EC 6: Structural Use of Masonry

EC 6: Calcul des structures en maçonnerie

EC 6: Mauerwerk als Ingenieurbaustoff

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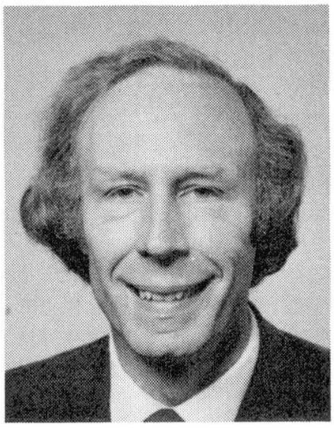


Barry Haseltine, born 1933, was educated at Imperial College, London, graduating in civil engineering. He has been a consulting engineer for most of his career and has been closely involved with the masonry industry in their research work and publications. For many years he has Chaired the British Standards Institution Committee dealing with masonry and in also the Chairman of Sub-Committee 6 of TC 250, responsible for the masonry structural Eurocode EC 6.

SUMMARY

The paper describes the framework of the Eurocode 6 Design of Masonry Structures and outlines the full plan of work for the various parts. Parts 1 and 10 are described to the extent that the drafting work has so far been completed.

RESUME

Cet article présente le cadre dans lequel l'Eurocode 6 a été écrit. Il décrit également le plan de travail complet des différentes parties et il termine en examinant l'état actuel des parties 1 et 10.

ZUSAMMENFASSUNG

Der Beitrag beschreibt die Struktur von EC 6, Bemessung von tragendem Mauerwerk, und skizziert den umfassenden Arbeitsplan der verschiedenen Normenteile. Teile 1 und 10 werden in ihrem gegenwärtigen Entwurfsstand dargestellt.

1.0 INTRODUCTION

This paper is written as one of a sereies of detailed descriptions of Eurocode work to be read in conjunction with the paper by Dr.Gunter Breitschaft on the conceptual approach for the Eurocodes. Masonry, used here to cover brickwork, blockwork and natural stonework laid in a variety of mortars, is a widely used material in the world at large and in Europe in particular. Several thousand years experience in the use of masonry gives it a pre-eminent position as a building material that leads to some difficulties because of the diverse range of units i.e. bricks, blocks, pieces of stone, that have developed over the centuries, but more particularly in the last one. The local traditions of building have been adapted to suit the environment in which the material is used with the result that there is a vast array of techniques for building masonry walls throughout the area of interest in Eurocode 6.

Apart form the use of locally available natural stones, which have led to such variety and richness of buildings in those areas lucky enough to possess the material, the most usual form of masonry was clay brickwork, not differentiating here as to the size, which can imply in some countries, brick or block depending on the area. Clay masonry was used for its facing qualities as well as for its weather resistance and durability, but in some Countries it was rendered and was not seen by the user. Units made in any one area were only used locally because of transport difficulties and it depended very much on the quality of the clay available to the brickmaker, so that one sees colours of brick appropriate to the way in which the local material burns. Places with very fine clay, such as the Po Valley in Italy have made large intricately perforated units for use in, not only walls, but floors and shell roofs.

In this century various types of concrete masonry unit have been developed to the extent that very lightweight aerated units are now available to provide high insulation qualities in the wall. This rich and diverse range of materials and methods of use has given the Code Committee more problems than have probably been experienced with the other structural materials, because one Country or Region finds it difficult to appreciate the problems its method of design would cause in another area where the traditions are very different.

The following parts have been, or are intended to be, produced to complete EC6:

Part 1 : The design of masonry structures : General rules for buildings
Part 2 : Design, selection of materials and execution of masonry
Part 3 : Simplified calculation methods and simple rules for the design of masonry
Part 10 : Fire performance of masonry structures

Of these Parts, Part 1 is well advanced and was subjected to National examination when the Eurocodes were still under the auspices of the European Commission; it is now the subject of intensive work in the CEN TC250/SC6 PT1 to produce a version that can be issued as an ENV in 1994. Parts 2 & 3 have not yet been started. Part 10 was offerred for discussion among Community members at a conference held in Luxenbourg and subsequently, and again the comments are being incorporated with a view to an ENV being published in 1994.

The specifications for masonry units and ancillary components and mortar are needed on a European wide level in order properly to use Eurocode 6. This work is being undertaken by TC125 who has produced in excess of 60 draft Standards that, at the time of this conference, are likely to be submitted for National enquiry. TC125 has an interest in the way in which its units are specified in work and accordingly is anxious to see Part 2 prepared; it wishes to co-operate actively in its preparation.

This paper has been sub-divided into parts covering the Parts of the Eurocode as outlined above.

2.0 EUROCODE 6 : PART 1

2.1 Scope

Part 1 contains principles and rules of application for the design of unreinforced and reinforced masonry elements, including walls, beams and columns. The Rules are intended for use in building or Civil Engineering structures but not for bridges. The original Commission programme included Part 1A : Detailed Rules for lateral load design. Part 1B : Complex shape sections in masonry structures, and a Part 1C that has now been incorporated into Part 1.

The Commission did not allow work to start on a structural Eurocode until an International pre-code document was available. For masonry this was the work of CIB Commission W23, who published their report 58 in 1980 and report 94 in 1987.

For drafting reasons the section dealing with unreinforced masonry was drafted first and has been the subject of National examination. A large amount of comment was received and work is part-way through in incorporating that in a revised version. The section covering reinforced masonry, including prestressed, was subjected to National examination more recently and the comments are just beginning to be considered by the project team. The Eurocodes are primarily intended for the use in the design of new structures but could well be used for analysis of existing masonry buildings where the information would be applicable.

In the drafting of Eurocode 6, the Drafting Panel were required to remain within the general layout of Eurocodes agreed by the Co-ordination Group. The Eurocodes use a subdivision of 'Principles' and 'Rules of Application'. A Principle is something for which no alternative approach is possible, and a Rule of Application is a means, but not necessarily the only means, of satisfying that Principle. There has been some criticism of EC6 in the National Examination, largely on the basis of the excess complication indicated in Section 2, which is common to all the Eurocodes. In practice, this Chapter will be little used by the designer and only those parts of it that give the partial safety factors will be of interest to him. When there is an EC Actions, a large part of the present Section 2 will be removed and reference made to Part 1 Basis of Design, of that document.

In the following paragraphs, aspects of Euorocde 6 Part 1 are highlighted and discussed.

2.2 Section 1

This section includes the scope, definitions and symbols, it requires no comment here.

2.3 Section 2 Basis of Design

This section is common to all of the Eurocodes so that there is a unified approach to the definitions of limit states and design situations. Actions, characteristic values, design values, material properties and material partial safety factors, are all given in this section. Much of the chapter is material independent but material dependent parts have been added, eg the partial safety factors for material for masonry are different from those for other materials and are given in Section 2. Unreinforced masonry does not usually require the consideration of the Serviceability Limit State, as satisfying the Ultimate Limit State usually avoids cracking and deflection problems. This is not so for Reinforced Masonry, when both the Ultimate and Serviceability Limit States need to be addressed.

The extract of EC6, Section 2, given below shows the Partial Safety Factors for loads and materials.

Ultimate Limit State

γ_F	permanent load	1.35
	imposed load	1.50

Partial coefficients for material properties, γ_M

			Category of construction control		
			A	B	C*
Masonry	Category of manufacturing control	A	2.0	2.3	3.5 *
		B	-	2.5	3.5 *
Anchorage bond			1.5	1.8	*
Steel				1.15	

* Category C construction control should not be used for reinforced masonry.

When verifying the stability in the case of accidental actions, the γ_M for masonry may be taken as 1.2, 1.5 and 1.8 for categories A, B and C respectively.

For serviceability limit state verification, $\gamma_M = 1.0$

Some countries presently differentiate partial safety factors according to the manufacturing control of the masonry units and the control of workmanship on the building site. This approach has been adopted in EC6; in this way it is hoped that the differences in safety level resulting from varying control will be evened out. Because EC6 must cover a wide range of unit manufacture and construction techniques across the Community and EFTA countries, four partial safety factors have been given, covering two levels of manufacturing control and three of construction control (Note that 2 spaces in the matrix of 6 are not used). The figures range from 2 to 3.5 but it is expected there will be a move to reduce these numbers in the Project Team. Commission instructions on the Attestation and Conformity of materials might affect the way in which the Manufacturing Control categories are used.

2.4 Section 3 : Materials

This section describes the types of masonry unit to which the code applies, the types of mortar and their properties. Much of the detail presently given in the text will be replaced by simple references to the Material Standards being produced by TC125. The strength of masonry in compression, flexure and shear is given. The most important of these strengths is the characteristic compressive strength of masonry, f_k, which is described in relation to the strength of the unit and the mortar. The flexural strength, f_{xk}, is related to the water absorbtion of clay units, the type of unit and the mortar. The shear strength, f_v, is related to the type of unit, mortar and extent of vertical loading.

The properties of reinforcment, prestressing steel and concrete infill are given.

2.4.1 Characteristic Compressive Strength of Masonry f_k

The basic shape of the formula for the Characteristic Compressive strength, f_k, was given in the National Examination draft. Since then, many wall and wallette results have been analysed and formulae for masonry made with general purpose mortar, lightweight mortar and thin joint mortar, have been developed. For normal masonry ie. made with mortar containing sand up to 5mm,

$$f_k = K.\, f_b^{\,0.65} .f_m^{\,0.25} \text{ N/mm}^2$$

where f_b is not taken to be greater than 75N/mm²,

and K is 0.60 for Group 1 masonry units when the thickness of the masonry is equal to the width or length of the units so that there is no longitudinal mortar joint through part of the length of the wall.

or is 0.55 for Group 2 masonry units when the thickness of the masonry is equal to the width or length of the units so that there is no longitudinal mortar joint through part of the length of the wall.

or is 0.50 when, for Group 1 and 2 masonry units, there is a longitudinal mortar joint through part of the length of the masonry or, for certain walls, throughout the whole length of the masonry.

or is 0.3 for Group 3 units.

f_b is the normalised compressive strength of the masonry units in the direction of the applied loading, calculated from the mean crushing strength of the units, tested in accordance with (CEN Standard Ref: CEN/TC125/N34) and multiplied by the factor δ, to allow for the height and width of the units as given in Table 3.2.

f_m is the compressive strength of the general purpose mortar.

2.4.2 Characteristic Shear Strength f_{vk}

The shear strength of masonry is based on the Coulomb approach such that the characteristic shear strength of unreinforced masonry, f_{vk}, may be taken as:

$$f_{vk} = f_{vko} + 0.4\sigma_d \geq 0.05\, f_b$$

but not greater than certain limiting values of from 1.0 to 1.7N/mm².

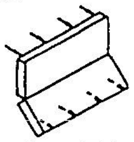
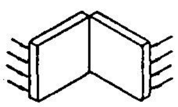
where f_{vko} is the shear strength at zero σ_d and varies from 0.1 to 0.3

σ_d is the design vertical compressive stress in the wall at the level under consideration using the load combination giving the least vertical load

f_b is the normalised compressive strength of the unit.

2.4.3 Characteristic Flexural Strength of Masonry f_{xk}

The idea of allowing "tension" in masonry, albeit in out of plane flexure, surprises some designers in Europe, and yet how else does a masonry wall transmit wind forces to the bracing elements of the structure? The suggested table of flexural strengths presently in EC6 is reproduced below. It is recognised that this Table, based as it is largely on British practice, may need some modification in the editorial process.

	Plane of failure parallel to bed joints 			Plane of failure perpendicular to bed joints 		
Mortar type	M15 M20	M10 & M5	M2	M15 M20	M10 & M5	M2
Clay units with a water absorption:						
less than 7%	0.7	0.5	0.4	2.0	1.5	1.2
between 7% and 12%	0.5	0.4	0.35	1.5	1.1	1.0
over 12%	0.4	0.3	0.25	1.1	0.9	0.8
Calcium silicate units	0.3		0.2	0.9		0.6
Concrete units or highly perforated units with a characteristic compressive strength $\geq$ 3.5 N/mm² used in walls of thickness* :						
up to 100 mm	0.25		0.2	0.45		0.4
250 mm	0.15		0.1	0.25		0.2

* The thickness should be taken to be the thickness of the wall, for a single-leaf wall, or the thickness of the appropriate leaf, for a cavity wall. Linear interpolation is permitted for thicknesses between 100 and 250mm.

2.5 Section 4 - Design of Masonry

This section gives the fundamental requirements for design of constituent structural members for structural behaviour under normal loads and under accidental situations other than earthquakes. The reason that earthquake loading is not covered is that this subject is part of EC8 that has material dependent sections to supplement each of EC's 2 to 7, giving the additional design requirements for the earthquake situation.

The design of masonry walls is subdivided into three main sections:

Walls subject to vertical loading under the ultimate limit state

Shear walls under the ultimate limit state
Walls subjected to lateral loads under the ultimate limit state

The design of reinforced sections is given according to the Action effect, eg compression, bending, bending and compression.

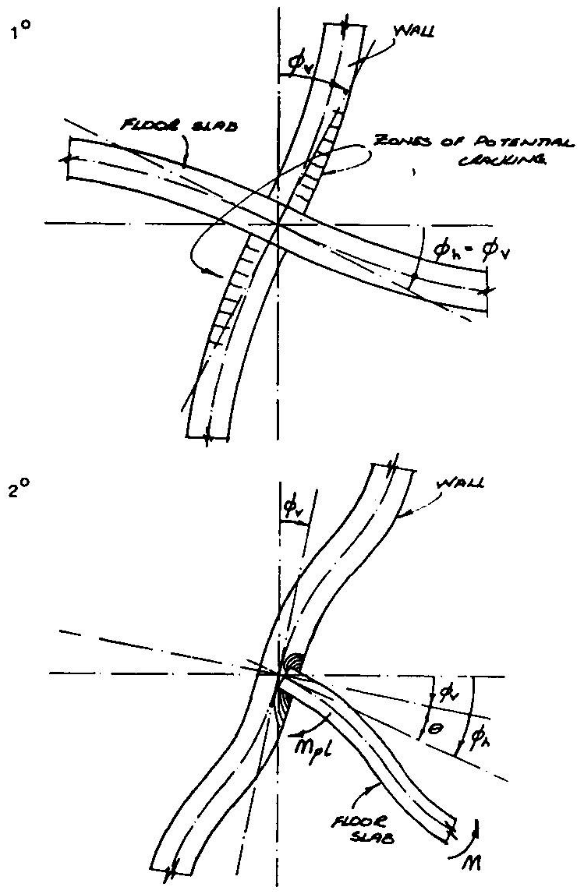
In each case the relevant verification is given.

Certain points of interest in this Section, as discussed below.

2.5.1 Eccentricity

The concept of an accidental eccentricity, e_a, explicitly used in design is normal in some countries for reinforced concrete but is rarely applied to masonry. If thin walls are traditional, an accidental eccentricity based on a proportion of the effective height, can be very large and can have a disproportionate effect on the design capacity of the wall.

The structural eccentricity to be allowed for may be calculated from first principles or a very simple model may be adopted. Most calculations of eccentricity make use of some sort of frame analysis which inevitably assumes a rigid connection between the floors and walls. In masonry, such a rigid connection is not normally achieved so that the angle of rotation of the floor is not the same as the angle of rotation of the wall. This usually means that the eccentricity calculated by rigid frame analysis is too high. A very simple approach is to assume a hinged arrangement of floor and wall. The three possible arrangements are given in Figure 1.



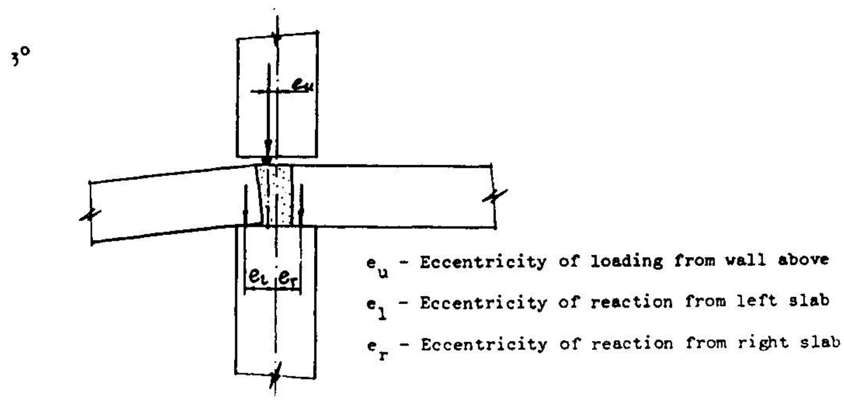


Fig.1 Floor Wall Junctions in Masonry

1. Rigid system
2. Semi-rigid system
3. Hinged system

The National Comment suggests that the eccentricity obtained from frame analysis may be reduced by from one third to two thirds depending on the thickness of the wall.

2.5.2 Allowance for Slenderness and Eccentricity

In the verification of a wall for vertical load capacity a reduction factor, Φ is applied to allow for the effect of slenderness and eccentricity. The slenderness ratio having been calculated from rules given concerning effective height and effective thickness, a capacity reduction factor is given at the top or bottom of the wall and the centre of the wall, as shown below. It will be noticed that an eccentricity due to creep is mentioned in the formula for use at the centre of the wall. This is a controversial subject and one suggestion made is that a lower partial safety factor for materials could be permitted if a "more rigorous" calculation, including the effects of creep, is carried out. It has yet to be determined whether there really is any effect from creep in eccentrically loaded walls, however.

Φ at top or bottom of wall

$$\Phi_i = 1 - 2\frac{e_i}{t}$$

e_i = structural eccentricity +
any eccentricity from horizontal loads e_h +
accidental eccentricity e_a

Φ at centre of wall

$$\Phi_m = 1.14\left(1 - 2\frac{e_{mk}}{t}\right) - 0.02\frac{h_{ef}}{t_e}$$

but not greater than $\left(1 - 2\frac{e_{mk}}{t}\right)$

$$e_{mk} = \frac{M_1 + M_2}{2\ N_m} + e_{hm} + e_{creep} \pm e_a$$

2.6 **Section 5 : Structural Detailing**

Guidance on types of wall, minimum thickness, bonding, connections, recesses, chases, damp proof courses, thermal and long term movements and masonry below ground, together with detailing aspects of the incorporation of reinforcement - eg min. percentage, max. size, are all given in this section.

Many countries in Europe assume that unreinforced masonry walls must be tied together with ring beams or ring anchors at each floor level, but this is not universal. EC6, therefore, recognises that the tying together may be carried out by timber floors or beams as are traditional in eg. the United Kingdom.

A detailed section on chases and recesses has been the subject of much comment from some countries.

2.7 **Section 6 : Construction**

It is a principle of the Eurocodes that work on site is only covered to the extent necessary to lead to building quality that is adequate for the assumptions made in the design sections, and these are so given.

Having decided that there will be three categories of construction control, these have to be defined in words. As presently drafted the words are probably not sufficiently explicit to differentiate between the categories and in the Editorial process some tightening up will be required.

3.0 **EUROCODE 6 : PART 2**

Work of this part has not yet started but is very much needed to supplement Part 1 and for use by the materials suppliers. This Part will need to go a little further than dealing with construction, only to the extent that safety requires, because otherwise masonry walls that are actually structural elements cannot be built for want of the additional information that this Part will give. Masonry is rather alone in having this problem in that it performs not only as purely structural elements but as elements that have a small structural significance and yet are the weather enclosing parts of the building. Another CEN Committee TC125 has a strong interest in the production of this Part and has set up a task group to work closely with the SC6 PT4, effectively to produce a joint document.

4.0 **EUROCODE 6 : PART 3 : Simplified Calculation Methods and Simple Rules for Masonry**

In some European countries, Germany for instance, it is normal to have a Code giving simplified calculation methods that are based on the more complete Code and may give more conservative results. Those countries have strongly supported the idea of having such a part for Eurocode 6.

Other countries, notably the United Kingdom, have simple Rules which do not involve engineering calculations but lead to buildings within the strictly limited scope of the Rules that are safe; they are mainly used for domestic buildings. Those countries that have such Rules strongly support their inclusion in the Eurocodes and this type of document is foreseen in the interpretative document No.1.

5. EUROCODE 6 : PART 10 : Fire Performance of Masonry Walls

The format of Part 10 of each of the structural Eurocodes should be similar having been set down by a coordinating Committee involving a Member from each of the Codes covering each of the materials. The extent to which detailed calculation methods can be given for structural fire design varies from material to material, but a chapter is foreseen in which the appropriate information can be given. For masonry there is as yet no calculation method for predicting the fire performance of walls although work is being done to develop one. The traditional way in which the fire performance of a masonry wall has been assessed is for National documents to give minimum thicknesses for a given material to achieve a stated period of fire resistance. There is as yet no CEN Standard for testing the response of masonry walls to fire but there has been an ISO one for many years. Most European countries use furnaces that comply with the ISO Standard but no all the data available has been prepared in recent times. Much masonry fire resistance data is quite old but this does not necessarily invalidate it when the type of material is still valid. It has however, presented some difficulty in producing European tables for fire resistance that the data is not from one coherent set of results. Also tests tend to have done on locally popular materials and types of wall, but as already mentioned in the introduction, traditions across regions and frontiers are frequently very different one to another. The National comment on Part 10 has not been large and centres mainly on the problem areas that any one country has noticed in maintaining the historic periods of fire resistance for given local material and constructions. The Project Team is currently examining this input with a view to producing their revised draft.