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Brick Technical Bulletin - Characteristics Flexural Strength (F_{kx}) Flexural Bond Strength of Concrete Masonry Bricks

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Characteristic Flexural Strength (Fkx)s

The International Concrete Brick Association (ICBA) commissioned an independent report in the summer of 1991 in anticipation of the new EC6 design code compared with the soon to be superseded BS 5628, Part 1; Code for Masonry. The proposed values given in EC6 were deemed to be disadvantageous to concrete masonry; particularly bricks. The testing and subsequent report by CERAM, (British Ceramic Research Limited) was then condensed and published as ICBA Technical Bulletin 2, a copy of which is attached.

The tests consisted of several wallettes being constructed and then tested to destruction by the then draft CEN test method. This test method is still current and hence the results can be considered realistic and relevant today.

Four types of brick were tested;

A frogged brick

A Solid, no frogs or perforations brick

A 3 holed perforated brick

A high strength concrete Engineering quality brick.

The results of the tests clearly indicated that;

- The mean FKx values for the plane of failure perpendicular to the bed joints are much greater than the values given in the then Standard; BS 5628:part1; 1992.

- The mean values are generally greater than the comparable values given in BS 5628 for clay and calcium silicate bricks.

- The mean values are well in excess of the proposed EC6 values and can be used to support an alteration to draft EC6.

The data provided by Marshalls shows an Fkx value of 0.53 both parallel and perpendicular to the bed joints although the tested values in the report indicate higher values particularly perpendicular to the bed joints. The original data published by Marshalls was taken as an average across all brick types although it should be feasible to utilise specific values for each brick type. n.b; for the sake of clarity we have only referred to values using grade M4 mortars. The Fkx values for concrete bricks across mortar designations (i), (ii) and (iii) gave a fixed value of 0.3 N/mm^2. The achieved value for a 3-hole perforated brick was 0.29 parallel to bed joints but 1.46 N/mm^2 perpendicular to bed joints, against the BS 5628 value of 0.9N/mm^2.

Bond strength

For Aggregate concrete masonry units produced to BS EN 771-3: 2011, clause 5.12.1 Shear Bond Strength states "For aggregate concrete masonry units to be used in elements subjected to structural requirements the shear bond strength of the unit in combination with mortar shall be declared in terms of the characteristic shear strength in accordance with EN 1052-3. The declaration may be made based on fixed values as in 5.12.3. The manufacturer should decide whether the value of bond strength has been obtained from the fixed values or from testing. [Note: In most cases it is expected that use of the fixed values will be sufficient.] Consequently Marshalls, in similar fashion to the majority of other brick manufacturers (concrete and clay), use the fixed value derived from EN 998-2; 2003, Annex C, of 0.15 N/mm^2.

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STRENGTH OF MASONRY

The successful design of unreinforced Masonry involves establishing that the Characteristic Compressive Strength (fk) and, in bending, the Characteristic Flexural Strength (fkx) of Masonry walls are suitable for the purpose. Both these factors are covered in the provisions of BS 5628: Part I: 1992.

1. Characteristic Compressive Strength
The factors affecting fk values are as follows

a. Compressive Strength of Masonry units
b. The shape of Masonry units (ratio of height to least horizontal dimension)
c. The form of the units (solid or hollow)
d. The mortar designation

Recent independent research carried out for ICBA by Ceram Research, a NAMAS approved laboratory, on three types of concrete brick yielded the excellent unit compressive strengths shown in Table I (Capped Specimens) and Table 2 (Ground Specimens).

Results of Characteristic Compressive Strength Tests by Ceram Research on storey-height walls and on wallettes using all three types of brick and a designation (iii) mortar are shown in Tables 3 and 4. These:

Firmly established concrete bricks in the mainstream of compression data.

Highlighted favourable comparison with (fk) values in BS5628: Part I : 1992 (See Table 5 below).

Established consistency of results with those obtained using draft EC6 calculation method.

Established a relationship between results for storey-height walls and for wallettes to facilitate further research.

Extracts from BS 5628: Part I : I 992 are reproduced with the permission of BS/. Complete copies of the standard can be obtained by post from BS/ Sales, Linford Woad, Milton Keynes, MK I 4 6LE.

TABLE I. Capped Specimens

Number	Engineering Quality	Facing Brick	H/S Common
1	57.5	23.2	52.8
2	60.3	23.6	56.9
3	64.6	22.3	63.8
4	58.3	22.0	55.2
5	56.2	24.5	65.3
6	62.5	25.1	49.1
7	59.1	23.9	47.1
8	65.7	30.5	62.2
9	60.9	28.7	49.0
10	58.8	25.1	58.5
Mean	60.4 N/mm^2	24.9 N/mm^2	56.0 N/mm^2
S.D.	3.1 N/mm^2	2.7 N/mm^2	6.5 N/mm^2
C.V.	5.1%	10.8%	11.6%

Source: Cerom Research

TABLE 2. Ground Specimens

Number	Engineering Quality	Facing Brick	H/S Common
1	64.1	27.7	50.4
2	69.1	25.7	52.7
3	74.8	25.6	48.8
4	71.8	23.4	49.7
5	72.8	35.5	58.4
6	69.5	27.1	53.5
7	67.4	26.9	61.2
8	68.7	36.8	63.9
9	74.7	30.6	72.2
10	73.4	27.9	70.5
Mean	70.6 N/mm^2	28.7 N/mm^2	58.1 N/mm^2
S.D.	3.5 N/mm^2	4.3 N/mm^2	8.6 N/mm^2
C.V.	5.0%	15.0%	14.8%

Source: Cerom Research

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TABLE 3. Compressive Strength: Storey-Height Walls

Brick Type & Wall No.	Dimensions (mm)		Load (kN)	Failure Stress (N/mm²)	Mean Failure Stress (N/mm²)	Correction for Effect of Deflection		
	Breadth	Depth				Deflection (mm)	Failure Stress (N/mm²)	Mean Failure Stress (N/mm²)
Engineering Quality								
1	1336	103	1831	13.31		6.21	14.16	
2	1331	104	1878	13.57		2.70	13.93	
3	1323	103	2021	14.83	13.90	13.16	17.00	15.03
Facing Quality								
1	1337	103	1439	10.45		1.05	10.56	
2	1333	103	1597	11.63		0.03	11.63	
3	1331	102	1461	10.76	10.95	6.25	11.46	11.22

Source: Cerom Research

TABLE 4. Compressive Strength: Wallettes

Number	Engineering Quality	Facing Brick	H/S Common
1	21.52	18.60	21.61
2	24.17	13.92	21.79
3	22.12	10.66	20.56
4	23.80	11.73	17.24
5	19.22	14.15	17.92
Mean	22.17 N/mm²	13.81 N/mm²	19.82 N/mm²
S.D.	1.99 N/mm²	3.05 N/mm²	2.12 N/mm²
C.V.	9.0%	22.1%	10.7%

Source: Cerom Research

TABLE 5. Characteristic compressive strength of masonry, (fk) in N/mm2 constructed with standard format bricks.

Mortar designation	Compressive strength of unit (N/mm²)								
	5	10	15	20	27.5	35	50	70	100
(i)	2.5	4.4	6.0	7.4	9.2	11.4	15.0	19.2	24.0
(ii)	2.5	4.2	5.3	6.4	7.9	9.4	12.2	15.1	18.2
(iii)	2.5	4.1	5.0	5.8	7.1	8.5	10.6	13.1	15.5
(iv)	2.2	3.5	4.4	5.2	6.2	7.3	9.0	10.8	12.7

Source: BS 5628: Part I: 1992

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2. Characteristic Flexural Strength
The factors affecting f1oc values are as follows :

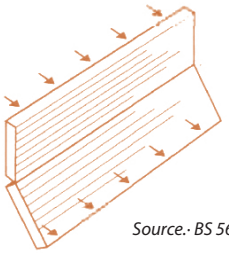
a. Physical properties of the masonry units
b. Wall thickness
c. Direction of plane of failure (parallel to, or perpendicular to bed joints)
d. The mortar designation

Table 6 opposite indicates the proposed f1oc values in the draft version of Eurocode 6 and compares these with BS 5628 values.

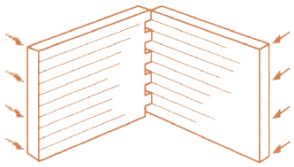
Clearly the values given for fkx are disadvantageous to concrete brickwork. If, through lack of data, half the table values were used, the difficulties would be exacerbated. Of most importance is the reduction in strength when the failure is perpendicular to the bed joint. This has a double disadvantage, as in walls which span in two directions the design method apportions load in proportion to the flexural strength in that direction.

BS 5628: Part 1: 1992 gives Characteristic Flexural Strength values (fkx N/mm²) for various types of brickwork as shown below in an extract from table 3 of that document.

Plane of failure parallel to bed joints



Plane of failure perpendicular to bed joints



Source.· BS 5628: Port/: /992

TABLE 6. Relative Values for Characteristic Flexural Strength (F_{kx})

Mortar Type	Plane of failure parallel to bed joints		Plane of failure perpendicular to bed joints	
	M15, M20, M10, M5	M2	M15, M20, M10, M5	M2
B5 5628	0.3	0.2	0.9	0.6
EC6	0.25	0.2	0.45	0.4

Source: Cerom Research

TABLE 7. Characteristic flexural strength of masonry fkx N/mm²

Mortar designation	Plane of failure parallel to bed joints			Plane of failure perpendicular to bed joints		
	(i)	(ii) and (iii)	(iv)	(i)	(ii) and (iii)	(iv)
Clay bricks having 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 bricks	0.3		0.2	0.9		0.6
Concrete bricks	0.3		0.2	0.9		0.6

Source: Cerom Research

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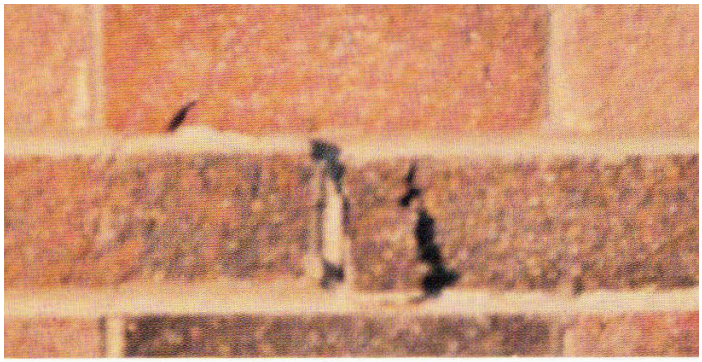
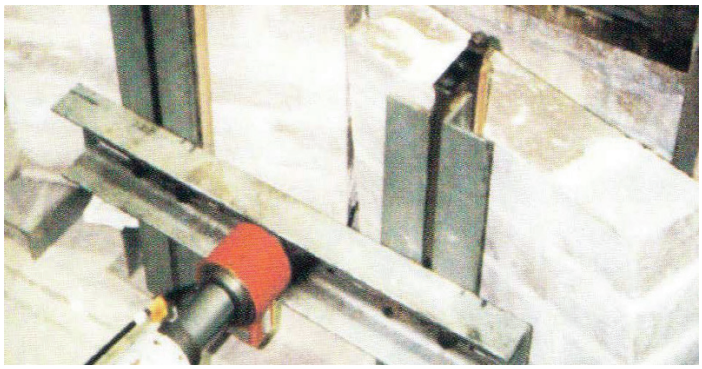
IN THE CASE OF CONCRETE BRICKS, NEITHER THE BS VALUES NOR THOSE GIVEN IN DRAFT EUROCODE 6 ARE DATA-SUPPORTED

ICBA have recently clarified the position by commissioning Ceram Research to test the flexural performance of the most commonly used combinations of concrete bricks and mortars. Wallettes comprising three types of facing brick in 1:1:6 (cement: lime: sand) mortar and Engineering Quality concrete bricks in both 1:1:6 and 1:1/4:3 mortars were tested in both planes of failure (parallel to and perpendicular to the bed joints). Testing was in accordance with Pr/EN GGGG-2 (draft CEN test method) and closely followed Appendix 'A' of BS 5628 : Part 1 : 1992.

The results of this research are shown in Tables 8-12 and in figures



Concrete Facing Brick Under Testing



Testing F /exuml Strength

TABLE 8. FROGGED BRICKS, 1:1:6 MORTAR

	FLEXURAL STRENGTH N/mm²	
Number	Perpendicular to bed joint	Parallel to bed joint
1	1.82	0.65
2	1.64	0.77
3	1.77	0.80
4	1.38	0.86
5	1.54	0.68
Mean	1.63 N/mm²	0.75 N/mm²
S.D.	0.18 N/mm²	0.09 N/mm²
C.V.	11.0%	11.6%

Source: Cerom Research

TABLE 9. CONCRETE FACING BRICK, 1:1:6 MORTAR

	FLEXURAL STRENGTH N/mm²	
Number	Perpendicular to bed joint	Parallel to bed joint
1	1.69	0.40
2	1.68	0.57
3	1.74	0.76
4	1.68	0.56
5	1.81	0.53
6	1.92	0.58
7	1.84	0.61
8	1.80	0.31
9	1.70	0.57
10	1.53	0.43
Mean	1.74 N/mm²	0.53 N/mm²
S.D.	0.11 N/mm²	0.12 N/mm²
C.V.	6.3%	23.6%

Source: Cerom Research

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The results of the research by Ceram Research clearly indicate:

- That the mean fkx values for the plane of failure perpendicular to the bed joints are much greater than the values given in BS 5628 : Part 1 : 1992.
- That the mean fkx values for the plane of failure parallel to the bed joints are, with one exception, greater than the values given in BS 5628 : Part 1: 1992.
- That the mean values are generally greater than the comparable values given in BS 5628 for clay and calcium silicate bricks.
- That the mean values are well in excess of the proposed EC6 values and can be used to support an alteration to draft EC6.

TABLE 12. ENGINEERING QUALITY CONCRETE BRICKS, 1:1:6

	FLEXURAL STRENGTH N/mm²	
Number	Perpendicular to bed joint	Parallel to bed joint
1	2.01	0.64
2	1.83	0.74
3	2.09	0.60
4	1.95	0.60
5	2.24	0.81
6	1.97	0.79
7	2.14	0.63
8	1.81	0.67
9	2.11	0.51
10	1.69	0.75
Mean	1.98 N/mm²	0.67 N/mm²
S.D.	0.17 N/mm²	0.10 N/mm²
C.V.	8.6%	14.9%

Source: Cerom Research

TABLE 10. 3-HOLE PERFORATED, 1:1:6 MORTAR

	FLEXURAL STRENGTH N/mm²	
Number	Perpendicular to bed joint	Parallel to bed joint
1	1.63	0.38
2	1.33	0.25
3	1.48	0.25
4	1.20	0.31
5	1.68	0.26
Mean	1.46 N/mm²	0.29 N/mm²
S.D.	0.20 N/mm²	0.06 N/mm²
C.V.	13.7%	20.7%

Source: Cerom Research

TABLE 11. ENGINEERING QUALITY CONCRETE BRICKS, 1:$^1/_4$:3

	FLEXURAL STRENGTH N/mm²	
Number	Perpendicular to bed joint	Parallel to bed joint
1	2.41	0.83
2	1.96	1.16
3	2.58	0.92
4	1.89	0.83
5	2.75	1.09
6	1.86	1.08
7	2.12	0.95
8	1.82	0.65
9	1.94	0.91
10	1.69	0.94
Mean	2.10 N/mm²	0.94 N/mm²
S.D.	0.36 N/mm²	0.15 N/mm²
C.V.	17.1%	15.9%

Source: Cerom Research

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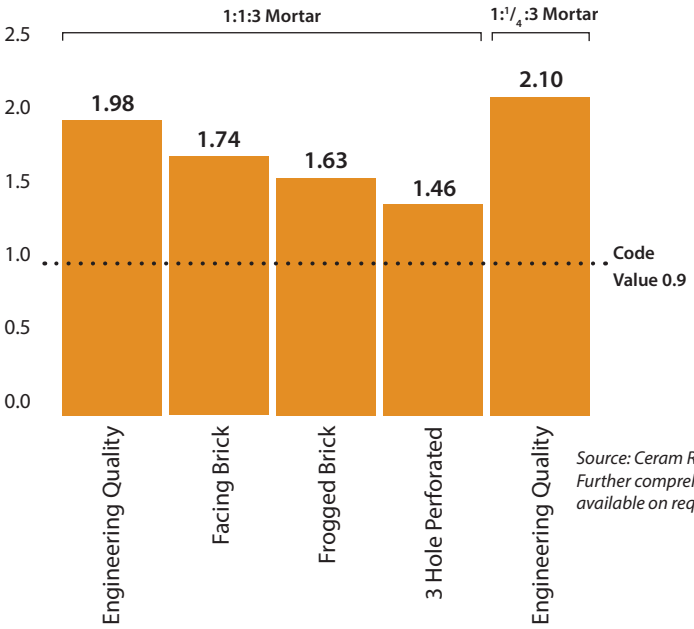
Figure 1. ***FigureMean 1.70***

Flexural Strength: PERPENDICULAR TO BED JOINTS

N/mm²



Source: Ceram Research
Further comprehensive informtion available on request.

Figure 2. ***FigureMean 0.56***

Flexural Strength: PARALLEL TO BED JOINTS

N/mm²