THE DEVELOPMENT OF DESIGN METHODS FOR REINFORCED AND UNREINFORCED MASONRY BASEMENT WALLS

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SUMMARY

This paper looks at the development work required to produce an Approved Document to the Building Regulations for England and Wales which enables the use of reinforced and plain masonry basement walls. The paper describes the background research required to develop the guidance and how this has been translated into practice. Finally, the paper considers research undertaken into the enhanced lateral load performance of dense masonry constructed with thin-joint mortar and the future potential for its use in basement walls.

INTRODUCTION

Basements were once very common in domestic building in the UK, but following the First World War, when large numbers of 'Homes fit for Heroes' were built, basements were largely omitted. Land at that time was relatively cheap and techniques for producing low cost basements for mass housing largely undeveloped.

The development of the private housing sector in the UK has been based on affordable value for money dwellings. Designers have improved space utilisation within the shell of the house in response to rising land costs and the recognition that starter homes must be affordable if the proportion of owner-occupiers is to increase. There has historically been little demand from either buyers or developers for the inclusion of basements in dwelling except for the utilisation of part-basements on sloping sites. The increase in land costs in the UK, however, when coupled with the need to optimise the useful space within the house shell, has resulted in renewed interest in basements in the UK.

This contrasts with many countries in Europe and North America where basements have continued to be incorporated into new dwellings. Nowadays such space tends to be used for additional living (rather than storage) space and the construction industry has developed ways of making basements cheaper to construct, warmer and drier.

Many of today's housing developments are, of necessity, on poor ground. This often results in the need for deep foundations where considerable excavation is required. In such circumstances the provision of a basement is often cost effective.

The Building Regulations for England and Wales provide performance based requirements for building construction (Building Regulations 2000). These regulations are supported by "Approved Documents" which, if complied with, result in buildings likely to be accepted as complying with the Building Regulations. As an example, Approved Document A gives guidance on structural requirements, provides simple rule for masonry houses and indicates which codes are acceptable for structural design (Approved Document A 2004). In addition to Approved Documents sponsored by the Civil Servants responsible for the Building Regulations the facility exists for the private sector to develop Approved Documents and submit them for approval.

Until 1997, the use of basements in the UK was inhibited by the lack of comprehensive design guidance of the type now included in the Approved Document "Basements for Dwellings" (Approved Document 1997). This document provided excellent design guidance for reinforced masonry walls but the absence of an economic design procedure for plain masonry was a severe limitation because plain masonry walls would, in many situations, be more cost effective than other solutions such as reinforced concrete and reinforced masonry.

This paper firstly considers some of the background development work required to produce a private sector "Approved Document" to the Building Regulations for England and Wales which enabled reinforced masonry basement walls to be readily designed by simple rules. It then considers further development work to improve the design of unreinforced plain masonry basement walls and enable their inclusion in the Approved Document. Finally, the paper considers research undertaken into the enhanced lateral load performance of dense masonry constructed with thin-joint mortar and the future potential for its use in basement walls.

PROJECT 1. ASSESSMENT OF LOADS.

The first phase of the work on basements required a detailed assessment of the lateral loads to which basement walls are subjected and the resultant bending moments and shear forces for the most likely conditions of basement wall end fixity. The use of a concrete floor for the ground floor of the dwellings was assumed and the floor was considered either to provide propping in each direction or to provide full fixity. It was found that for the purpose of design it was possible to simplify the soil types in the UK drained clay, drained granular and wet clay and granular. Table 1 shows the maximum moments produced by the three load cases when the basement wall is considered as a propped cantilever.

Table 1. Maximum moments produced by the three load cases when the basement wall is considered as a propped cantilever

Load Case	Maximum Moment kNm/m run	Maximum Shear Force kN
Drained Clay	12.24	25.5
Drained Granular	7.83	19.58
Wet cay or Granular	11.90	29.76

Table 2 shows the maximum moment produced by the three load cases when the basement wall is considered fixed at each end.

Table 2. Maximum moments produced by the three load cases when the basement wall is considered fixed at each end

Load Case	Maximum Moment kNm/m run	Maximum Shear Force kN
Drained Clay	8.16	20.4
Drained Granular	5.88 (base) -3.92 (top)	17.12 7.34
Wet cay or Granular	8.93 -5.96	26.04 11.16

This phase of the project highlighted the fact that the methods of assessing the loads had been derived for deep basements and tended to overestimate the loads to which relatively shallow domestic basements are subjected. The results were published in 1991 (Roberts 1991) and incorporated into the production of the first edition of the Approved Document "Basements for Dwellings" which was published in 1997. Two basic structural options were provided, reinforced masonry or reinforced concrete.

Table 3 shows one of the tables contained in the Approved Document and indicates the masonry and reinforcement requirements for a wall retaining 2.7 m of soil.

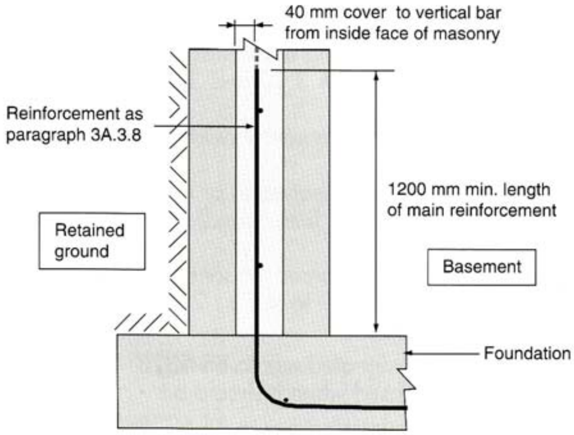
Table 3. Table 3A.2 of the Approved Document showing design information for a propped reinforced masonry wall retaining a maximum of 2.7m of soil.

Table 3A.2 Minimum masonry and reinforcement requirements for propped wall retaining a maximum of 2.7 m of soil

Foundation type	Soil type (well drained)	Vertical load (kN/m) up to	Moment taken as acting at base of wall (kNm/m)	Block compressive strength (N/mm²)	Brick compressive strength (N/mm²)	Area of reinforcement, As (mm²/m)
Raft	Clay and granular	70	20	10	20	620
		50	15	7	20	460
		30	10	7	20	280
Strip	Clay	70	17	7	20	530
	Granular		12	7	20	340

The basic form of reinforced masonry construction used in the Approved Document is grouted cavity construction and Figure 1 shows a wall detail from the document.

Figure 1. Section showing reinforced masonry wall detail from the Approved Document.



PROJECT 2: DEVELOPMENT OF DESIGN METHOD FOR PLAIN MASONRY

The next phase of the project involved the investigation of the design methods for plain masonry basement walls. The major output from the project was a design method, which facilitates the use of plain masonry in basement walls and thereby offers the potential to achieve a significant reduction in the cost of building basements in dwellings and small buildings. Initially, existing methods of basement wall design were considered.

Preliminary investigations identified six design methods to be considered further:

1. EC6 Annex E empirical approach (ENV 1996-1-1 1995)
2. EC6 Part 3 simplified approach (prENV 1996-3 1997)
3. BS 5628 Clause 36.8 with stiffening coefficients (BS 5628 Part 1 1992)
4. BS 5628 Clause 36.4 with allowance for vertical load (BS 5628 Part 1 1992)
5. Fracture method for lateral load (Sinha 1980)
6. Elastic analysis using finite elements

Method 1 was given in Annex E of EC6 and was based on one of the methods used in Germany. Method 2 was a variation of the EC6 method mentioned above but had been simplified for direct tabular use. Method 3 referred to Clause 36.8 of BS 5628: Part 1. This clause in the British Standard described an analytical method based on arch thrusts and then referred to clause 32, another method based on walls sustaining eccentric vertical loads. Method 4 was a design method given in Clause 36.4 of BS 5628 based on the yield line method which utilised the flexural properties of masonry but makes an allowance for vertical loads. Method 5 was a combination of method 4 and 6 and method 6 was an elastic analysis and so obtained the cracking load of masonry. At an initial stage in the project analytical techniques which only determine the cracking loads of walls were considered inappropriate. Thus methods 5 and 6 above were not pursued. The methods described in Clauses 32, 36.4 and 36.8 of BS 5628: Part 1 were included.

Final design recommendations

The conclusion was that the capacity of a solid wall subject to lateral earth pressures and vertical applied loads may be obtained from consideration of loads and moments using a factor of safety against overturning of 1.5.

Full height solid walls

The load n_{min} required to enable a full height solid plain masonry to carry a lateral earth load and ground surcharge may be obtained from:

$$n_{min} \geq \frac{K\gamma_e \bar{h}^3}{3.76tH}\left(H - \bar{h} + \frac{2}{3}\bar{h}\sqrt{\frac{\bar{h}}{3H}}\right) - \gamma_e t\left(H - \frac{h_e}{2}\right) \qquad (1)$$

Where H is the height of the wall between supports
$\bar{h}$ is the equivalent loading height
h_e is the retained height
K is the coefficient of active pressure
t is the thickness of the wall
γ_e is the density of the retained material

Also $n_{min} \leq \frac{f_d t}{3}$ in order to control the bearing strength (2)

Where f_d is the design strength of masonry
t is the thickness of the wall

The wall should also be checked to ensure that it has adequate strength in shear but this is not likely to be a critical design factor.

Any waterproofing system should be shown to be capable of coping with the expected crack width (w_k) which may be determined from:

$$w_k = h_j(4n_o / Et) \qquad (3)$$

or where the vertical load exceeds the minimum load derived from above from:

$$w_k = h_j \left\{2n_{act}(t - x) / Ex^2\right\} \qquad \text{where} \qquad x = \frac{n_{act}t}{2n_{min}} \qquad (4)$$

Where h_j is the vertical distance between bed joints
n_{min} is the load determined from above
n_{act} is the actual load on the wall
E is the modulus of elasticity of the masonry
t is the wall thickness

Note that the above approach is appropriate for soils developing a triangular pressure diagram. Further evaluation is needed where this is not the case in order to develop the correct n_{min} equation.

Solid walls supporting a cavity wall

A solid wall supporting an upper cavity wall may be designed as a solid wall, as given above, where the ground floor slab extends through the wall and has sufficient strength to enable transfer of loads towards the inner face of the lower wall.

Where the outer leaf is not supported by the floor, then the lower wall should be analysed for the independence of the loads from the inner and outer leaves and for any stepped section that occurs.

Types of wall

The above design recommendations apply to walls constructed of masonry units so laid as to create a bonded solid wall, and grouted cavity walls and double-leaf (collar jointed walls) that meet the conditions given in BS 5628: Part3 (BS 5628: Part 3 1985). The recommendations would also apply to bonded voided walls (e.g. Quetta and rat trap bond) but in practice such walls, as with grouted cavity walls, are more commonly used for reinforced walls.

Two way spanning walls

It is possible to extend the approach to allow for walls spanning in two directions but the dimensions for domestic basements make this impractical, as there is a growing tendency to opt for single large area room. This often results in a wall with a length/height (aspect ratio) of 2 or more and thus the wall will tend to span vertically.

However, bearing in mind this limitation, a plain masonry retaining wall may be designed for two way action by determining the vertical and horizontal moments using a recognised method of obtaining moments in flat plates, e.g. finite element or yield line. The vertical span may then be designed in accordance with the design recommendations given above and the horizontal span as a reinforced member following the introduction of reinforcement in either bed joints, bond beam or similar. Because the loading is permanent rather than transient (wall subjected to wind loads) it is not considered acceptable to design the horizontal span as a plain section.

The results of this work were published in 2002 and carried forward into the subsequent project (Roberts et al. 2002).

PROJECT 3. PRODUCTION OF THE REVISED APPROVED DOCUMENT

Changes to the Building Regulations for England and Wales in 2000 resulted in the need to update the Approved Document before consideration could be given to incorporating the results of the second project. This second edition was published in 2004 and the development work on the additions to the document was progressed in parallel (Approved Document 2004).

An Approved Document is given formal status under the Building Regulations and has to progress through an approval process before it can be recognised. Firstly the proposed changes need to be approved by the Civil Servants responsible for the regulations, secondly it needs to be approved by the Building Regulations Advisory Committee and, finally, once all those comments are taken into account, it is subject to a public consultation. The public consultation documents were issued in July 2005 and included proposals for both plain masonry and plain concrete basement walls (both projects having been undertaken at Kingston University). Following consideration of the comments received the final publication has been typeset and is due for publication as an Addendum by the end of 2007 (Approved Document Addendum 2007). The Addendum contains a number of tables to cover a range of retained heights and types of masonry units. Table 4 shows a table from the Addendum dealing with a 2.7 m high plain masonry retaining wall. As would be expected the performance of plain masonry basement walls is very dependent upon the total vertical dead load applied.

Table 4. Table 3C.1 from the Addendum to the Approved Document.

Table 3C.1 Thickness required for 2.7 m high plain masonry retaining wall.
Minimum unit gross dry density 1800 kg/m^3.
Minimum unit strength 7.3 N/mm^2 blocks, 10 N/mm^2 bricks.

Soil type	Retained height, *h* (m)	Total vertical dead load applied to retaining wall (kN/linear m)					
		55	45	35	25	15	5
		Required thickness of wall (mm)					
Granular	2.7	265	315	385	495	645	875
	2.6	255	305	365	465	615	845
	2.5	235	285	345	445	585	815
	2.3		245	305	385	525	735
	2.1			255	335	455	655
	1.9			215	285	395	585
	1.7				235	325	505
	1.5					265	415
	1.3	Min. thickness* 200					345
	1.1						265
Clay	2.7	355	415	505	625	795	1045
	2.6	335	395	475	595	765	1005
	2.5	315	375	455	565	725	965
	2.3	275	325	395	495	645	875
	2.1	235	275	335	435	575	785
	1.9		235	285	365	495	695
	1.7			235	305	415	605
	1.5				235	335	505
	1.3	Min. thickness* 200				265	415
	1.1						325

* Below the dotted line, the minimum wall thickness may be reduced to 140 mm where the bottom of the window opening is no further than 1.0 m from upper level of restraint.

PROJECT 4. LATERAL LOAD PERFORMANCE OF DENSE MASONRY CONSTRUCTED WITH THIN JOINT MORTAR

The development of thin joint mortars has led to the ability to significantly enhance the lateral load performance of masonry. For dense masonry brick and block units the flexural strength

of the masonry can typically be increased through the use of thin joint mortar to 5 or 6 times that obtained using conventional mortar. Figure 2 shows a prefabricated thin joint brickwork wall under test in the laboratory and Figure 3 a dense blockwork wallette specimen for flexural testing in accordance with the requirements of BS 5628.

Figure 2. Prefabricated thin joint brickwork wall under test in the laboratory.

Figure 3. Thin joint dense block wallette test specimen

The ability to enhance the flexural strength by the use of thin joint mortars offers the potential to reduce the thickness of plain masonry basement walls and produce further economy in the design of basements. Cement based thin joint mortars are gradually increasing in popularity in the UK and hence the application techniques are becoming more widely understood. The potential therefore exists to further develop the Approved Document to incorporate thin joint construction.

CONCLUSIONS

1. Basements are an attractive proposition for use in dwellings in the UK particularly because they maximise the use of available land and are very energy efficient. The development of simplified design guidance has been essential in order to encourage their wider use.
2. The Approved Document "Basements for Dwellings" and the 1997 Amendment incorporate cost effective solutions for domestic scale basements.
3. The development of up to date design guidance for the use of basements in dwellings has required the output from a series of research projects to provide the necessary supporting information.
4. The acceptance processes for the introduction of design guidance in the form of an Approved Document of necessity takes a significant number of years.
5. Attracting the necessary funding to support the required research also serves to disrupt and delay the introduction of new design guidance.

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