting the extent of localised failure, and the use of consequence classes.

Section 4 Impact

This section starts by considering the field of application and the representation of actions. It then considers accidental actions caused by road vehicles, fork lift trucks, derailed rail traffic under or adjacent to structures, ship traffic, and helicopters.

Section 5 Internal Explosions

This section has three parts; field of application, representation of action, and principles for design

Annex A (I♦) Robustness of Buildings - Design for Consequences of Localised Failure from an Unspecified Cause

This annex is especially important for UK engineers as it provides design guidance similar to that introduced to the UK Building Regulations in 2004. It is quite likely that this will be the design methodology recommended in the UK National Annex to EN 1991-1-7. It contains eight sections starting with the scope

♦ Annexes labelled 'I' are informative

and field of application. Subsequent sections are: introduction, consequence classes of buildings, recommended strategies, effective horizontal ties, effective vertical ties, nominal section of load-bearing wall, and key elements.

Annex B (I) Guidance for Risk Analysis

This annex contains information some of which is expected to be transferred to EN1990 in future editions of the Eurocodes. It has nine sections; introduction, definitions, description of the scope of a risk analysis, methods of risk analysis, risk acceptance and mitigating measures, risk mitigating measures, modification, communication of results and conclusions, applications to buildings and civil engineering structures.

Annex C (I) Dynamic design for impact

This annex has four sections. It starts with a general discussion and then considers impact dynamics, followed by impact from aberrant road vehicles and impact by ships.

Annex D (I) Internal explosions

This annex covers dust explosions in rooms, vessels and bunkers, natural gas explosions, together with explosions in road and rail tunnels.

2.3 Consequence classes

Perhaps the biggest change for engineers versed in pre-December 2004 UK design will be the introduction of consequence classes. These classes specify how different categories of building should be designed to deal with accidental actions.

The concept of consequence classes was introduced in EN1990 for the purpose of reliability differentiation. The criterion for classification of consequences is the importance, in terms of consequences of failure, of the structure or structural member concerned. The consequence classes given in EN 1990 are reproduced in table 2.

Table 2: Definition of Consequence Classes in EN1990

Consequences Class	Description	Examples of buildings and civil engineering works
CC1	Low consequences for loss of human life, and economic, social or environmental consequences small or negligible	Agricultural buildings where people do not normally enter (e.g. storage buildings). Greenhouses
CC2	Medium consequences for loss of human life, economic, social or environmental consequences considerable	Residential and office building, public buildings where consequences of failure are medium
CC3	High consequences for loss of human life, or economic, social or environmental consequences very great	Grandstands, public buildings where consequences of failure are high

A recommended categorisation of consequence classes is given in Annex A of EN1991-1-7 (reproduced here as table 3), although EN1991-1-7 allows the classification to be specified in National Annexes. The categorisation given in the UK Approved Document (2004) [3] is closely aligned with that in EN1991-1-7; however, there are minor differences which are outlined in table 4.

Table 3 Categorisation of Consequence Classes in EN1991-1-7

Class	Example of categorisation of building Type and Occupancy
1	Single occupancy 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 $1^{1}/_{2}$ times the building height.
2 Lower Risk Group	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 1000m^2 floor area in each storey. Single storey educational buildings All buildings not exceeding two storeys to which the public are admitted and which contain floor areas not exceeding 2000 m^2 at each storey.
2 Upper Risk Group	Hotels, flats, apartments and other residential buildings greater than 4 storeys but not exceeding 15 storeys. Educational buildings greater than single 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 the public are admitted and which contain floor areas exceeding 2000 m^2 but not exceeding 5000 m^2 at each storey. Car parking not exceeding 6 storeys.
3	All buildings defined above as Class 2 Lower and Upper Consequence Class that exceed the limits on area and number of storeys. All buildings to which members of the public are admitted in significant numbers. Stadia accommodating more than 5000 spectators

Table 4 Differences in Consequence Class definitions between EN 1991-1-7 and the UK.

Class	EN1991-1-7 (items not in BR – A3)	BR - A3 (items not in EN1991-1-7)
1	Single occupancy houses not exceeding 4 storeys	Houses not exceeding 4 storeys
2A	Retailing premises not exceeding 3 storeys of less than 1000 m^2 floor area at each storey	Retailing premises not exceeding 3 storeys of less than 2000 m^2 floor area at each storey.
3	Stadia accommodating more than 5000 spectators.	Grandstands accommodating more than 5000 spectators.
		Buildings containing hazardous substances and/or processes

2.4 Design Situations

Design situations are classified in EN 1990. The strategies are illustrated in Figure 3.1 of EN1991-1-7 which is reproduced here as figure 1.

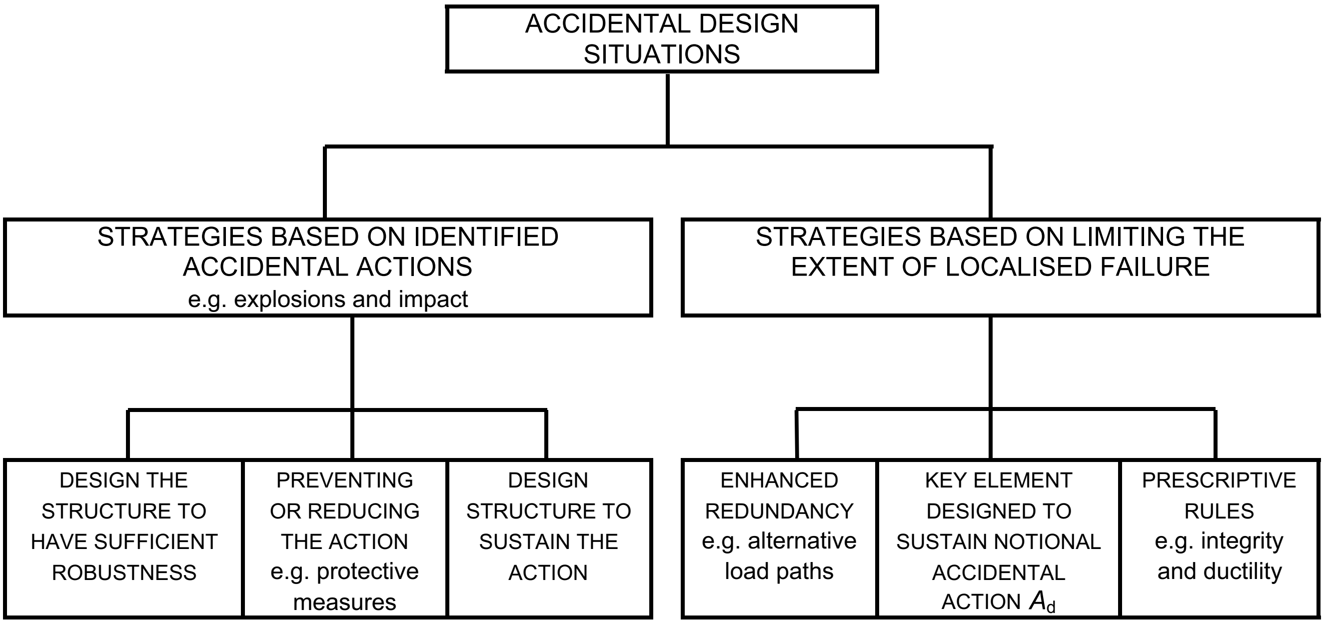


Figure 1 - Accidental Design Situations

It can be appreciated that there are two different design strategies and the strategy to adopt may depend on the situation being considered. The strategy concerned with limiting localised failure will be considered first as this aligns with current UK guidance. EN 1991-1-7 states that the events to be taken into account may be given in the National Annex, or agreed for individual projects.

2.5 Recommended strategies to ensure that buildings are sufficiently robust to sustain localised failure without a disproportionate collapse - for EN1991-1-7 Annex A and Buildings Regulations A3 (post June 2004)

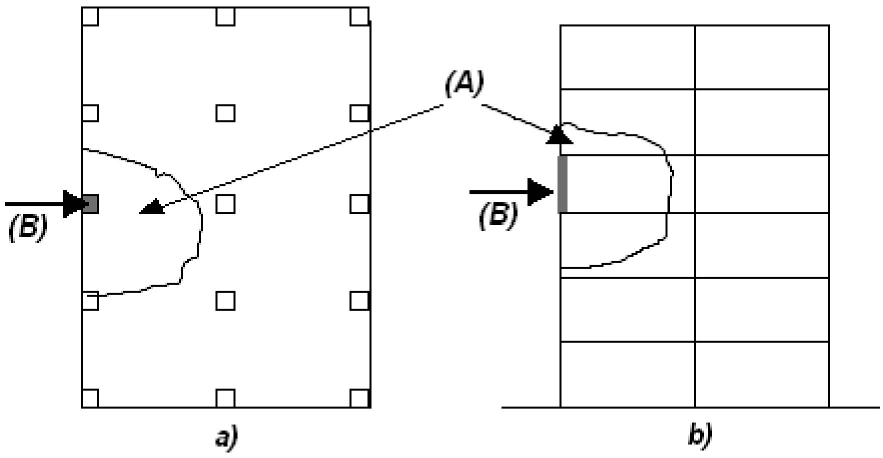
There are many similarities between the recommendations in EN1991-1-7 Annex A and the current Building Regulations. Table 5 gives the recommendations made in both documents.

From Table 5 it can be seen that the recommended procedures for determining the required strength of the ties are similar, albeit EN1991-1-7 refers to other parts of that code (A5 & A6), whereas the Buildings Regulations refer to the British Standards listed earlier. Not surprisingly there are similarities for this strength determination, but also a few differences which will be considered next. Design for specific accidental actions and risk analysis will be considered later.

EN 1991-1-7 Annex A5 considers effective horizontal ties, first for framed structures and then for load-bearing wall construction. A6 considers vertical ties, also for framed structures and then load-bearing wall construction.

Table 5. Recommended strategies to ensure that buildings are sufficiently robust to sustain localised failure without a disproportionate collapse

Class	EN1991-1-7	BR - A3
1	Provided a building has been designed and constructed in accordance with the rules given in EN1990 to EN 1999 for satisfying stability in normal use, no further specific consideration is necessary with regard to accidental actions from unidentified causes.	Provided that the building has been designed and constructed in accordance with the rules given in this approved document, or other guidance under Section 1, for meeting compliance with requirements BR A1 and BR A2 in normal use, no additional measures are likely to be necessary.
2A	In addition to the recommended strategies for Class 1, the provision of effective horizontal ties, or effective anchorage of suspended floor to walls, as defined in A.5.1 and A.5.2 respectively for framed and load-bearing wall construction should be provided.	Provide effective horizontal ties, or effective anchorage of suspended floor to walls, as described in the codes and standards *(these are listed in 4.1.3.1.above)*.
2B	In addition to the recommended strategies for Class 1, the provision of - Effective horizontal ties, as defined in A.5.1 and A.5.2 respectively for framed and load-bearing wall construction (see definition) together with effective vertical ties, as defined in A6, in all supporting columns and walls should be provided, or alternatively, The building should be checked to ensure that upon the notional removal of each supporting column and each beam supporting a column, or any nominal section of load-bearing wall as defined in A7 below (one at a time in each storey of the building) that the building remains stable and that any local damage does not exceed a certain limit, see Note 1. Where the notional removal of such columns and sections of walls would result in an extent of damage in excess of the agreed limit, or other such limit, then such elements should be designed as a 'key element'. See A8. In the case of load-bearing wall construction, the notional removal of a section of wall, one at a time, is likely to be the most practical strategy to adopt.	Provide effective horizontal and vertical ties, as described in the BSI codes and standards in all supporting columns and walls, or alternatively, check that upon the notional removal of each supporting column and each beam supporting one or more columns, or any nominal length of load-bearing wall (one at a time in each storey of the building) that the building remains stable and that the area of floor at any storey at risk of collapse (if any) does not exceed 15% of the floor area of that storey or 70m^2, whichever is smaller, and does not extend further than the immediate adjacent storeys (diagram 25) see Note 2. Where the notional removal of such columns and sections of walls would result in an extent of damage in excess of the above limit, then such elements should be designed as a 'key element'.
3	A systematic risk assessment of the building should be undertaken taking into account both foreseeable and unforeseeable hazards.	A systematic risk assessment of the building should be undertaken taking into account all the normal hazards that may reasonably be foreseen, together with any abnormal hazards. Critical situations for design should be selected that reflect the conditions that can reasonably be foreseen as possible during the life of the building. The structural form and concept and any protective measures should then be chosen and the detailed design of the structure and its elements undertaken in accordance with the recommendation given in the listed codes and standards.
	Note 1. The limit of admissible damage may be different for each type of building. The recommended value is 15% of the floor, or 100 m^2, whichever is greater, in each of two adjacent storeys. EN 1991-1-7 figure A1 is reproduced here as figure 2	Note 2. Diagram 25 in BR A3 is essentially the same as EN1991-1-7 figure A1 except the values of the recommended area.



Key

(A) Local damage not exceeding 15 % of floor area in each of two adjacent storeys
(B) Notional column to be removed
a) Plan b) Section

Figure 2 – Recommended Limit of admissible damage

The guidance given in EN1991-1-7 Annex A is similar to that given in British Standards, although the latter tends to provide more detailed information. For framed structures, the information in A5 is similar to that in BS 5950:2000 clause 2.4.5.2 even adopting the same figure. Some minor differences occur (including symbols), for example the tensile load for internal ties in A5 is:

$0.8\ (g_k + \psi q_k)\ sL$ *or*   75 kN   whichever is the greater   (here ψ =1)

whereas in BS 5950 the equivalent load is

$0.5\ (1.4g_k + 1.6q_k)\ s_tL$ but not less than 75 kN

A similar correspondence can be found between A6 and the British Standards and also with A7 which defines the nominal section of load bearing walls.

For load-bearing wall construction A5.2 considers two classes. Class 2 buildings lower risk group, in which appropriate robustness should be provided by adopting a cellular form of construction designed to facilitate interaction of all components including an appropriate means of anchoring the floor to the walls. And Class 2 buildings of the upper risk group in which continuous effective horizontal ties should be provided in the floors. The recommended actions are similar to those in BS5628 clause 37.

A8 discusses key elements, and requires the element to be capable of sustaining an accidental action of A_d applied in horizontal and vertical directions (in one direction at a time) to the member and any attached components having regard to the ultimate strength of such components and their connections. Although A_d can be selected within the National Annex a value of 34kN/m^2 is recommended. The 34 kN/m^2 value aligns with UK practice although in EN1991-1-7 the loading should be in accordance with expression (6.11b) of EN 1990, whereas in the UK the loading should be assumed to act simultaneously with 1/3 of all normal characteristic loading (i.e. wind and imposed loading).

2.6 EN1991-1-7 recommendations for design for specific accidental actions

In the previous section the guidance for the design of robust buildings or for the consequences of localised failure from an unspecified cause was considered, but EN1991-1-7 also considers design for specific actions, namely impact and explosion. It may well be that the UK National Annex simply recommends design using Annex A to align with the new UK practice. However, as this is not yet confirmed, it is pertinent to consider the guidance related to specific accidental actions, especially as EN 1991 labels Annex A as Informative not Normative. In their National Annex, the UK may choose to make Annex A Normative.

The concept of design for specific accidental actions is therefore new to most UK designers, although the UK regulations were developed as a result of the gas explosion at Ronan Point. Hence, it may be inferred that the UK regulations are appropriate for design to avoid disproportionate failure in the event of an internal gas explosion.

2.6.1 Internal explosions

EN1991-1-7 considers various types of internal explosions which are listed in section 2.2 herein. For this report, only internal gas explosions (deflagrations) in buildings are considered, and EN1991-1-7 restricts these to explosions in single vented rooms. Although it is not specifically stated, in buildings of Classes 2 and 3, standard windows and doors are usually much weaker than walls and floors and hence can be considered to act as vents in the event of an internal explosion.

EN1991-1-7 states that for Class 1 structures, no specific consideration of the effects of an explosion should be necessary other than complying with the rules for connections and interactions between components provided in EN 1990 to EN1999.

For Class 2 structures EN 1991-1-7 considers the normative design situation to be a natural gas explosion in a vented single room. It provides two simple empirical formulae for determining the equivalent static pressure to be used in design; both of which require the vent failure pressure. For situations where the provision of natural gas is totally impossible, an unspecified reduced value of the equivalent static pressure may be permissible. This does not consider the type of multi-room explosion that occurred at Ronan Point [5], and this is why the calculated pressures will be much less than the 34 kN/m^2 given in UK codes. It also ignores cylinder explosions which are a large proportion of the explosions recorded in the UK. As peak pressures in a single room explosion are controlled primarily by the vent strength, the pressures generated by cylinder explosions can be as high as those from piped gas explosions, so any reduction in the equivalent static pressure should be carefully considered.

For Class 3 structures some information is given in Annex D dealing with advanced design for explosions, although a normative design situation is not defined and much is left to the individual designer. This topic will be considered later.

2.6.2 Impact

EN 1991-1-7 considers impacts from a variety of sources including road and rail vehicles ships and helicopters. For this report, only road vehicle impacts on buildings are considered. EN1991-1-7 limits this to buildings used for car parking, parking garages, buildings in which vehicles or fork lift trucks are driven or buildings that are in the vicinity of traffic.

For explosions the code gives specific advice for the various consequence classes, but this is not the case for vehicle impacts; hence the general guidance is probably relevant, i.e. for Class 1 no specific consideration is necessary; for Class 2 a simplified analysis by static equivalent models may be appropriate; whereas Class 3 may require a risk analysis and use of refined models such as dynamic analysis, non-linear models and load structure interaction.

EN1991-1-7 states that actions due to impact shall be determined by taking into account the impact velocity of the impacting object and the mass distribution, deformation behaviour, damping characteristics of both the impacting object and the structure. It also suggests the type of material properties that should be used in design.

Equivalent static forces may be used for verification of static equilibrium, strength verification and determination of deformations. However, if the structure is designed to absorb impact energy by elastic-plastic deformation the equivalent static loads may be determined by considering both plastic strength and deformation capacity of structural members.

Conservative approximations may be made on the assumption that the impacting body absorbs all of the impact energy (known as a hard impact). For this latter case equivalent static forces are given for vehicle impact on members supporting structures over or adjacent to roadways and for forces due to impact on superstructures. The area of application of the collision force is also specified.

Annex C (I) of EN1991-1-7 provides more detailed information on dynamic design for impact but it does not provide guidance on non-linear material behaviour. It provides some relatively simple formulae for determining the maximum force in a hard impact or the required ductility to absorb the collision energy for a soft impact. It then considers the determination of the velocity of an aberrant road vehicle and provides design values for vehicle mass, velocity and dynamic impact force for a range of road types.

2.7 Risk analysis for Class 3 buildings

The guidance for the design of Class 3 buildings for specific actions is considered in the previous section, and it can be appreciated that much is left to the designer. For robust design to limit the extent of localised failure the requirements are much clearer, although their implementation may not be straightforward. The requirements state:

> *A systematic risk assessment of the building should be undertaken taking into account both foreseeable and unforeseeable hazards.*

Risk analysis is the topic discussed in Annex B (I) of EN1991-1-7 and in the introduction to that annex a pictorial overview of the envisaged risk analysis is given. This is reproduced here as Figure 3.

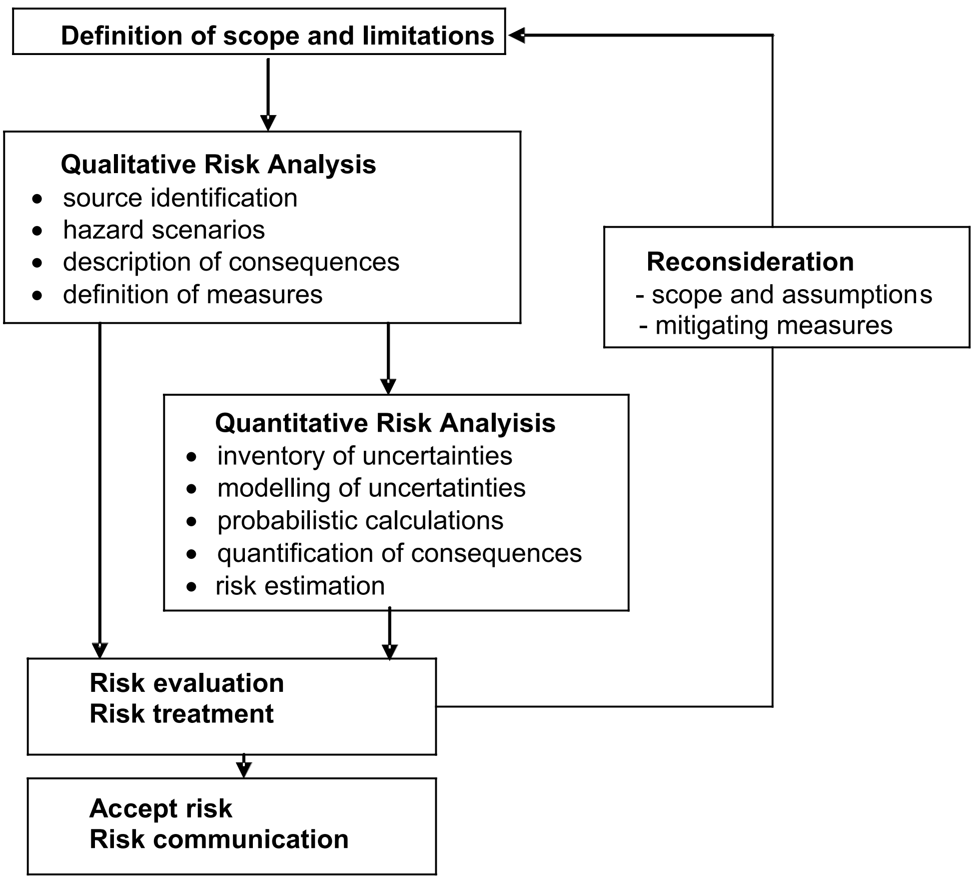


Figure 3: Overview of Risk Analysis

As can be seen from Figure 3, there are two types of risk analysis. First a qualitative analysis looking at the various hazards and their consequences, and secondly a quantitative analysis that is potentially more rigorous, but which may only be appropriate in certain circumstances. At the onset it should be stated that this is not an exact science and the primary gain is obtained through a systematic examination and recording of the potential hazards, the structure's vulnerability to these hazards, and if necessary the measures that can be taken to minimise any undesirable consequences. Therefore it is not appropriate to provide a set procedure for any specific type of building.

Logically design for Class 3 structures should consider the design rules for Class 2 (upper band) as a minimum. This may include considerations of specific defined incidents or the provision of general robustness - via tying, alternate load paths or key element design. However, a systematic risk analysis may result in enhancements to the Class 2 requirements or the provision of further hazard mitigating measures.

2.7.1 Qualitative risk analysis

A qualitative risk analysis is really a systematic consideration of the various hazard scenarios, recording what has been considered and the actions that are to be taken. The analysis should initially identify the potential hazards to which a building may be exposed. Logically this will include many other items besides those specifically identified as accidental actions including fire and possibly terrorist activities.

For each hazard a profile should be developed including a determination of various descriptors including magnitude, duration, frequency, probability and extent. It may well be necessary to consult various people (the stakeholders) regarding what hazards should be included in design and it may be reasonable to exclude some hazards. Further information on risk analyses can be found in refs [6, 7 & 8].

Next for each hazard it is necessary to understand how it will affect the structure and what impact this would have on the building contents, especially the building occupiers (immediate and longer term) and possibly the local community. This requires an assessment of the vulnerability of the construction, contents and economic value of its functions.

The systematic evaluation of the vulnerability of the assets to the various hazards should provide the base to develop a design strategy, maybe eliminating some hazards, reducing others, designing to resist specific hazards or even ignoring some. General robustness measures (i.e. those for class 2B) should be adopted for unforeseeable hazards (design or construction errors, unexpected deterioration, etc).

Once a risk has been determined it has to be decided whether it will be accepted or whether mitigating measures will be specified. To mitigate the risk the following measures may be taken:

- Structural measures, that is by designing over-strong structural elements or by designing for second load paths in case of local failures.
- Non-structural measures, that is by a reduction of the event probability, the action intensity or the consequences.

In some instances there may be conflicting requirements for different hazards and these should be considered carefully. For example, the use of laminated windows may reduce the damage to external explosions (usually detonations) but serve to increase the pressures in internal gas explosions (deflagrations).

The results of the risk analysis should be presented as a list of consequences and probabilities and their degree of acceptance should be discussed. The probabilities may need to be expressed in relative terms, i.e. high, moderate, low, unless more detailed information is available. Recommendations for measures to mitigate risk that naturally arise from the risk analysis should be stated.

It is sensible to compile the results of the work and reasons for the various decisions, in a written report which may need to be peer reviewed. The report may need to be re-evaluated periodically or when there is a change in circumstances which may affect specific hazards and thereby require different mitigation measures.

2.7.2 Quantitative evaluation

In a rigorous quantitative assessment, mathematical calculations are used to determine the expected consequences from the whole range of hazards. This provides a potentially more accurate picture of the risk (and the benefits of avoiding it) than the qualitative method. However the basic data related to the risk may not be sufficient to warrant a rigorous mathematical treatment.

Within the procedures outlined in Annex B (I) of EN 1991-1-7 there is the option of undertaking a quantitative risk analysis. The equation to be used to determine probability of failure for any one specific hazard is of the type:

$$P_f(T) = N\int_0^\infty P(F|M=m)\, f_M(m)\, dm$$

where: N is the total number of relevant events in the time period T

$f_M(m)$ is the probability density function of the random magnitude M of the hazard

and $P(F|M=m)$ is the conditional probability of failure for the specified hazard.

However, it is important to consider whether the available information is sufficient to make such an analysis worthwhile. The statistical data available regarding internal gas explosions in housing in the UK is summarised in the next section and this is probably as detailed as any statistical data on a specific accidental action. Nevertheless, it is apparent that it is still not possible to determine the intensity of a gas explosion with any confidence, except for single room explosions which may be less severe than multi-room explosions. Therefore for this important accidental action hazard, it is not yet sensible to place any confidence in a quantitative analysis. This is not saying that the analysis methods are incorrect, and indeed raising this issue may well serve to generate more useful data and information in the future. The quantity and quality of data for use in such analyses is a prime consideration.

A full quantitative risk analysis would require this form of evaluation for all identifiable hazards and the determination of the total risk. Whilst this might be a laudable objective it does not seem a viable option at present.

2.7.3 Statistical data

When discussing hazards the risk of occurrence arises and it is worthwhile taking a brief overview of the available information. With accidental actions the main guidance in the UK was developed for gas explosions, this being initiated following the progressive failure of one corner of Ronan Point in 1968 as a result of a gas explosion. Since then a significant amount of information has been collected regarding the frequency and severity of gas explosions, hence this may be considered to represent the most comprehensive statistical information related to any form of accidental action. Considering gas explosions in dwellings in the UK, the annual probability of three categories of explosion and indicative peak pressures are given in table 6.

Table 6 Annual probabilities of gas explosions in dwellings (from ref 5).

	Probability of occurrence	Estimated peak pressure
Any explosion	0.079×10^{-4}	
Significant explosion	0.015×10^{-4}	< 17 kN/m^2
Severe or very severe explosion	0.005×10^{-4}	> 17 kN/m^2

The probability of 10^{-4} is that suggested in the Eurocodes as the maximum representative value for an accidental action. From the designers view point it is only the significant and severe explosions that are of concern. Broadly speaking the significant gas explosions occur in a single room and are either produced by piped gas or cylinder/aerosol gas (the latter accounting for approximately 25% of this type of explosion in the UK). The peak pressure for this type of explosion is limited by the venting of the explosion due to failure of the weakest element in the room, usually the window or door. For this type of explosion EN1991-1-7 provides guidance for estimating peak pressures (this being the design recommendation for Class 2 structures). The severe explosions (including the very severe category) occur in more than one room and are primarily related to piped gas (due to the requirement for a large source to provide an explosive mixture in several rooms). Here the initial explosion in one room propagates into other rooms, but in so doing causes a progressively more turbulent situation which results in a much more violent explosion and one which is not simply limited by structural venting. This is the type of explosion that occurred at Ronan Point. No guidance is available for the determination of the pressures in this type of explosion although they can be significantly larger than those for a single room event.

It can be appreciated that although the hazard for which Class 3 buildings should be designed is known (i.e. severe or very severe gas explosion) and the risk of its occurrence can be determined, the tools are not available to determine explosive pressures in this type of explosion accurately. Therefore, it is not easy to evaluate the consequences of this type of explosion, even for a reasonably well defined scenario. As a result, design is likely to be based on general robustness principles, which as it happens were first developed in the UK for this very hazard scenario.

The other hazard specifically considered in EN1991-1-7 is impact, and some statistical data is given in ref [9]. It was concluded that the average risk of significant vehicle impacts on buildings in the UK is greater than the corresponding risks of gas explosions although there are relatively fewer severe impacts. Not surprisingly the statistics show that when considering accidental impact from vehicles the building location is critical. It follows that given the opportunity, risk can be minimised by locating the building away from roads, or by using bollards or safety barriers to prevent vehicles reaching the building, or by using others barriers like ramps or street furniture for the same purpose. This is especially important if 'key' elements of the building are vulnerable. EN1991-1-7 provides guidance for the evaluation of impact forces if it is necessary to design key elements for this eventuality. For this hazard the provision of general robustness measures, which were originally based upon resistance to gas explosions, may not be ideal.

2.8 National Annex

EN 1991-1-7 gives alternative procedures, values and recommendations for classes with notes indicating where national choices may have to be made. Therefore the National Standard implementing EN 1991-1-7 should have a National Annex (NA) containing all Nationally Determined Parameters (NDPs) to be used for the design of buildings and civil engineering works to be constructed in the relevant country.

National choice is allowed in EN 1991-1-7 through the clauses listed in table 7. For each clause related to buildings a brief description is given.

Although the UK National Annex may not be available until the end of 2007, it is reasonable to assume that the default parameters given in the Eurocode will be adopted, except where those default values differ from current UK practice, in which case the latter may be preferred.

The National Annex may only contain information on those parameters which are left open in the Eurocode for national choice, known as Nationally Determined Parameters, to be used for the design of buildings and civil engineering works to be constructed in the country concerned, i.e. :

- values and/or classes where alternatives are given in the Eurocode;
- values to be used where a symbol only is given in the Eurocode,
- country specific data (geographical, climatic, etc) e.g. snow map,
- procedure to be used where alternative procedures are given in the Eurocode.

It may also contain :

- decisions on the application of informative annexes;
- references to non-contradictory complementary information to assist the user to apply the Eurocode.

Table 7 Clauses where the UK National Annex may give alternative rules or guidance
A brief description is given for clauses relating to buildings.
The clauses highlighted in grey do not relate to buildings.

Paragraph	Item
2 (2)	Classification of accidental actions *The NA or the individual project may specify the treatment of accidental actions (impacts) which are not classified as free actions.*
3.1(2)	Strategies for Accidental Design Situations *Notional values for identified accidental actions are proposed. These values may be altered in the NA or for an individual project and agreed for the design by the client and the relevant authority.*
3.2(1)	Level of risk *Levels of acceptable risks may be given in the NA as non-contradictory, complementary information.*
3.3(2)	Notional accidental action *The NA may define the model which may be a concentrated or a distributed action and the design value* A_d. *The recommended model for buildings is a uniformly distributed load applicable in the horizontal and vertical directions (one direction at a time) to the key element and any attached components (e.g. claddings, etc). The recommended value is 34* kN/m^2 *for building structures.*
3.3(2)	Limit of localised failure *The NA may state the acceptable limit of "localised failure". The indicative limit for building structures is 100* m^2 *or 15% of the floor area, whichever is less, on two adjacent floors caused by the removal of any supporting column, pier or wall.*
3.3(2)	Choice of strategies *The NA may state which of the approaches given in 3.3 are to be considered for various structures.*
3.4(1)	Consequences classes *The NA may provide a categorization of structures according to the consequence classes in 3.4(1). A suggested classification of consequence classes relating to buildings is provided in Annex A.*
3.4(2)	Design approaches *The NA may give reference to, as non conflicting, complementary information, appropriate design approaches for higher and lower consequence classes of the structure.*
4.1(1)	Definition of lightweight structures
4.1(1)	Guidance on impact forces transmitted to the foundations
4.3.1(1)	Values of vehicle impact forces *For hard impact from road traffic the design values may be defined in the NA*
4.3.1(1)	Impact force as a function of the distance from traffic lanes *The NA may prescribe the force as a function of the distance*
4.3.1(1)	Types or elements of structure subject to vehicular collision *The NA may define types or elements of the structure that may not need to be considered for vehicular collision.*
4.3.1(2)	The treatment of the forces F_{dx} and F_{dy} *Rules for dealing with* F_{dx} *and* F_{dy} *may be defined in the NA*
4.3.1(3)	The conditions of impact from road vehicles *The NA may define the conditions of impact from road vehicles*

4.3.2(1)	Impact actions on underside of bridge decks
4.3.2(1)	Reduction factor r
4.3.2(2)	Use of F_{dy}
4.3.2(3)	Dimension and position of impact areas
4.4(1)	Value of impact forces from forklift trucks *The NA may give the value of the equivalent static design force F*
4.5	Type of rail traffic
4.5.1.2(1)	Structures to be included in each exposure class
4.5.1.2(1)	Classification of temporary structures and auxiliary construction works
4.5.1.4(1)	Impact forces from derailed traffic
4.5.1.4(2)	Reduction of impact forces
4.5.1.4(3)	Point of application of impact forces
4.5.1.4(5)	Impact forces for speeds greater than 120km/h
4.5.1.5(1)	Requirements for Class B structures
4.5.2(1)	Areas beyond track ends
4.5.2(4)	Impact forces on end walls
4.6.1(1)	Classification of ship impacts
4.6.2(1)	Values of frontal and lateral forces from ships
4.6.2(2)	Impact force due to friction
4.6.2(3)	The height of application of the impact force
4.6.2(4)	Impact forces on bridge decks from ships
4.6.3(1)	Dynamic impact forces from seagoing ships
4.6.3(3)	Value of the friction coefficient
4.6.3(5)	Dimension and position of impact areas
5.1 (3)	Procedures for internal explosion *The NA may give the procedures to be used for the types of internal explosions*

3. References

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