Globigerina Limestone
(TAL-FRANKA)
As a Structural Material

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Introduction to Masonry Construction

Our building stone has always been used as a structural material, even when other countries had discarded the structural strength of masonry and used the material only as infill in between a reinforced concrete or steel frame. We are fortunate in having a soft limestone that may be easily dressed to form aestethically pleasant wall panels.

It is not unusual nowadays for an architect to be commissioned to design a building 10 storeys high. The most economical form of construction which can be adopted is a hybrid structure, with a concrete frame on the lower floors and a masonry load-bearing structure above. With this number of floors, local masonry is being stressed to its limit. It is now very important that the properties of our local "Franka" be properly understood and researched, something which in the past has been underrated.

What properties, must a material have for it to be classified as a structural one? The properties are:
(i) load-bearing capacity;
(ii) fire resistant properties;
(iii) durability performance.

At the turn of the century till past the middle of this century, the trend in building has been in producing a concrete frame or a steel skeleton hidden by a glass façade. An increase in research during the past decade, helped by the energy crisis, have helped the "Brick (masonry) is Beautiful" campaign. It is now accepted that masonry forms an attractive durable cladding with good thermal acoustic insulation, excellent fire resistance, plus it is an economical structural material that can be built faster, cheaper and more easily than its rivals, steel and concrete.

Of the materials mentioned above, concrete suffers from durability. The matrix of steel bars and concrete creates corrosion and spalling problems. Many eminent engineers have been made to blush during their lifetime, not due to errors in structural calculations, but due to the deterioration of concrete buildings or bridges. These are being maintained, but concrete repair is a very expensive item, not envisaged as part of the required maintenance during the design stage, and reducing the expected rate of return for the developer. As an example we may take the University buildings at Msida where poor detailing has omitted the dampproof course to the concrete columns in the Arts block. This would, most probably, have not happened if stone piers had been used. Concrete repairs are being undertaken to these spalled columns, a building not much older than twenty years. Our churches and palaces built 400 or more years ago, are proof of the good durability properties of our local Franka, once good practice is followed.

Steelwork has low fire-resistance, demonstrated by the tragedy of the Main Hall at the Conference Centre. Specialized labour is required to erect a steel-frame. Ignoring fabrication time it is true that a steel frame has a short site erection time, but no other construction work can take place during the erection period. This is not the case with masonry structures where there is a continuous follow-on of other trades.

Large open space structures, such as factories, sports halls, hangers, etc., have traditionally been constructed in a steel or concrete portal, with infill sheeting or masonry. With the development of new structural forms in masonry diaphragm or fin walling, the roofing system may now be supported directly on the masonry, the structural form of masonry adopted catering for all the vertical load and wind forces. This efficient and economical form of construction can provide the structure, the cladding and insulation in one material erected by the main contractor using only one trade.

A disadvantage in using masonry would be an increase in the obstructed area over steel or reinforced concrete. There is no reason why piers in department stores or similar structures are not constructed in masonry having a higher compressive strength. Lower coralline limestone has a very good compressive strength, but is weak in tension. Reinforced and post-tensioned masonry may be used successfully where tension develops. Such structures can be retaining walls, silos etc.

The masonry arch was a very important structural element, spanning large distances. Before the advent of steel work, the first railway bridges were masonry arches. Masonry arches then went out of fashion and the theory of arches was almost forgotten. Further advances in the theory of arches were evolved during the past wars, as checking these arches for heavier loading was required. Today there is an awakening and also a revival of interest in the old structural form of the arch. Today research work is being carried out on the limit state design of masonry arches, (1) a method which will facilitate the tedious arch calculations. This may revive the demand amongst architects for arched ceilings due to their aestethic appeal.

The composite action between masonry panels supported on concrete beams, (2) should also be investigated as this will effect greater economies. A hotel block is normally a hybrid structure, the upper bedroom floors constructed in masonry, whilst the ground floor, where the foyer is located, requires large open floor areas supported on a concrete frame. The concrete beams and upper masonry walling are not to be designed as separate elements, but as a composite structure. The whole unit is to be designed as a deep beam, with the reinforcement in the concrete beam taking the tensile forces and masonry walling above taking the compressive forces. In this way the lever arm is increased with a corresponding decrease in steel required.

Well designed structural forms in masonry are most robust and more resistant to progressive collapse due to the inherent arching capabilities of masonry than other structures. For high rise buildings the plan layout should be disposed to give a high rigidity against horizontal wind loading.

Geological data on Franka

"Franka", is obtained from the lowest bed of the three distinct beds of Globigerina limestone, each bed being separated by a phosphorite conglomerate horizon. Globigerina limestone outcrops mostly in the south-eastern part of Malta, covering approximately two-thirds of the surface area. From the geographical map published by Pedley et al it may be noted that the outcrops of Globiogerina limestone are mostly of the lower bed. Its maximum thickness is about 300 ft. The quality varies along this depth and at approximately every 40'0" a "soll" layer is encountered.

The whole strata has been formed organically by the deposition of calcium carbonate from the cementing together on the sea-bed of the shells of Globigerina and other Foraminitera. The calcium carbonate content varies between 65% - 95% and traces of iron oxide exist in some deposits. It is not strongly bedded, hence its name freestone ("Franka").

From microphotographs of a thin section of Globigerina limestone, one may notice the similarities in pore structure to Portland Stone (U.K.). It is probable that good quality "Franka" would be acceptable for use in a more aggressive environment, as that in the U.K.

Nowadays quarrying is carried out in the Tal-Balal area and the Mqabba area, comprising Siggiewi, Mqabba, Kirkop and Qrendi.

(i) Load Bearing Properties of Franka

Masonry is a composite material. Its strength is dependent on the crushing strength of the masonry block and of the infilling mortar used. It also depends on the workmanship. The most common workmanship defects are:

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

(2) Mortar bed joints should not be thicker than 12mm (0.5"). Bedjoints of 16-19mm thickness result in a reduction of compressive strength of up to 30% as compared with 10mm thick joints.

(3) 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 highly absorbent block will result in a weaker mortar, with a resulting weaker wall panel.

The relevant code of practice for structural masonry, [(3)] after taking into consideration masonry unit strength, mortar strength and degree of workmanship available gives values for the compressive strength of masonry panels.

From tests carried out by Joseph Cachia [(4)], on local masonry blocks, collected from various quarries, the highest average crushing value on a dry sample was 32.9 N/mm^2 (4750 lbf/in^2) whilst the corresponding lowest was 15N/mm^2 (2175 $1bf/in^2$). The highest value was obtained on a "soll" sample. The soll sample was the densest and had the lowest void ratio and porosity. When tested in the fully saturated state the compressive strengths obtained were on average 39% lower. One may assume internal walling to have dried to its dry state, whilst for exposed walling an intermediate value is to be taken between the fully dry and completely saturated state. When blocks were tested normal to their bed of stratification the strength was higher than for blocks tested with their face parallel. The difference ranged from 0% to 21%, the average works out at 8%. It is to be noted that stone indicated as "soll" is discarded for masonry work where it remains exposed. This is because "soll" stone is found to weather badly and crumble easily, and because limewash and paint will not adhere readily to its surface. It is therefore normally relegated to use in foundations below DPC.

From a different source [(5)] the crushing strength of Coral limestone is given as 75N/mm^2 (11,000 lbf/in^2).

From tests carried out by W. Debattista [(6)] on local mortars the commonly used cement mortar mix having proportions 1:2:10 of cement, to coralline limestone sand to fine globigerina sand had an average crushing strength at 28 days of 1.85 N/mm^2 (265 lbf/in^2). A stronger cement mortar mix having proportions of 1:2:6 had an average crushing strength of 28 days of 4.5N/mm^2 (650 lbf/in^2). Debattista also carried out tests on lime mortars and a composite lime-cement mortar. The results obtained demonstrated that lime mortars were superior with regards to water retentivity, consistence retentivity, air content of freshly mixed mortar and flow. On the other hand cement mortars have a higher flexural and compressive strengths, together with a longer setting time. The composite lime-cement mortar exhibited intermediate workability and strength characteristics. The reintroduction of lime into our mortar mixes is to be encouraged due to better properties achieved.

With reference to the Code of Practices on structural masonry[3], the following information is given:

4 mortar types are defined according to crushing strengths achieved after 28 days.

Type
(i) having a strength of 16 N/mm^2
(ii) having a strength of 6.5 N/mm^2
(iii) having a strength of 3.6 N/mm^2
(iv) having a strength of 1.5 N/mm^2

So our 1:2:10 mortar mix is classified as type (iv) mortar, and the 1:2:6 mortar mix classified as type (iii). In reinforced masonry work, [(3a)] suggests the use of mortar type (i) and

(ii) only, showing the importance of the use of high strength mortars.

As stated previously the compressive strength of a wall panel depends on a combination of the respective mortar and masonry unit strength. The greater the proportion of mortar/unit area of block, the lower the strength of the wall panel. The code of practice (3), therefore gives different values for 6" or 9" masonry units.

The following two tables derived from the Code of Practice [3] give wall panel strengths for a given masonry block and a given mortar designation.

The values of the ultimate strengths of wall panels are to be divided by the relevant factors of safety to obtain the allowable working load. An average value for load is 1.5, whilst for material strength with average workmanship a value of 3.0 is quoted. So the global factor of safety to be used is approximately 4.5.

Tests on 26 different 1/3 scale wall panels have been crushed to destruction by P. Buhagiar.[7] Masonry blocks used were from 3 different quarries having different strengths. The Mqabba blocks had an average of 20N/mm², Naxxar blocks had an average of 22.5N/mm², whilst the Siggiewi blocks had an average of 17N/mm². No mortar mixes were used, a cement mortar (1:3:12) having a crushing strength after 28 days of 1.75N/mm² (type (iv)) and a composite cement—lime mortar (1:1:2:4) having a crushing strength after 28 days of 5.9N/mm², (type iii). The greatest variation from the Code of Practice, [3] was on the 6" blocks. Another anomaly was that the blocks from the Naxxar quarry, with the highest crushing strength, achieved the lowest wall panel loading. By further tests conducted by P. Buhagiar,[7] this is attributed to a high initial rate of absorption, which, as mentioned earlier on, would affect the mortar strength.

TABLE 1

Estimated Compressive Strength of Masonry for 9" blocks (N/mm²)

Mortar Designation	Compressive Strength of Unit N/mm²			
	Globigerina			Coralline*
	18	**20**	**23**	**75**
(i)	9.5	10.3	11.4	26.3
(ii)	8.2	8.9	9.7	20.8
(iii)	7.6	8.0	8.8	18.0
(iv)	6.8	7.2	7.8	15.2

TABLE 2

Estimated Compressive Strength of Masonry for 6" blocks (N/mm²)

Mortar Designation	Compressive Strength of Unit N/mm²			
	Globigerina			Coralline*
	18	**20**	**23**	**75**
(i)	12.3	13.3	14.7	34.4
(ii)	10.7	11.5	12.6	27.0
(iii)	9.9	10.4	11.4	23.4
(iv)	8.9	9.3	10.0	19.3

**Value for coralline wall panels were extrapolated from Code of Practice [3], as a block having such a high crushing strength is not quoted, but quoted in ref. (3a) and values obtained agreed.*

Buhagiar [7] concludes that the same strength should be used for the 6" and 9" local masonry blocks, disregarding the higher values attributed to the 6" masonry blocks. A 6" thick unit is more slender than 9"; so could not slenderness effects have reduced the crushing load? It must be borne in mind, that during the tests the mortar beds were fully filled, which does not always occur in practice.

From the above, it may be concluded that for preliminary design calculations a masonry block having a crushing strength of 20N/mm² (2900 lbf/in²) may be adopted.

(ii) Fire-Resistance of Franka

The temperature rise at any particular depth below the surface of a wall exposed to fire depends on the intensity of the fire, on the period of exposure and on the thermal diffusivity of the material. The intensity of fire in a store with inflammable materials, would be higher than that inside a church. Building stones have a low thermal diffusivity. Hence the rate at which the temperature rises within the body of the wall is correspondingly slow. This high temperature would not exist within even a moderate depth below the surface. This difference in temperature between the outer and inner parts of masonry creates a steep temperature gradient which may cause cracking or spalling. It is damage of this kind that calls for repairs, mostly in columns, window-jambs, cornices, sills, mouldings, and similar projecting features.

For temperatures up to 400°C, heat causes the development of a pink or reddish-brown colouration, in Franka containing iron-oxide. For Franka free from iron-oxide the colour becomes greyish. The depth of this colouration seldom exceeds a depth of 3/4". At higher temperatures, in the region of 600°C, the colour disappears and calcination starts. Calcination involves the driving off of carbon dioxide, from the limestone calcium carbonate and leaves a residue of calcium oxide or quicklime. Considering the depth of the coloured stone, referred to above, and the temperatures indicated, it is not to be expected that there should be any considerable degree of calcination of limestone in a building fire. Calcined limestones have a dull, earthy appearance, differing from the original limestone.

It has been proved that there is no significant reduction in crushing strength of limestone for temperatures up to 400/450°C. Thereafter the strength decreased and at 600°C the masonry retains 60% of its original strength.[8] Since in a building fire the effects are confined to the outer layers, no serious loss occurs to the strength of the masonry unit. But in staircases, which are stressed in tension, it is better to reconstruct any masonry stairs exposed to fire, unless it can be shown to be unnecessary by loading tests.

It is usually considered safe to rebuild on existing walls, after considering the effects of any lateral movements of masonry wall induced by thermal expansion or stresses resulting from collapse or partial collapse of roof or walls. It is also to be ensured that no future damage can result from falling fragments.

(iii) Durability of Franka

There are many fine buildings which have been erected over 400 years ago and are still in a structurally safe condition. But even in the same buildings, it is noted that some masonry units weather to a different degree than others. This may be due to their position relative to the weather. SIlls, balustrades, stone courses between ground level and d.p.c. and courses immediately below a cornice are known to deteriorate more than masonry in other locations. The reason for this faster deterioration may be due to being exposed to weather on all faces for balustrades, or being sheltered from the wash-down effect of rain on courses below a cornice. But when in a wall panel there exist masonry units with different deterioration effects, then the cause must be due to the internal matrix composition of the franka unit. In this case, tests will be required for the selection of better quality Franka.

Exposure tests carried out by the Building Research Station in 1958[9] have shown that franka is susceptible to salt attack. The closer the masonry is to the sea, the specified masonry ought to have a higher durability. Terraced houses built about 40 years ago, on the Birzebbugia seafront, have badly decayed masonry. The probability is that masonry was supplied from a nearby Birzebbugia quarry, which tests have proved to be of an inferior quality. A good damp-proof membrane is a requisite, as salts from the ground are also known to cause deterioration. An interesting fact is that quarry face stone (ġidra) deteriorates less than fair-faced stone.

From the same work carried out in 1958,[9] it was concluded that any sulphate attack on the stonework through atmospheric pollution was small and of little consequence. Is this true nowadays, if one considers the Hamrun/Marsa area being subjected to pollution due to the burning of coal for power generation? The principal acid products of the combustion of coal are carbon dioxide and sulphur dioxide. Carbon dioxide exists in the atmosphere and its effect on limestone masonry is considered to be of relatively little consequence. The production of acid sulphur gases by the combustion of coal is more important. Coal contains on average 1—2% of sulphur, which on combustion is oxidised to sulphur dioxide or sulphur trioxide, which in contact with water forms sulphurous and sulphuric acids. Not all the sulphur escapes into the air, some remains in the ash or the chimney soot, neither does all the sulphur dioxide which escapes, enter into combination with limestone in buildings. Nevertheless, actual damage is caused, its severity will have to be ascertained by future tests. Soot deposits cause disfiguration, and due to acid materials which it brings into close contact with the Franka under projecting features accumulating into thick black incrustations, also causes chemical disintegration.

Due to "Franka" not being strongly bedded, the difference in weathering due to units placed on sides differing from its bedding plane is not so marked, but varies according to quality of masonry: the better type of Franka showing slight or no difference.

The Building Research Station has a standard method of examination for the selection of natural building stone. [10] Below are listed a number of tests, which ought to apply for our environment and type of stone. In 1958 [9] [5] a limited number of tests was carried out on Franka samples together with further tests in 1985 [4] and results are discussed. Limestones have a broadly similar chemical composition. Chemical analysis is of no use to durability assessment. It is the internal structure of a limestone rather than its composition, that gives the clue to durability.

Indirect Measures of Pore Structure:

(1) Porosity is the volume of pores within a stone, expressed as a percentage of the total volume. It is conveniently measured by vacuum saturation with water. Values range around 10—20% although they may be as low as 10% and as high as 40%. The value for Franka samples was around 35%. A "soll" sample gave a low 27.8%[4]. Values for Coral limestone are in the region of 10%[5].

Porosity gives no indication of the way the pore space is distributed, whether there are many fine pores or otherwise.

(2) Saturation co-efficient is measured by drying stone used for porosity test. It is then soaked in water for 24 hours. The saturation co-efficient is the proportion of pore space that becomes filled with water during soaking. Values range from 0.4—0.95, the high value indicating a high proportion of fine pores, being a stone of low durability whereas a value of 0.4 would be a stone of high durability. The value for Franka samples was around 68%, being a grey region as on its own the saturation co-efficient is an unreliable guide to durability.

(3) 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 two methods most widely used for the distribution of pore sizes is the mercury porosimetry and the suction plate technique. The underlying principle, being that the pressure required to force mercury into an empty pore (or suck water out of a full pore) is dependent upon the size of the pore. The value for Franks samples fell between a grey middle of 50 — 80%, which on its own merit may not be used to classify its durability characteristics.

An improved indication of durability may sometimes be obtained by combining two properties.

For the Franka samples tested it was concluded [5] that a wet/dry compressive strength ratio of 0.58 appears to mark a dividing line between a better and a poorer stone. This value appears to be confirmed also by tests carried out by Cachia [4] comparing his values of wet/dry strengths with his description of the respective quarries. One anomaly appears in an Mqabba quarry which is described as of poor quality masonry, but the wet/dry ratio works out at 0.7. The tests on this sample were carried out perpendicular to bedding plane not normal to bedding plane as in the other tests. Could this be the reason for the anomaly?

The 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 105. A tentative value has been established at 1050 [5]. More tests are required to confirm this result.

Direct Tests of Durability

Direct tests are intended to subject the stone to the same condition that it will encounter in use, but in a more agressive form.

The Crystallisation test is one. A stone sample is subjected to cycles of immersion in sodium sulphate, followed by drying in an oven. The test is comparative and the loss in weight obtained must be compared with the result of a standard stone, known to have good durability characteristics. For the Franka samples tested, the change in weight was between 20 — 30%, with a poor sample being as high as 49%. A high proportion of micro pores, together with a high loss in weight due to crystallisation test, indicates stone to be less durable.

Physical Properties Affecting Durability

When a material is exposed to the sun, the surface becomes hotter than the underlying mass, that is, a thermal gradient is set up in the material. On the contrary, at night, radiation causes the surface to become colder than the material beneath it. These temperature differences cause unequal expansion, and thus set up stresses in the material. The propagation of temperature through a material depends on its thermal conductivity and on its heat capacity, and the relation, conductivity/Heat capacity per c.c. is known as the diffusivity. Unlike metals, building materials have low thermal conductivities and relatively high specific heats, hence their diffusivity is low and the stresses correspondingly higher than they would be in materials of higher diffusivity. But the temperature gradient, set up in normal circumstances is unlikely to be of serious consequence.

With certain building materials, changes in moisture content result in changes in volume. This swelling on wetting results in shrinkage on drying. Such types of material, would be less desirable to be used on an exposed façade. The moisture expansion of limestone is negligible and so no precautions are necessary to avoid shrinkage cracking. Shrinkage cracks are visible where a building built in Franka abuts against one built in concrete blockwork.

The linear co-efficient of thermal expansion of limestone is also low, so expansion joints are not required on moderate lengths of Franka walling.

Need for Classification of Quarry Sites:

It is a fact that the quality of local Franka varies as it is a natural material. Franka is used exactly as it is found, there is no processing or manufacturing involved, which may change its quality. However, the engineer ought to be advised in his selection. For instance, Franka used in an inland location, such as Rabat may not be suitable for use on the Sliema sea-front due to the deleterious action of the sea-spray. Nor is it suitable in the Marsa area because the pollution there produces harmful acids. The franka used on the wall panel of a façade may not be suitable for the balcony balustrading or the overhead cornice. Ideally, the Franka obtainable from a quarry, should be graded according to its durability. A list should be compiled indicating the suitable use of Franka from a particular quarry, taking into consideration its durability, the environment where the Franka is to be used and its location in the building fabric.

Having convinced ourselves of the favourable properties of Franka, then we must use it as a truly structural material, not as an infilling wall panel. Its obvious use is as a wall panel transmitting loads vertically downwards, but its geometrical layout may be utilized to transmit horizontal wind or earthquake forces to the ground. In shed buildings, fin or diaphram walling may be used for the side and gable walls. The above methods are more economical locally, besides incurring less costs-in-use expenses, when compared to other more evolved structural systems. Developing the structural uses of Franka would also lead us towards an improved architectural aesthetic modelled on the successful past where the form and the function were completely and inseparably intertwined. A

References:

(1) Professor Heyman — Masonry Arch Design
(2) R H Wood — Studies in Composite Construction
(3) BS 5628 Structural Use of Masonry pt 1 Unreinforced masonry
(3a) BS 5628 Structural Use of Masonry pt 2 Reinforced & Prestressed Masonry
(4) Cachia J (1985) The Mechanical & Physical Properties of Globigerina Limestone as used in local Masonry Construction (Uppublished B.E & A (Hons.) Dissertation).
(5) BRE — Note C965
(6) Debattista W (1985) Masonry Mortars (Unpublished B.E & A (Hons.) dissertation).
(7) Buhagiar P (1985) Structural Masonry; experimental determination of the compressive strength of a wall (unpublished B.E & A (Hons.) dissertation)
(8) BRE — Note 21 the Repair of Stone-Work Damaged by Fire.
(9) BRE — Note B188 the Maltese Islands, Use of Limestone for Building.
(10) BRE — The Selection of Natural Building Stone.

DO WE KNOW OUR LIMESTONE?

ALEX TORPIANO

Mr D. H. Camilleri's article makes very interesting reading indeed, and the author is to be congratulated for highlighting the reemergence of masonry as a structural material worthy of scientific study. It is indeed deplorable that out knowledge of limestone masonry is so superficial, and that we depend so much either on research done abroad (mostly on brickwork and concrete blockwork) or on folklore, as to how to best use this beautiful material. It is perhaps indicative that only relatively recently have we managed to include the study of structural masonry in the syllabii at University, alongside the more educationally affirmed concrete and steel. We have, at the same time, striven to encourage more basic student research into the material. It is gratifying to note that Mr Camilleri makes extensive reference to three dissertations which were the first attempts at basic research in masonry in recent years; I am happy to say that currently we have another four students undertaking similar research in masonry. As all the students concerned will confirm, the main stumbling block to their studies is the lack of..., well, everything really — the lack of real laboratories, the lack of space in our make-do laboratories, the lack of basic equipment, the lack of funds in general.

Perhaps, the Chamber of Architects and Civil Engineers, and the profession in general, can encourage commercial companies to help in this research by donations and sponsorships.

It was felt necessary to make some comment about points raised in Camilleri's article. It must be stated, first of all, that although the dissertations quoted are admirable pieces of work, the test sample is yet too small for us to extrapolate the results statistically. Many more tests are required before we can be sure about the correct characteristic strength to be used, and the correct partial safety factors applicable.

We have, as yet, no clear idea on the range of compressive strengths which the combination, of variable masonry unit strength, variable mortar quality, and variable workmanship, will produce — statistically speaking, we have no measure of the standard deviation of compressive strengths.

For this reason, it is necessary to be careful when talking about safety factors. The quoted value of 4.5 may suggest an inordinately high safety factor, unless we appreciate that in limit state theory the partial safety factors are based on a semi-probabilistic approach — in crude terms, they are based on the chances that a component material with a strength tending towards the lower end of the acceptable range be loaded by forces tending towards the upper end of the expected range. It is therefore not simply the average load by a specified factor. It is obvious that where there is a material about which not much is known, or which is not as commonly used, as is the case with masonry in the U.K, the degree of uncertainty is higher, hence also the value of the partial safety factor. As more information becomes available and reliable, such factors are modified.

Our understanding of the interaction between the masonry unit and mortar, in resisting in-plane loads, is slowly increasing, although not everything is yet clear. It is accepted that the main limit to the axial capacity of a masonry panel is the transverse tensile strain capacity of the unit. In other words, in a uni-axial stress state, whilst the masonry unit - mortar system is compressed in one direction, unequal transverse strains, resulting from Poisson's ratio effect, are set up in both mortar and unit. The friction at the interface translates these unequal 'free' strains into transverse stresses, tensile in the unit, compressive in the mortar, and the system fails either by the tensile failure of one (vertical splitting) or the compressive failure of the other. With this mechanism in mind, it is not correct to say that the filling of the vertical joints has no effect on the strength of the wall. It is true that some tests of concrete block walls have exhibited an insignificant effect,[1] but other researchers[2,3] have demonstrated how a concentration of lateral stresses occurs in the vicinity of the perpends, and that hence the infilling of the perpends has an effect on the strength of the wall. The analogy of an elastic plate with vertical slots, and the resultant concentrated stresses at the tips of the slots, is also made by Sementsov [4] to explain why vertical cracks start at, and propagate from under the vertical joints. The exact effect of vertical joints in our masonry construction is certainly not clear.

The effect of the horizontal joints is likewise related to the transverse lateral strains. Ideally, a mortar thickness of zero implies that no differential lateral strains are set up; the wall would therefore achieve the strength of the constituent masonry units, were it not for the fact that, unless the faces of the units were perfectly smooth and plane, points of contact result wherein concentrated stresses reside. As long as the joint thickness is small, the effect of the opposite faces of the masonry unit act like the platens of a concrete cube crushing machine. The lateral compressive stresses restraining the mortar enable it to sustain stresses in excess of the uni-axial mortar cube strength. As the joint thickness in-

"There is no proof that quarry faced masonry deteriorates any less than fair-faced masonry"

creases, the restraining platen effect decreases, so that the panel strength decreases until it levels out (at about 25mm for brickwork) [5,6] at approximately the level of the mortar cube strength.

It is further to be pointed out that the reasons a highly absorbent block produces a weaker panel are related more to the loss of workability — i.e. reduction of the bedding effect of the mortar — rather than the loss of strength of the mortar; in fact, a mortar with a low w/c ratio will, like concrete, be stronger than one with a high w/c ration, provided they can both be compacted to the same degree. This is mentioned with regard to the effect of plasticizers in mortar.

Similar comments are in order as regards the strength of 6" walls as compared to 9" walls. Theoretically, the ratio of the height of unit to least horizontal dimention influences the magnitude of the above-mentioned platen effect - just as the proportions of the sample in the concrete crushing test. Therefore, extrapolating from the table of BS5628 (which the code allows, but which must be understood for what it is, an **estimate** of the strength), the strength of the 6" wall is expected to be higher than that of a 9" wall. On the other hand, it may also be argued that (a) slenderness effects (b) the greater capacity of a 9" wall to re-distribute stresses (the code reduces capacity for sections of small area) would require that strength of a 9" wall be higher than that of a 6" wall. Bearing in mind that our bedding material is never as uniform as expected in the code, it is unwise to make any assumptions about relative strength. In the tests mentioned, there were no significant differences between 6" walls and 9" walls (even after making allowance for slenderness). P Buhagiar's conclusion that the same strength should be used for 6" and 9" walls seems thus reasonable. It is worth emphasizing that, in reality, the values in the code BS5628 can only give us some guidance, until we have more data specific to Malta.

The problem of durability, and the associated ones of treatment, preservation, and consolidation, are problems which have to be tackled with great care. The mechanisms of deterioration, particularly that of honeycombing, are not yet fully clarified. The position of the stone in the final building, the origin of the stone, the chemical and micro-physical characteristics, as well as the ambient conditions all have an effect on these processes, to a degree as yet not fully determined.

The development of good detailing standards depends on the understanding of such mechanisms; but it seems that even elementary standards are ignored in contemporary practice. The upper parts of the relatively recently constructed masonry bridge to Fort St. Angelo are in almost as bad a state as the worst stretches of our bastions, for the simple reason that the provision for surface water drainage on the bridge deck is inadequate.

I would further suggest that there is, to my knowledge, no proof that quarry-faced masonry deteriorates any less than fair-faced masonry; certainly any dusting and discoloration of the surface is less apparent, but this is quite different from saying that it deteriorates less.

Much more work on the durability problem needs to be done in Malta. The lead has already been given by work by the BRE, referred to by Mr D H Camilleri, and by Cassar et al [7]; but it needs to be followed up and placed into the format of a long-term programme. Other work also needs to be done on the structural aspects of masonry. To mention two applications referred to in Mr D H Camilleri's article, we need, for example, to know more about the long-term bond between concrete and limestone masonry before we can confidently adopt design procedures for composite action; likewise, although the use of limit state principles in masonry arches is now fairly widespread, work needs to be done on the effect of friction on the applicability of theories derived in reality for perfectly-plastic materials in the absence of friction.

For the last three years one of my ambitions has been to set up a Masonry Studies Unit, or Research Centre, at University, so that we could eventually be sure that we know how to best use our local building material. Up to now, financial resources have limited any development, but, perhaps greater awareness of the problems will spurthe industry to help. A

References:

(1) Read, J.B. and Clement, S.W. "The strength of concrete block walls, Phase III", C & CA Technical Report 42.518, Nov. 1977.

(2) Probst, P "On the mechanism of failure of centrical loaded brick masonry", Proc. Vth Int. Brick-masonry Conf, Washington DC, 1979

(3) Smits, A. "Failure mechanism of centrally loaded masonry walls", Proc VIth Int. Brickmasonry Conf., Rome, 1982.

(4) Sementsov and Kameiko (eds) "Designers manual of masonry inc...", Israel Program for Scientific Translations, Jerusalem, 1971.

(5) Stafford-Smith, B. "An examination of stresses in mortar compression joints". Proc. Conf. on Joints in Structures. Inst. of Struct. Eng. & Univ. of Sheffield, 1970.

(6) Stafford-Smith, B, and Carter, C. "Distribution of stresses in masonry walls subjected to vertical loading". Proc. II Int. Brickmasonry Conf., BCRA 1970.

(7) Cassar, J., and Vannuci, C.