KTP – CPD for PERITI

THE USE OF LOCAL SUSTAINABLE MASONRY AS A STRUCTURAL MATERIAL

MODULE I – PHYSICAL PROPERTIES OF FRANKA

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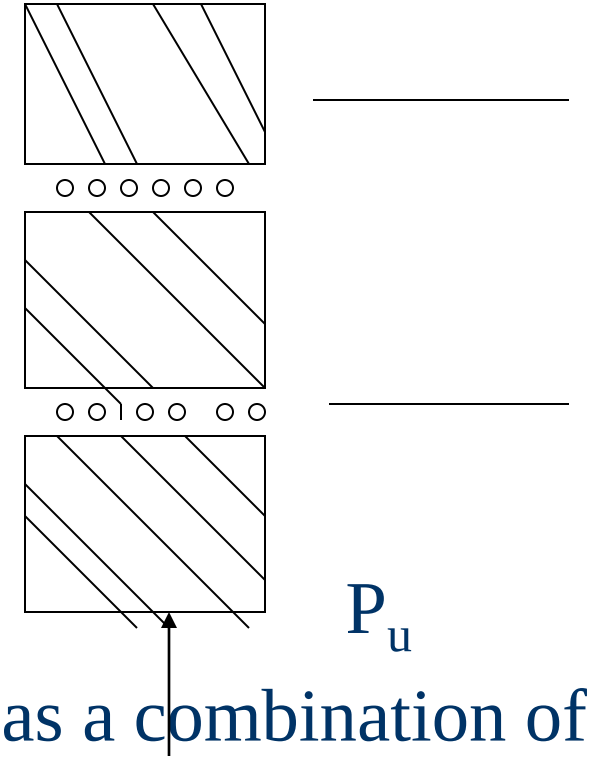
MASONRY AS A COMPOSITE BRITTLE MATERIAL



masonry strength (f_b)

mortar strength (f_m)

P_u

P_u as a combination of masonry unit & mortor strengths

$f_k = k.f_b^{0.65} \, . \, f_m^{\ 0.25}$ (EC6)

STRUCTURAL MATERIALS IMPORTANT PROPERTIES

- Dimensional Stability
- Durability
- Fire Resistance
- Strength capacities & stiffness

Table 1

Material	Ultimate Stress (N/mm^2)	Modulus of Elasticity (N/mm^2)	Density (KN/m^3)	Coeff of Thermal Expansion *10^{-6}/^{o}C	Embodied Energy MJ/kg (Embodied CO$_{2)}$) (kg/t)	Material Factor of Safety γm
Mild steel	275	205000	70	10.8	35(2030)	1.0
High Yield steel	460	200000	70	10.8	35(2030)	1.0
Pre-stressing wire	1570	200000	70		35(2030)	1.15
Reinforced concrete	20-60	28000	24	10.8	8(203)	1.5
Timber:						
Softwood	10-30**	7000**	6	3.5**	2(1644)	1.3***
Hardwood	35-70**	12000**		3.5**	3(2136)	
Franka Masonry	7.5	21000 μ = 0.22	20	4.0	2(32)	2.5-3.5
Aluminium Alloy	255	70000	24	23.0	300(17000)	1.2
Glass fibre composite	250	20000	18		100(8070)	1.7
Float glass	7(28)*	70000	25	8.3	15(1130)	1.0
Toughened glass	50(56)*	70000	25	8.3	20(1130)	1.0

* Gust loading; ** Parallel to gram; ***EC5 - Timber

MASONRY MOVEMENT JOINTS

Joints should be provided to minimize the effects of movement cause by drying shrinkage, moisture expansion, temperature variations, creep and settlement.

To be noted that from Table 2, the low movement characteristics of limestone. Compared with most other materials used in the structure of a building, masonry is relatively stiff and brittle. It does not readily absorb distortions arising from movement or displacement nor readily redistribute high localized stresses.

Table 2 – Guide to the Properties

Properties	Dense concrete blockwork	Lightweight concrete blockwork	Aerated concrete blockwork	Globigerina Limestone	Lower Coralline Limestone
Weight (kN/m^3)	15 - 21	7 - 16	4-9	17	21
Compressive strength (N/mm^2)	7 - 35	3.5 - 10.5	2.8 - 7	15 - 37.5	35 - 75
Flexural strength (N/mm^2)				1.1 - 4.7	
Elastic modulus (kN/mm^2)	10 - 25 or 300f_k^*	4-16	1.7-8	17	
Reversible moisture movement (%)	0.02 – 0.06(-)	0.03 – 0.06 (-)	0.02 – 0.03 (-)	0.01 (+)	
Initial moisture expansion (+) or drying shrinkage (-) (%)	0.02 – 0.06 (-)	0.05 – 0.06(-)	0.05 – 0.09 (-)	0.01	
Coefficient of thermal expansion (X10^{-6}/^{o}C)	6 - 14	7 – 12	8	4	
Long-term natural water absorption (%)				15.6	6.7
Thermal conductivity at 5% moisture content (W/m^{o}C)	0.6 – 1.3	0.20 – 0.44	0.10 – 0.27	1.3	

DIFFERENT MATERIAL RATES OF THERMAL & MOISTURE MOVEMENT

Table 3

MATERIAL	COEFFICIENT OF THERMAL EXPANSION/ ^{0}C X 10^{-6}	APPROXIMATE DRYING SHRINKAGE - % IN AIR AT 65% RH
Wood	3.6 to 5.4	2.0 to 4.0 (across the grain) 0.1 (along the grain)
Glass	9.0	-
Steel	10.8	None
Concrete	10.8	0.3 to 0.12
Plastic	17.0	-
Copper	17.2	None
Aluminium	23.0	None
Limestone	4.0	0.01
Mortar	11-13	0.04 – 0.1

Where different materials are connected together or connected to parts of a building not subject to external changes of temperature, care has to be taken in design to accommodate the expansion and contraction of one relative to another, limit and control cracking. Many constructional materials shrink on drying and expand again on wetting, this process being partially or wholly reversible.

MOVEMENT IN FRANKA

To determine the movement likely to take place it is necessary to combine the individual effective movement due to thermal moisture & other effects.

The effective thermal & moisture effects are not directly additive

The moisture expansion of limestone is given at +0.01%

Table 3

The coefficient of thermal expansion is given at $4/^{o}C \times 10^{-6}$

Considering a 1.0mn length for $\Delta t = 20^{o}C$

Increase in length (mm)

Table 2

$1000 \times 4 \times 10^{-6} \times 20 = 0.08$mm

representing a 0.008% increase in length

Total temperature + effective moisture movement

= 0.008% + 0.01%/2 = 0.0.13%

Assuming modern filler can compress to 50% for a 10mm movement a joint width of 20mm is required at a spacing given by 10mm/0.13mn

= 75m spacing

MOVEMENT IN CONCRETE B/W

This 75m spacing is to be compared to the 6m – 10mm joint spacing specified for concrete hollow blockwork due to its high irreversible drying shrinkage.

For reinforced concrete hollow blockwork this joint spacing may be increased to

12m for an L/h = 2

18m for an L/h = 4

Non-loaded unrestrained parapet walls should be provided with twice the amount of movement provision.

DURABILITY OF FRANKA

Limestones have a broadly similar chemical composition

CaO	45.2 - 50.40%	P_2O_5	0.23 - 0.29%
CO_2	37.6 - 39.65%	S_1O_2	1.2 - 7.6%
CI	0.058- 0.43%	Fe_2O_3	0.11 - 1.25%
MgO	3.75 - 6.03%	$A1_2O_3$	0.15 - 0.80%

(Vella et al 1997)

Soll has a significantly higher content of silica 5%, being a measure of its clay content.

It is the internal structure of a limestone rather than its composition that gives the clue to durability

FURTHER TO DURABILITY OF FRANKA

Porosity is the volume of pores within a stone, expressed as a % of the total volume. Values range around 10 –20%, although they may be as low as 10% and as high as 40%. The value for franka is around 35%. A sol sample has a low at 27.8% Cachia (1985). Values for coral limestone are in the region of 16% Bonello (1988). Void ratios had been measured at 38.6%-58.6% (Cachia 1985) & 30.2% - 53.04% (Sammut).

Microporosity is the proportion of the total pore space of pores having an effective diameter less than 5 microns. A stone with high proportions of very fine pores is less durable than a stone that has mainly coarse pores. The value for franka samples falls between a grey middle of 50 - 80 %, which on its own merit may not be used to classify its durability characteristic. Zammit had however measured this value at 91.5%.

AN IMPROVED INDICATION OF DURABILITY - may be obtained by combining 2 properties

For the franka samples tested by Cachia (1985) it was concluded that a wet/dry compressive strength ratio of 0.58 appears to mark a dividing line between a better and a poorer stone. For the franka samples tested by Cachia (1985) this appears to be confirmed, however a dividing line between a very poor sample (0.56) and a very good sample (0.59) is too fine and a better indication of durability appears to be obtained by dividing the wet/dry strength ratio by microporosity and multiplying the result by a factor, with a tentative value given at 1050.

DIRECT TESTS OF DURABILITY – Crystallisation Test

- Following several immersions in $NaS0_4$ followed by drying in an oven, loss in weight obtained
- For most samples this was between 20-30% with poor sample as high as 49%
- A high % of micropores together with high loss in weight could be an indication of a less durable stone.

BRS NOTE B188(1958) NOTE C965

FIRE RESISTANCE OF FRANKA

- Building stones have low thermal diffusivity. Hence temperatures rise, within body of wall is correspondingly low. The high temperature would not exist within a moderate depth below surface. A steep temperature gradient exists between the outer and inner parts causing splitting. Splitting is more pronounced in hollow blocks.
- For temperatures up to 400^{o}C pink or reddish brown coloration occurs for Franka containing $Fe_2\ O_3$. Free of $Fe_2\ O_{3,}$ a greyish colour develops with the depth of coloration rarely exceeding 20mm.
- Around 600^{o}C, colour disappears & calcinations occur with depth rarely exceeding 1cm. Calcinated limestone has a dull earthly appearance.

FURTHER TO FIRE RESISTANE OF FRANKA

No significant reduction in crushing strength occurs up to 400/450^{o}C.

At 600^{o}C the masonry retains 60% of original strength thus it is expected safe to re-build on existing walls except those stressed in tension.

Moulded glass soften or flow at 700^{o}C/800^{o}C cast iron forms drops or sharp edges are rounded at 1,100^{o}C/1,200^{o}C, 650^{o} for aluminium 1,000^{o} for bronze.

Table 4 - Mortar mixes from BS5628 Pt 1

Mortar designation	Types of mortar (proportion by volume)		Mean compressive strength at 28 days (N/mm^2)	
	Cement: lime: sand	Cement: sand with plasticiser	Preliminary (laboratory) tests	Site tests
(i)	1:0 to ¼: 3	-	16.0	11.0
(ii)	1:1/2:4 to 41/2	1:3 to 4	6.5	4.5
(iii)	1:1:5 to 6	1:5 to 6	3.6	2.5
(iv)	1:2:8 to 9	1:7 to 8	1.5	1.0

The inclusion of lime in our mortars is to be advocated as it improves workability, water retention and bonding properties. Lime mortar is softer and less rigid than cement, and can accommodate slight movement and settlement. Lime is more porous and allows the wall to breathe, reducing the effects of rising damp, applicable in conservatin projects Lime mortar takes longer to achieve strength and so limits the speed of rate of laying.

Table 5 gives the strengths of Maltese Mortars from tests carried out by Debattista (1985)

MORTAR CONSTITUENTS	PROPORTION BY VOLUME	COMPRESSIVE STRENGTH 28DAYS-N/mm^2	FLEXURAL STRENGTH	W/C
Cement, Carolline Sand, Fine Globigerina sand	1:2:10	1.86 (iv)	0.58	3.5
Cement, Carolline Sand, Fine Globigerina Sand	1:2:6	4.48 (iii)	1.30	2.0
Cement, carolline Sand, Coarse Globigerina sand	1:3:12	0.92	0.20	4.4
Cement, White lime, carolline Sand, coarse globigerina sand	1:1.14:2:4	1.43	0.29	2.5
White lime, fine globigerina sand	1:2	1.32	0.56	2.1

LOAD BEARING PROPERTIES OF MASONRY WALL PANELS

a) The horizontal bed joins should be filled completely with mortar. Incompletely filled bed joints may reduce the strength of masonry panels by 33%. Failure to fill vertical joints has little effect on the compressive strength but are undesirable for weather and force, exclusion and sound insulation.

b) Mortar bed joints should not be thicker than 10mm. Bedjoints of 16 –19mm thickness, result in a reduction of compressive strength of up to 25% as compared with 10mm thick joints.

c) Before laying mortar the block is to be well wetted to reduce its suction rate, plus a proportion of lime in the mortar mix will help the mortar mix to retain its water. A high absorbent block will result in a weaker mortar, with a resulting weaker wall panel.

Table 6 - Characteristic Compressive stress f_k of 225mm thick masonry N/mm^2 for specified crushing strength – as per BS 5638 pt 1

Mortar Designation	***Globigerina***				***Coralline***
	Compressive Strength of Unit (N/mm^2)				
	15	***17.5***	***20***	***35***	***75****
I	8.6	9.6	10.6	16.3	27.4
II	7.6	8.4	9.2	13.4	22.6
III	7.2	7.7	8.3	12.2	
IV	6.3	6.8	7.4	10.4	

** as per BS 5628 pt2* *(Source: Structural Integrity Handbook BICC)*

Cachia (1985) noted in testing highest franka crushing value of 32.9N/mm^2 and the corresponding lowest at 15N/mm^2

Table 7 - Characteristic Compressive stress f_k of 180mm thick masonry N/mm2 for specified crushing strength – as per BS 5628 pt1

Mortar Designation	*Globigerina*				*Coralline*
	Compressive Strength of Unit (N/mm^2)				
	15	***17.5***	***20***	***35***	***75****
I	9.9	11.0	12.2	18.7	31.6
II	8.7	9.6	10.5	15.4	24.8
III	8.2	8.8	9.5	14.0	
IV	7.2	7.8	8.5	12.0	

** as per BS5628 pt2* (Source: Structural Integrity Handbook BICC)

Shape Factor 265/180 = 1.47

Table (2b)10.6 – 5.2N/mm^2

Table (2k) 2.4 – 10.4/mm^2

Interpolating 5.2 + 5.2, 0.872/1.4 = 8.45N/mm^2

Table 8 – Blockwork Characteristic Strength f_k Data

Blockwork type mm	***Average Characteristic Strength N/mm2***	***Average Coefficient of variation %***	***Period***	***Best Year %***	***Worst Year %***
115	5.86	18.23	1991 1994	1992 13.37%	1991 25.29%
150	7.51	16.25	1991 1996	1993 12.58%	1991 20.28%
225 singlu	7.50	13.01	1991 -1996	1993 9.43%	1996 19.61%
225 dobblu	8.67	12.93	1991 -1996	1995 10.92%	1996 14.86%

Source: Grech (1997)

An important concept to introduce is shell bedding, with mortar laid on the 2 outer edges only. The design strength should be reduced by the ratio of the bedded area to the gross area.

Table 9 - Characteristic Compressive stress f_k of 225 thick concrete hollow blockwork in N/mm^2

Mortar Designation	***Compressive Strength of Unit (N/mm^2)***							
	2.8	***3.5***	***5.0***	***7.0***	***10***	***15***	***20***	***35***
I	2.0	2.5	3.6	4.4	5.1	6.3	7.4	11.4
II	2.0	2.5	3.6	4.2	4.8	5.6	6.4	9.4
III	2.0	2.5	3.6	4.1	4.7	5.3	5.8	8.5
IV	2.0	2.5	3.1	3.7	4.1	4.7	5.2	7.3

Table 10 - Characteristic Compressive stress f_k of 150 thick concrete hollow blockwork in N/mm^2

Mortar Designation	***Compressive Strength of Unit (N/mm^2)***							
	2.8	***3.5***	***5.0***	***7.0***	***10***	***15***	***20***	***35***
I	2.6	3.2	4.6	5.4	5.9	6.7	7.4	11.4
II	2.6	3.2	4.6	5.2	5.5	6.0	6.4	9.4
III	2.6	3.2	4.6	5.1	5.3	5.6	5.8	8.5
IV	2.6	3.2	4.1	4.5	4.7	5.0	5.2	7.3

Table 11 - Partial Safety factors γ_m characteristic loading & materials strength for normal design loads.

Ultimate Limit State	BS	EC	
permanent load	1.4	1.35	γ_G
imposed load	1.6	1.50	

Material	*Special Category BS*	*Normal Category BS*	*BS 5628*
Masonry	(EC6/B)	(EC6/C)	
Compression	2.5 (2.8)	3.1 (3.5)	Pt1
Compression/flexure	2.0 (2.8)	2.3 (3.5)	Pt 2
Flexure	2.8 (2.8)	3.5 (3.5)	Pt1
Shear	2.5 (2.5)	2.5 (3.5)	Pt1
Shear	2.0 (2.8)	2.0 (3.5)	Pt 2
Bond	1.5 (2.0)	1.5 -	Pt2
Strength of steel	1.15 (1.15)	1.15 -	Pt 2
Wall ties	3.0 (2.5)	3.0 (2.5)	Pt 1

When considering the probable effects of misuse or accident, the values given should be halved.
EC8 gives a γ_m of 1.7 and 2.0 for Categories B & C

DESIGN LOADS IN KN/M FOR NORMAL CATEGORY – $f_k t/\gamma_M$

Table 12 - Design axial loads for various wall types

Material	*Crushing strength N/mm2*	*Mortar type IV KN/m*	*Mortar type III KN/m*	*Mortar type II KN/m*
225 franka	20	537	602	
225 qawwi	75			1640
180 franka	20	493	551	
150 franka	20	469	522	
225 block dobblu	8.5	283	319	
225 block singlu	7	268	297	
150 block	7	217	246	
115 block	5	163	185	
225 infilled block	15	457	522	551
225 infilled block with 12mm bar at 225 centres	15			944
225 infilled block with 20mm bar at 225 centres	15			1206

The above table demonstrates the low load bearing capacity of concrete b/w of crushing strength 7N/mm^2, as being approximately 50% for equivalent thick franka of crushing strength 20N/mm^2.
(Source – Structural Integrity Handbook BICC)