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Has the introduction of Eurocode 6 benefitted the use of autoclaved aerated masonry in the UK?

ABSTRACT: On March 31st 2020 the UK masonry design code, BS 5628 [1-3], was withdrawn leaving BS EN 1996 (Eurocode 6) [4-7] and the associated National Annexes [8-11] as the structural masonry code for the UK. BS 5628 was the first limit state design code for masonry in the world when it was introduced in 1978 and allowed efficient use of both slender walls and low strength units.

Eurocode 6 has brought together from the participating countries input from a wide spectrum of designers including those from countries where thicker masonry walls are normally used.

This paper examines the effect of some of the change in the design code on the potential use of autoclaved aerated concrete and identifies areas of the Eurocode that need further consideration and development.

1. Introduction

Eurocode 6 follows the general presentation of the material Eurocodes in that Part 1.1 covers the design of plain and reinforced masonry whilst Part 1.2 deals with structural fire design. There are two further parts, Part 2 which deals primarily with the selection of materials and execution of masonry and Part 3 which covers simplified calculation methods for unreinforced masonry structures.

Eurocode 6 has been developed to enable the designer to use masonry units made from clay, calcium silicate, aggregate concrete, autoclaved aerated concrete (AAC or Aircrete), manufactured stone and natural stone. European standards for these materials have been published by the National Standards bodies and form part of an array of standards relating to masonry produced under the auspices of CEN TC 125. In the case of AAC the standard for masonry units is BS EN 771-4 [12].

The standards supporting Eurocode 6 were developed within a common framework but it has not proved possible to standardise all the test methods used by the different materials. Words like brick and block have disappeared from the European vocabulary and they are all referred to as masonry units. All products now need to be specified by their performance requirements.

When the standards supporting the use of masonry in Eurocode 6 were introduced in 2004 it was necessary, as an interim measure, to update the three parts of BS 5628 to accommodate the revised material standards and test methods. These new parts of BS 5628 were published at the end of 2005, two of the key factors that changed being:

The six new masonry unit standards each introduced new methods for determining the compressive strength of masonry units [13]. The method of determining the characteristic compressive strength of masonry changed from testing storey height panels to much smaller masonry wallette specimens [14].

2. Implementation of Eurocode 6 in the UK

2.1. Characteristic compressive strength

The characteristic compressive strength of masonry is no longer presented in the form of tables but as an equation. This equation includes the normalized strength of the masonry and the strength of the mortar. The normalized strength is new to the UK and relates the compressive strength of the unit determined by test to a standardized shape and moisture content. The normalized compressive strength is the compressive strength of the units converted to the air dried compressive strength of an equivalent 100 mm wide by 100 mm high masonry unit. The detail is contained in the test methods for masonry units BS EN 772-1:200. The advantage to the designer is that the normalised strength is independent of the size of the units used in the final construction thereby obviating the need for re-calculation.

The characteristic compressive strength of masonry (other than shell bedded masonry) is determined from the results of tests in accordance with EN 1052-1[19]. The tests are carried out on small wallette specimens rather than the storey height panels used in BS 5628. The designer has the option of either having the units intended to be used in a project tested or to use the values determined form the UK National database. The latter values are provided in the UK National Annex in the form of the constants to be used in the following equation:

$f_k = K f_b^{\alpha} f_m^{\beta}$ [Equation (3.1) of Eurocode 6] where:

f_k is the characteristic compressive strength of the masonry, in N/mm^2,

K is a constant,

α, β are constants,

f_b is the normalised mean compressive strength of the units, in the direction of the applied action effect, in N/mm^2,

f_m is the compressive strength of the mortar, in N/mm^2.

Values of K to be used with equation 3.1 are provided in the UK National Annex Table NA.4 and are shown below in Table 2.

2.2. Values given for the design of AAC in the UK national annex to EN 1996-1-1

The partial safety factors for use with masonry are given in National Annex Table NA.1 and shown here in Table 1 for aac.

Table 1

VALUES SELECTED FOR γ_M IN THE UK.

Class of execution control:	γ_M	
	1	2
When in a state of direct or flexural compression		
units of category I	2,3	2,7
units of category II	2,6	3,0
When in a state of flexural tension		
units of category I and II	2,3	2,7

Two levels of attestation of conformity are recognized, Category I and category II and this is declared by the manufacturer of the masonry units. Two classes of execution control are recognized in the UK, 1 & 2. Table 2 shows the values of K, α and β for use in equation 3.1 of Eurocode 6.

Table 2

VALUES FOR USE IN EQUATION 3.1 OF EUROCODE 6 IN THE UK.

Type of unit AAC Group 1	General purpose mortar	Thin layer mortar	Lightweight mortar
K	0,55	0,80	0,45
α	0,7	0,85	0,7
β	0,3	0	0,3

3. Design comparison of vertical load capacity

Feedback from designers suggests that they are finding Eurocode 6 to be more conservative than BS 5628 and this is examined by way of a design comparison.

3.1. Design example

To compare the outcomes of design to BS 5628 with Eurocode 6 consider the loadbearing wall shown in Figure 1 which has a design load of 75 kN/m (with no eccentricity of load) and determine the load capacity of the wall when constructed from 2.9 $N{\cdot}mm^2$ aac units 215 mm high by 140 mm wide using a 1:1:6 (designation (iii):M4) mortar. Normal manufacturing and construction control apply. Ignore the self weight of the wall.

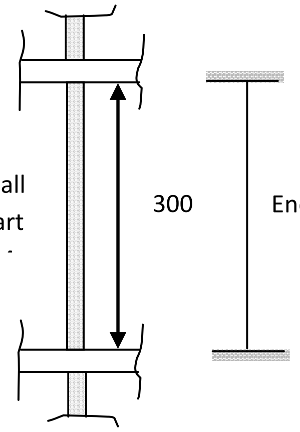

Fig. 1. Wall considered for design comparison.

3.2. *Solution to* BS 5628

The characteristic strength is obtained from Tables 2(a-d) of BS 5628:Part 1.

Aspect ratio for unit = 215/140 = 1.54

f_k (characteristic compressive strength of the masonry) is obtained by linear interpolation.

Table 2(b) for aspect ratio of 0.6 gives f_k = 1.40 N/mm^2

Table 2 (d) for aspect ratio between 2.0 and 4.5 gives f_k = 2.80 N/mm^2

Interpolating:

$$f_k = 1.4 + \frac{(1.54 - 0.60)}{(2.00 - 0.60)} (2.8 - 1.4) = 2.34 \text{ N/mm}^2$$

Checking Wall Capacity:

Effective height, h_{ef} = 0.75 x 3.0 = 2.250 m

- Slenderness ratio = 2250/140 = 16 (<27 the limiting value)

Effective thickness t_{ef} = t = 140 mm

Hence for capacity reduction factor β, Table 7 gives β (axial load) = 0.83

Categories of (manufacture/construction) control are normal

- partial factor γ_m = 3.5

Design vertical load capacity/unit length = $\beta{\cdot}t{\cdot}f_k/\gamma_m$ = $0.83{\cdot}140{\cdot}2.34/3.5$ = 77.69 kN/m run.

Therefore the loadbearing capacity is sufficient when designed to BS 5628.

3.3. Solution to Eurocode 6

The normalised strength of the masonry is the unit strength as tested corrected to covert the moisture content at test to an air dry value and corrected by a shape factor. For aac units the moisture correction is 1.0. The shape correction for the 215 mm high by 140 mm wide units is 1.3.

Thus the normalised strength, f_b =2,9 · 1,0 · 1,3 = 3,77 N/mm²

Equation 3.1 of Eurocode 6 and Table NA.4 of UK National Annex (NA)

$f_k = K f_b^{\mathring{a}} f_m^{\hat{a}}$ = 0,55 · 3,77^0,7 · 4^0,3 = 2,12 N/mm²

Checking Capacity:

Effective height, $h_{ef} = \rho_2 h$ = 0,75 · 3000 = 2250 mm

Effective thickness, $t_{ef} = t$ = 140 mm

∴ Slenderness ratio = 2250 / 140 = 16,1 (< 27 limiting value)

(Therefore the effects of creep may be ignored, NA.2.14 of UK NA)

Hence eccentricity of design vertical load at the top and bottom of the wall,

$$e_i = (M_{id} / N_{id}) + e_{he} \pm e_{init} \geq 0,05t$$

Therefore e_i = 0 + 0 + 5,0 = 5,0 mm (i.e. 0,036t)

where $M_{id}/N_{id} = 0$

e_{he} = 0 (horizontal loads effect)

$e_{init} = h_{ef}/450$ = (3000 · 0,75) / 450 = 5,0 mm

e_i is 0,05 t at top and bottom of the wall which are the minimum eccentricity design values to be used

Therefore capacity reduction factor $\phi_i = 1 - 2(e_i / t) = 1 - 2(0,05t/t)$ = 0,9

And eccentricity of design vertical load in the middle of the wall,

$$e_m = (M_{md} / N_{md}) + e_{hm} \pm e_{init} \geq 0,05t$$

Therefore $e_{mk} = e_m + e_k$ = 0 + 0 + 5,0 = 5,0 mm (i.e 0,036t)

where $M_{md}/N_{md} = 0$

e_{hm} = 0 (horizontal loads effect)

$e_{init} = h_{ef}/450$ = (3000 x 0,75) / 450 = 5,0 mm

e_k = 0 (creep effect)

e_{mk} is 0,05 t at mid-height of the wall which is the minimum eccentricity design value to be used

Hence for E = 1000f_k (6790 N/mm²) Part 1.1 Annex G equations or Figure G1 gives:

Φ_m = 0,72 which governs the design

Class 2 execution control ∴ γ_m = 3,0

Design resistance per unit length $N_{Rd} = \Phi\, t\, f_d$ from Table NA.1 of UK NA

Where design strength, $f_d = \frac{f_k}{\tilde{a}_m}$ for vertical load on the units in the normal direction of loading

N_{Rd} = 0,72 x 140 x 2,12 / 3,0 = 71,23 kN/m run

In this particular example the capacity would not be sufficient when designed to EC6.

3.4. Comparison of results

The results of design to BS 5628 and Eurocode 6 for this design example are presented in Table 3. The same approach has been used to provide value for two block widths, two block heights and three strength levels.

4. Discussion

In the UK calibration exercises were conducted prior to the introduction of Eurocode 6. Typically these looked at the range of results

Table 3

COMPARISONS OF WALL CAPACITY FOR THE DESIGN EXAMPLE.

Unit width mm	Unit height mm	Compressive strength of units N/mm²	Capacity of wall to BS 5628 kN/m	Capacity of wall to Eurocode kN/m	Reduction in capacity %
140	215	2,9	77,55	70,92	8,55
140	215	7,3	155,09	135,33	12,74
140	215	10,4	193,86	173,38	10,57
100	215	2,9	50,57	41,08	18,77
100	215	7,3	101,14	78,40	22,49
100	215	10,4	126,43	100,44	20,56
140	300	2,9	97,70	73,57	24.70
140	300	7,3	195,41	140,39	28,15
140	300	10,4	244,26	179,87	26,36

obtained from the design equations and the appropriate values of γ_m. While these global changes appear to have worked well for higher strength squat units low strength masonry units appear to have been disadvantaged in the UK.

Other factors which affect the outcome of design to Eurocode 6 include the correction factors applied for shape and moisture content. A small adjustment to the moisture correction for aac masonry in the UK is justified because of an oversight in the way the correction factor was determined for the National Annex but this would not result in a large change in the outcome.

Other relevant factors include the effective thickness of cavity walls although the changes are relatively small especially for wider units.

Ideally design comparisons need to be considered holistically and the present example does not consider, for example, the differences in the assessment of loads and the corresponding partial factors used. Further design examples will be completed to examine the economy of design to Eurocode 6 in a range of design situations and will be published at a later date.

5. Conclusions

– The current values selected for aac masonry units in the National Annex to Eurocode 6 in the UK appear to be less economic than the British Standard BS 5628 which it replaced. In the example selected here the Eurocode was between 8.5% and 28% more conservative. This supports feedback received from UK designers.

– Given the promotion of the Eurocodes as the most advances structural design codes in the world it is important that designers are encouraged by the outcomes of designs to the Eurocodes rather than discouraged.

– It is fortunate that many aac masonry units are used in constructions which comply with the "Simple rules" contained in Building Regulations and do not need to be designed to the Eurocode.

References

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