THE TREATMENT OF CONCENTRATED LOADS IN MASONRY DESIGN CODES

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ABSTRACT

In Europe, Eurocode 6: Design of Masonry Structures – Part 1-1: Common rules for reinforced and unreinforced masonry structures has recently been ratified and is about to be published by the European Standards organisation CEN. It will replace the existing design codes of all European countries, which are members of CEN after a period of co-existence. It will also be used in various other countries around the world.

One aspect of Eurocode 6 that is different from both existing UK practice and Canadian code proposals is the treatment of concentrated loads.

Eurocode 6 Design of Masonry Structures, BS5628 Code of practice for use of masonry, and draft Canadian Code S304.1-04 Design of Masonry Structures each assume different load spreads in the masonry. In addition, the enhancement factors for stress immediately below the concentrated load vary as a result of different calculation procedures.

This paper explores these differences and compares some simple situations. The extent of the differences in the various approaches is highlighted and observations made. Finally, the authors advocate harmonising the approaches adopted by the codes and indicate some of the considerations necessary.

KEYWORDS: concentrated loading, codes

INTRODUCTION

The treatments of concentrated loads in Eurocode 6, Masonry Structures – Part 1-1 Common rules for reinforced and unreinforced masonry structures [1], BS 5628: Part 1: Structural use of unreinforced masonry [2], and the Canadian Standards Association draft S304.1-04 Design of Masonry Structures [3] are compared.

Eurocode 6, Masonry Structures – Part 1-1 (EC6) has yet to be published in its final form and Canadian Code S304.1-04 Design of Masonry Structures (S304) is under revision so draft versions have been used in this paper. BS5628 Code of practice for use of masonry (BS5628) is the only one of the three, which was published, and in force at the time of writing.

Each of the codes limits the maximum magnitude of a concentrated load to the lower of an enhanced bearing stress immediately under the load or the stress from the concentrated load at a prescribed distance below the bearing. Each code has a different approach to the enhancement factor immediately under the bearing and to the total spread of the concentrated load when calculating the stress in the masonry at a specified level below the concentrated load.

This paper considers two simple examples of a wall built of solid masonry units laid in a full bed of mortar with a concentrically loaded bearing over the full thickness of the wall a) at a point within the length of the wall remote from the ends and b) at a point at one end of the wall. The wall is of sufficient length to enable the concentrated load to fully spread along the length of the wall to the level in the masonry where the stress is considered according to the individual code requirement.

The calculations for the examples take the particular case of a 150 mm thick, 2.5m wall high of solid masonry. The concentrated load is applied concentrically through a stiff 150mm by 100mm plate bearing across the full 150mm thickness of the wall.

In the first case, the concentrated load "A" is placed within a length of the wall so that the load may spread in both directions along the wall to the maximum extent of spread allowed by the relevant code (see Figure 1).

In the second case, the concentrated load "B" is applied at the end of a wall where the load may only spread in one direction (see Figure 2).

To limit this study to a comparison of the different treatments of concentrated loads, the differences in the treatment of uniformly distributed loading in each of the codes are not considered in this paper.

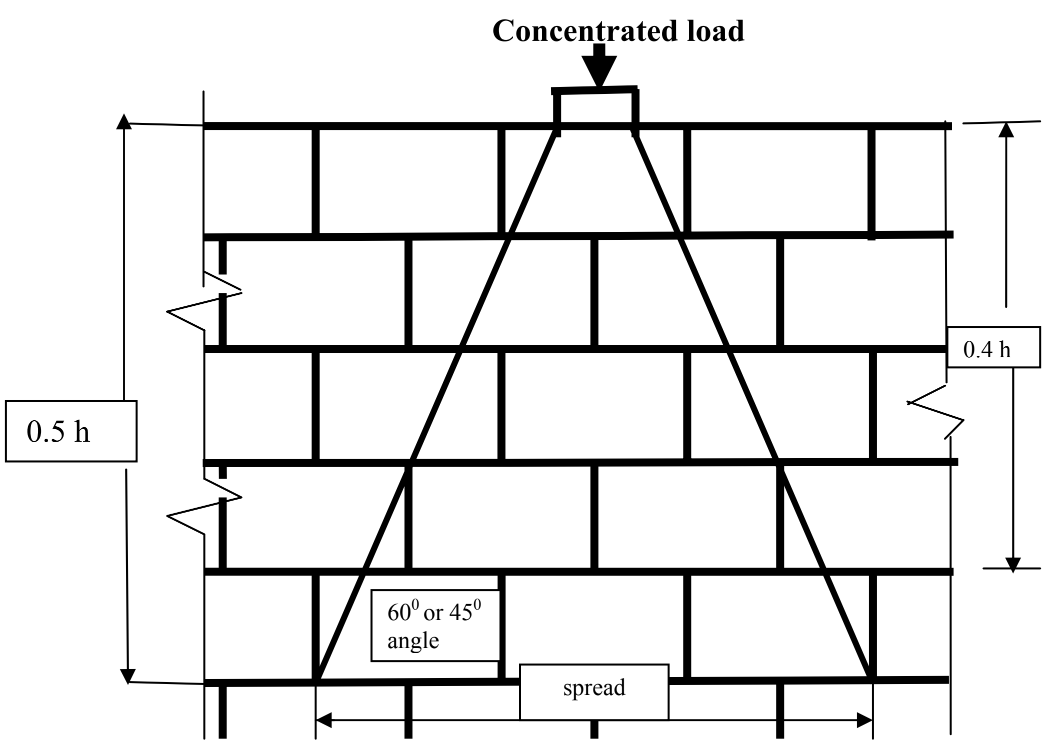

Figure 1 - Load Case A

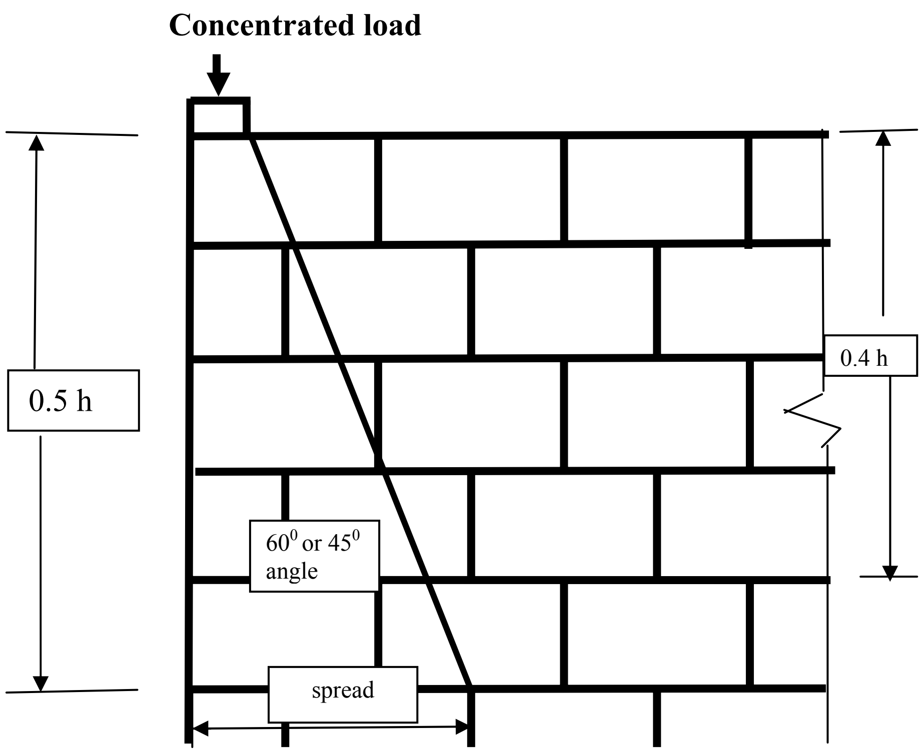

Figure 2 – Load case B

CALCULATION TO FINAL DRAFT EUROCODE 6

According to EC6, when a wall with thickness t, built with solid masonry units laid on a full bed of mortar is subjected to a concentrated load without any eccentricity in the plane of the wall, the design value of the vertical load resistance of the wall N_{Rdc} is given by:
The product of an enhancement factor β (calculated according to Equation 1), the loaded area A_b and the design strength of the wall f_d .

where $$\beta = \left[1 + 0{,}3\frac{\alpha_1}{h_c}\right]\left[1{,}5 - 1{,}1\frac{A_b}{A_{ef}}\right] \qquad \text{Equation 1}$$

and

α_1 is the distance from the end of the wall to the nearer edge of the loaded area,
h_c is the height of the wall to the level of the load,
A_b is the loaded area
The loaded area is the product of the dimension of the bearing in the plane of the wall "l" and the thickness of the wall "t" where the bearing is across the whole thickness of the wall.
A_{ef} is the effective area of bearing.
and
$\frac{A_b}{A_{ef}}$ is not to be taken greater than 0.45.

Limitations for the maximum values of β are 1.5 or $1.25+\alpha_{1/}2h_c$ whichever is the lesser.

The effective length of the bearing is determined at the mid height based on a load spread of not more than that of a line from the edge of the concentrated load which strikes the mid height level at 60^o to the horizontal, plus the width of the bearing "l".
The effective area of bearing is the product of the effective length of the bearing and the thickness of the wall "t" where the bearing is across the whole thickness of the wall.

For load case A, the calculated value of enhancement β is 1.55 but the calculated cut off ($1.25+\alpha_{1/}2h_c$) for the maximum enhancement is 1.5 and therefore the limit of 1.5 of the design strength of the wall (f_d) applies in this case. See Table 1.
For load case B, the calculated value of enhancement β is 1.37 but the calculated cut off ($1.25+\alpha_{1/}2h_c$) for the maximum enhancement is 1.25 and therefore limit of 1.25 of the design strength of the wall (f_d) applies in this case. See Table 1
The calculated spread (effective length of bearing at mid height) is 1.54m for load case A and 0.82m for load case B i.e.15.4 and 8.2 times the width of the bearing. See Table 1.

Table 1 - EC6 Calculations

	α_1, m	h_c, m	A_b, m^2	A_{ef}, m^2	t, m	l, m	β	$1.25+\alpha_1/2h_c$	max spread, m
Concentrated load remote from the ends of the wall Load case A	Not less than 1.25	2.5	0.015	0.232	0.15	0.10	1.55	1.5	1.54
Concentrated load at end of the wall Load case B	0	2.5	0.015	0.123	0.15	0.10	1.37	1.25	0.82

CALCULATION TO BRITISH STANDARD BS 5628

BS 5268 states increased local stresses may be permitted beneath the bearing of a concentrated load of a purely local nature. The element applying the load should be sensibly rigid such as a beam, column or lintel, or a suitable spreader. What constitutes a purely local nature for different types of concentrated loads is shown in diagrammatic form in the code. For load case A, bearing across the full thickness t, the maximum bearing width l is 8t. For load case B, bearing across the full thickness t, the maximum bearing width l is 2t.
The concentrated load may be assumed to be uniformly distributed over the area of the bearing and dispersed in two planes within a zone contained by lines extending downwards at 45° from the edges of the loaded area.
The effect of the local load combined with stresses due to other loads should be checked:

a) at the bearing, assuming a local design bearing strength of $1.5f_k/\gamma_m$ for a bearing across the full thickness of the wall where f_k is the characteristic strength of the masonry and γ_m is the partial safety factor for the material.
b) at a distance of 0.4h below the bearing where the stress due to the design loads should be not greater the design strength. The overlapping stress from more than one concentrated load may be considered.

For both load case A and load case B, the value of enhancement is 1.5 of the characteristic compressive strength of the masonry immediately under the concentrated load where there is no reduction for slenderness.
The calculated spread of the load (at 0.4h below) is 2.10m for load case A and 1.10m for load case B i.e. 21 and 11 times the width of the bearing respectively. See Table 2.

Table 2 - BS5628 Calculations

	Distance from wall end, m	h, m	0,4 h m	Wall thickness t, m	Bearing width l, m	max spread, m
Concentrated load remote from the ends of the wall Load case A	Not less than 1.00	2.5	1.0	0.15	0.10	2.10
Concentrated load at end of the wall Load case B	0	2.5	1.0	0.15	0.10	1.10

CALCULATION TO DRAFT CANADIAN CODE S304

Bearing plate is the term used to indicate either a bearing from a beam or column transmitted to the masonry below through a bearing plate or by direct surface contact. There appears to be no limit to the size of a bearing plate which can be treated as a concentrated load except that the stress distribution is affected.

Concentrated loads are assumed to disperse wholly within the wall section being considered downward and outward from the outer edges of the bearing plate at an angle of 45° for solid unit brick masonry and fully grouted masonry. The dispersion shall not overlap the dispersion zone of another concentrated load for the purposes of calculation or extend beyond the end face of the wall or a movement joint or continuous vertical mortar joint in the wall unless the tying or bonding across the joint has been designed to transfer compressive loads to the adjacent masonry.

The local factored bearing resistance of solid unit brick masonry and fully grouted masonry is calculated as Equation 2 or Equation 3

$B_r = K_1 A_{bp}\, \phi_m\, f'_m$ for rectangular stress distribution Equation 2

or

$B_r = 1/2\, K_1 A_{bp}\, \phi_m\, f'_m$ for triangular stress distribution Equation 3 where

$K_1=0.55[1+0.5a_1/l_2]/[A_{bp}/A_h]^{0.3}$

or

$K_1 = 1{,}5 + \frac{a_1}{l_2}$

whichever is less,

but K_1 shall not be less than 1 .0

where

a_1 = the distance from the end of the wall or pier to the nearest edge of the bearing plate, mm

A_h= the effective area of dispersion of the concentrated load at mid-height of the wall, having the area of the bearing plate A_{bp} as the source of dispersion, and complying with Clause 7.14.2, mm^2

A_{bp} = area of the bearing plate, mm^2

l_2 = the length of the wall between ends and/or movement joints, mm

For load case A the maximum calculated enhancement is 2.0 and for load case B it is 1.5, assuming a rectangular stress distribution under the load. However, assuming the concentrated load is applied such that the bearing stress is triangular, the maximum calculated enhancement is 1.0 and the limit "shall not be less than 1.0" would apply.
The maximum spread along the length of the wall at mid height is 2.6m for load A and 1.35m for load B assuming a 45deg spread i.e. 26 times and 13.5 times the width of the bearing respectively. See Table 3.

Table 3 - S304.1 Calculations

	a_1, m	h, m	A_{bp}, m^2	Area dispersion, m^2	t, m	width, m	K_1=	or K_1=
Concentrated load remote from the ends of the wall Load case A	Not less than 1.25	2.5	0.015	0.39	0.15	0.1	2.29	1.98
Concentrated load at end of the wall load case B	0	2.5	0.015	0.20	0.15	0.1	1.30	1.5

SUMMARY OF CALCULATIONS FROM ALL THREE CODES

The results of the calculations from each of the three codes are shown in Table 4.

Table 4 - Enhancement factor under load and Design length in masonry

	Load Case A		Load Case B	
Code	Enhancement factor under load	Design length in masonry (spread), m	Enhancement factor under load	Design length in masonry (spread), m
EC6	1.5	1.5	1.3	0.8
BS5628	1.5	2.1	1.5	1.1
S304*	1.0	2.6	1.0	1.4
S304**	2.0	2.6	1.3	1.4

* When the concentrated load is from a member which spans like a beam and the bearing plate length is less than 300mm parallel to the span of the beam (the stress distribution on a bearing plate is assumed to be triangular)

** When the concentrated load is a) from a member which spans like a beam and the bearing plate length is 300mm or greater parallel to the span of the beam, or b) from a member which does not span like a beam

COMMENTARY

In 1988, Page and Henry [4] published recommended design rules for concentrated loads on walls built from solid masonry units derived from all previously reported experimental and analytical studies of the problem. These recommendations form the background to the current codes, however only the Canadian code uses the Page and Hendry formula. For the simple examples used in this paper, the Page, Hendry formula gives: in Load Case A, an Enhancement Factor of 2.0; and in Load Case B, an Enhancement Factor of 1.6. In the absence of research Page and Hendry indicated that the spread (at mid height) could be taken as 45^{o} or 60^{o}.

1. Comparison of assumed spreads in the codes

The maximum spread for calculating the stress in the masonry is different in each of the codes. EC6 only allows a maximum spread of 60^{o} compared with the maximum of 45^{o} in BS5628 and S304 (S304 only for solid 'brick' masonry). Thus there is an apparent reduction of approximately 40% in the maximum load which can be applied when designing to EC6 compared with BS5628. However, while EC6 and the Canadian code calculate the area of dispersion at the mid height of the wall below the concentrated load, BS5628 and calculates it "at a distance of 0.4h below the bearing". This has the effect of a reduction of 20% for BS5628 relative to EC6 while S304 has almost 25% greater dispersion than BS5628. The precise difference depends on the width of the bearing plate.

In the examples chosen for this paper the spreads, for walls where there is no limitation from ends of walls or positions of movement joints etc on the assumed spreads at the level in the masonry where the design stress is calculated, range from:

For loads remote from the ends, 1.54m in EC6 based on a 60deg spread to 2.6m in S301 based on a 45deg spread at mid height. For BS5628 the spread is 2.10m at 0.4 of the storey height below the load based on a 45deg spread.

For loads at an end, 0.82m in EC6 based on a 60deg spread to 1.35m in S301 based on a 45deg spread at mid height. For BS5628 the spread is 1.1m at 0.4 of the storey height below the load based on a 45deg spread.
EC6 and BS5628 consider the resulting stress including that from overlapping spreads from adjacent concentrated loads but S304 does not allow the spreads to overlap.

2. Comparison of enhancement factors

The maximum enhancement factor for stress permitted immediately under the type of bearing being considered varies between 1 and 2 depending on the position of the load and differences between each code.
In S304, the stress distribution on a bearing plate from any member that spans like a beam is assumed to be triangular for bearing plates less than 300mm long. The enhancement is half of that for a rectangular distribution. The other two codes do not make that distinction.
In EC6, the expression $1.25+\alpha_{1/}2h_c$ has an odd effect. The term α_1 (the distance from the edge of the bearing to the end on the wall) only allows the maximum enhancement of 1.5 to be used when α_1 is not less than $h_c/2$ which implies a 45^0 spread but a 60^0 spread is all that is allowed in the calculation.
In BS5628 the enhancement factor is either 1.5 or 1.25 generally depending on what proportion of the wall thickness is supporting the bearing.

3. Comparison of stress distribution immediately under the bearing.

Generally all three codes consider concentrated loads to exert uniform pressure under the bearing plate.
S304 makes an exception for the stress distribution on a bearing plate from any member that spans like a beam, where a triangular distribution is considered to exist for bearing plates less than 300mm long.
Also in BS5628, the assumption of uniform distribution does not apply in the special case of a spreader located at the end of a wall and spanning in its plane. In this case the distribution of stress "should be based on an acceptable elastic theory" and the maximum stress should not exceed twice the characteristic stress over the partial safety factor for the material. In all three codes, considering that generally the assumption is that there is a uniform bearing under the load, there is a remarkable lack on emphasis on the care needed to achieve a uniform bearing.

4. Comparison of maximum dimensions of a concentrated load

In EC6 the requirement is "$\frac{A_b}{A_{ef}}$ is not to be taken greater than 0.45" which appears rather generous.
In BS5628 what is a "purely local nature" is shown in diagrammatic form for different types of concentrated loads. For a load bearing across the full thickness t at a distance greater than 0.5t from the end of the wall the maximum bearing area is $8t^2$. For a similar load at the end of the wall the maximum bearing area is $2t^2$.
In S304 there appears to be no specified limit.

CONCLUSIONS AND RECOMMENDATIONS

1. As shown in Table 4, the enhancements and spreads of concentrated loads on masonry in these simple examples are different when using each of the codes. The enhancement factors and spread in the masonry (at mid height), particularly when comparing EC6 with S304, are very different. The reasons for these differences are beyond the scope of the simple comparison exercise undertaken for this paper. It is, however, recommended they should be examined by the code drafters in the interests of safety and economy.
2. Clearly there are other factors which should be the subjects of further research. These include, in particular, the definition of the maximum dimensions for a concentrated load and whether the spread is 60^0 or 45^0 or some other figure.
3. BS 5628 requires simpler calculations than the other two codes. They give values which are more conservative than those from the Page and Hendry recommendations and lie between those from the other two codes. Consideration should be given to whether the increased complexity in the other two (later) codes is justified.
4. Further examination of the full range of variables, including eccentric bearings and walls where the masonry is not solid, remains to be undertaken.

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